8th World Congress on Conservation Agriculture

BOOK OF EXTENDED ABSTRACTS OF THE 8th WORLD CONGRESS ON CONSERVATION AGRICULTURE

The future of farming

Profitable and Sustainable Farming with Conservation Agriculture

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8th World Congress on Conservation Agriculture

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FOREWORD

Not so long ago, if you suggested to farmers that they should plant crops without ploughing, most would have thought that you were crazy. Today, however, all across the world, millions of farmers – small and big – are now doing just this. More than 15% of the global cropland area is already being managed to produce crops without tillage, using an approach known as Conservation Agriculture (CA). This dramatic farming revolution has been driven largely by farmers who find themselves better off: they are the inventors of new locally adapted CA practices and they share their experiences internationally.

CA enables farmers to produce food profitably without damaging the environment. It delivers many environmental benefits to society such as climate change mitigation and conservation of land, water and biodiversity. Unlike tillage-based farming systems which are major emitters of greenhouse gases, CA systems sequester carbon within the soil and reduce emissions of methane and nitrous oxide as well as of carbon dioxide by reducing the use of fossil fuels, agrochemicals and other farm inputs.

Switzerland has played an active part in the global transformation towards sustainable farming systems and many of its own farmers are taking up CA-based sustainable land management practices. It was therefore appropriate that we should have hosted the 8th World Congress on Conservation Agriculture.

Given that sustainable land management policies are essential elements in policies for climate change mitigation, global food security and biodiversity conservation, they will play vital parts in reaching many of the UN's 17 Sustainable Development Goals.

I have taken note of the success of the 8th World Congress, of which we were proud to be hosts as well as active partners.

I am delighted to affirm Switzerland's commitment to doing all within its power to accelerate the enhancement and spread of CA at home and abroad.

Andreas Aebi, President,
Swiss National Council

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8WCCA

8th World Congress on Conservation Agriculture

PREFACE

After a delay of one year, the European Conservation Agriculture Federation (ECAF) in close cooperation with its member association the Swiss No-Till and the Food and Agriculture Organization (FAO) organized the 8th World Congress on Conservation Agriculture (8WCCA) as an on-line event. The Congress was attended by 783 participants including representatives of farmer associations, international organizations, scientific institutions, private sector, non-governmental and civil society organizations, from 108 countries and from both the developed and developing world. Almost 250 presentations were received from participants in all five continents.

Under the banner: **The Future of Farming – Profitable and Sustainable Farming with Conservation Agriculture**, the 8WCCA highlighted the global contribution of Conservation Agriculture towards achieving these outcomes. It also explored how CA land use can help to address humankind's major global challenges of climate change, environmental degradation and food security while safeguarding the livelihoods of small and large-scale farmers. The proven benefits of CA in terms of erosion control, carbon sequestration, biodiversity regeneration, and improved water and nutrient cycling are all contributing to the achievement of the manifold objectives of the international conventions and agreements including the Sustainable Development Goals, European Green Deal and F2F Strategy.

A major objective of the 8WCCA was to bring the achievements of CA Community to the attention of policy makers and relevant stakeholders in the public, private and civil sectors at the national and international level. This objective was supported by the attendance at the opening session of the Director General of the FAO, the European Commissioners for Agriculture, and for Environment, Oceans and Fisheries, the Chair of Agriculture and Rural Development Committee of the European Parliament, and representatives of the World Bank, Asian Development Bank, International Fund for Agriculture Development, the Global Farmers Network, the Consultative Group on International Agricultural Research, and the Intergovernmental Panel on Climate Change.

Transformation of tillage agriculture into CA is now occurring very rapidly through farmer-driven processes with support from national and international organizations. Consequently, millions of farmers and civil society are already reaping the wide range of economic, environmental and social benefits that CA offers. It was therefore very appropriate for the Congress to propose a global plan of action to transform 50% of global cropland area to CA by 2050.

The Congress noted that Europe still lags behind other regions in terms of CA adoption, and it is hoped that the 8WCCA will help to accelerate the uptake of CA in Europe.

Africa too needs special support to accelerate the adoption and spread of CA to address the challenges of food security, climate change and environmental degradation.

We therefore wholeheartedly embrace the decision at the 8WCCA that the next Congress, in 2024, will be held on the African continent, hosted by South Africa in collaboration with African governments and regional and national organizations.

Gottlieb Basch, President, ECAF
Emilio Gonzalez-Sanchez, General Secretary, ECAF
Reto Minder, President, Swiss No-Till
Wolfgang Sturny, Founding Board Member, Swiss No-Till

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OPENING SESSION

Dr QU Dongyu,

FAO Director-General

Distinguished Participants and Guests,
Ladies and Gentlemen,
Dear colleagues and friends,

I thank the European Conservation Agriculture Federation and the Swiss No-till Association for the opportunity to address the Congress.

The *Food and Agriculture Organization is the* Specialized Agency of the United Nations that leads international efforts to defeat hunger and malnutrition. The key challenge is to meet the growing demand for food, while reducing the pressure on natural resources and ecosystems. Current consumption patterns and existing agri-food systems are hindering efforts to achieve this. We see disturbingly high rates of food loss and waste, air pollution, greenhouse gas emissions, the loss of biodiversity, and resulting inequality. We urgently need to do things differently and act holistically to transform our agri-food systems. We have to create new solutions and find smarter ways to produce more with less input, while keeping in mind that there are no healthy foods without a healthy environment. That is why FAO's Strategic Framework endorsed last week by ministerial conference, focuses on the transformation to MORE efficient, inclusive, resilient and sustainable agri-food systems for better production, better nutrition, a better environment and a better life, leaving no one behind.

These 'Four Betters' represent a guiding principle and an innovative business model for how FAO is supporting the achievement of the 2030 Agenda. The 'Four Betters' also reflect the interconnected economic, social and environmental dimensions of agri-food systems. To produce more with less requires us to be truly innovative and environmentally thoughtful.

FAO is supporting its Members in achieving this delicate balance based on each local condition and priority. This includes **Conservation Agriculture,** integrated with other good agronomic practices, to prevent soil erosion, and promote biodiversity, biological interactions and efficient natural resource management.

Principles of Conservation Agriculture that **mitigate** climate change include:

- using no-till practices to sequester more carbon into soils;
- using fewer synthetic chemical inputs, and
- increasing the use of appropriate tools and modern machines, including adopting the latest digital and precision agriculture technologies.

Practices that **adapt** to climate change include:

- using quality seed, and planting superior crop varieties suited to specific environments;
- managing soil, water, nutrients and pests by retaining crop residue and growing cover crops;
- diversifying cropping systems; and
- applying integrated pest management strategies.

FAO promotes the creation of decent on and off farm employment opportunities, as well as reducing food loss and waste. To do so, it facilitates improved planning between urban, peri-urban and rural areas. We are fully aware of the need to engage more closely with the private sector to leverage innovations and technological advances. We recognize the complementary partnership between a thriving private sector and a public regulatory framework, and we support policies and strategies that can create enabling environments at national, regional and global levels.

Our new Strategy for Private Sector Engagement reflects this modern approach. FAO also recognizes the need for digital applications and the promotion of technologies. Advanced data systems, for instance, can inform management decisions for cropping systems in line with current climatic conditions. FAO's flagship Hand-in-Hand Initiative accelerates agricultural transformation and sustainable rural development to eradicate poverty (SDG 1) and end hunger and all forms of malnutrition (SDG2). In doing so, the evidence-based, country-led and country-owned Initiative contributes to attaining all of the Sustainable Development Goals. The initiative prioritizes countries where national capacities and international support are the most limited or where operational challenges, including natural- or man-made crises, are the greatest. It uses a range of metrics to support agricultural interventions, supported by a geospatial platform for aggregating big data.

Dear Colleagues,
To conclude**,** I would like to underscore that collective action by all and all tools in the box is essential, if we are to transform our agri-food systems. FAO is committed to engaging with all stakeholders to deliver meaningful and impactful solutions for farmers. Let us work together to attain the transformation of agri-food systems and achieve the SDGs.

I wish you all a successful Congress with a package of balanced solutions.

Thank you.

OPENING SESSION

Mr. Virginijus Sinkevičius

Commissioner for Environment, Oceans and Fisheries
DG Environment

A very good morning to all participants, and many thanks for this invitation.

You've asked me to say words about how the Commission supports sustainable agriculture, especially in the context of the European Green Deal. Every society is built on farming and food. The Green Deal reflects that – it's a broad quest for sustainability, in all the areas that matter. And that includes agro-ecology and Conservation Agriculture.

As you note in your title, we don't have a choice. The future of farming must be profitable and sustainable. Not just here in Europe, but all around the globe. Everywhere we look, we see existential threats. We see climate change and environmental degradation.

Soils are increasingly degraded, wilderness is constantly being destroyed, and wildlife populations are in decline. The loss of biodiversity is especially severe in agricultural areas. Almost all species and habitats related to agriculture are affected, from plants and wildflowers to pollinating insects and farmland birds. Scientists say that if we fail to tackle this crisis, farmers will be the first to suffer.

There will be more soil degradation, more water scarcity, even fewer pollinators and less natural pest control. We can and must revert this trend! If we do restore ecosystems and their services, farmers will be the first to benefit, and those benefits will continue for future generations. So, it's time to fix our broken relationship with nature.

Conservation Agriculture, by keeping soil intact as a living ecosystem, tackles problems where they arise. It recognises soil as a multifunctional, living system, vital for the environment and for society. Soils are home to one quarter of the world's biodiversity. And they provide many services that are essential to our survival. They safeguard the food supply, regulate the climate and the water cycle, and help with pest control. So, if we want to tackle the crises in our biodiversity and our climate, we have to start with soil.

In the European Union, our top political priority is implementing the European Green Deal. Together with the Recovery and Resilience Facility, it brings decisive action, building sustainability into the EU economy. Last year we adopted two major elements – the new EU Strategy for Biodiversity, and Farm to Fork, our Strategy for sustainable food. They both set targets that are ambitious but achievable, enabling our society to live within the boundaries of the planet. Farm to Fork aims for long-term food security, transforming the way we produce, process, market and consume. The Biodiversity strategy takes an integrated approach to nature, with measures for all the pressures it faces. It includes a plan to restore rivers and degraded ecosystems back to health. It promotes biodiversity-friendly farming practices and increase landscape diversity, bringing back at least 10% of landscape features on agricultural land. Both strategies share common targets, to be achieved by 2030. They include a 50% reduction in the use and risk of pesticides, which is very relevant for Conservation Agriculture. They also propose action to reduce nutrient losses by at least 50%, and action to maintain soil fertility. And we will increase the share of agricultural land under organic farming by up to 25%.

Most of the Green Deal elements have now been adopted, but there are two more major items on the way. The first is a new strategy for soil, to improve fertility, protect soil biodiversity, and comprehensively increase soil organic matter. It will provide a framework for renewed policy action on protection, strengthening existing measures and reducing threats. A new Strategy for forests is also on the way. It will aim for sustainable management, protecting ecosystems and their biodiversity, and strengthening resilience in the face of climate change.

The global challenges are huge, but it's not too late to meet them. It will take substantial change, with farmers at the heart of the process. Our aim at the European Commission is to keep farmers on board, and help them through this process of transition. Our Common European Agricultural Policy will continue to support them, securing funding for sustainable measures. That way we maintain current levels of productivity, in a sector that thrives. We all understand how our economy depends on healthy natural capital. And as we move through the transition, we'll need more nature-based solutions, and more approaches that are close-to-nature.

Climate change is already here. Around the globe, biodiversity is in steep decline, and the nature urgently needs protection. This situation has to change. We need practicable solutions for sustainable agriculture. We'll deliver those solutions by working closely with the people involved – farmers and landowners, land planners, industry executives, mayors and ministers. With more collaboration at local, regional, national and global levels, promoting and implementing sustainable land management. That way we deliver what Europe needs – sustainable agriculture for the longer term, while supporting all three pillars of sustainability, the ecological, the economic and the social.

That's the promise of the European Union, and it's how we'll deliver the European Green Deal.

All the best for your conference – I wish you fruitful discussions.

Thank you.

OPENING SESSION

Mr. Norbert Lins

Chair, Agriculture and Rural Development Committee
European Parliament

Dear Director General Mr Dongyu Qu (FAO),
Dear Commissioners,
Dear President Basch,
Dear Mr Amman and Hofer,
Ladies and Gentlemen,

Thank you for hosting this World Congress on Conservation Agriculture, and giving me this excellent opportunity to share some reflections on Food Systems, Innovation and Natural Resource Management for European Agriculture.

As a Chair of the European Parliament's Committee for Agriculture and Rural Development, I can assure you, that the future of Farming, the protection of natural resources, climate adaption and mitigation and keeping our agriculture competitiveness, productive and attractive are of our interest and constitute a scope of direct and indirect discussions during the AGRI Committee meetings.

The COVID-19 crisis has significantly affected many sectors and economies. The EU agriculture has also suffered significantly. The pandemic has also revealed the weaknesses of our food systems and has affected unfortunately the most vulnerable among us Moreover, unfortunately there are still many unknowns about the scale of the impact of the pandemic on the economy.

It is clear that for the future crisis we have to do the utmost to be prepared. Not only for future crisis, but especially to our changing climate. The way we produce and consume food has a direct influence on our climate and environment. And agriculture is the sector most affected by climate change. But luckily, agriculture is also the sector who can store carbon and become climate neutral by possibly 2035 - If supported by the right tools.

I am happy that today we can and need to take stock of the issues observed, and use them, as an opportunity to identify what, and where, we have to be better.
In consequence, there is a need for a transition to more robust food systems, using innovative technics, with more sustainable use of natural resources and where no one is left behind. To accomplish it, we need all actors across the value chain, not only in the EU but also globally.

However, for any proposed transition, we must not forget to support our farmers. I would like to underline that, they play a crucial role in ensuring our food security, producing healthy and nutritious food for our citizens. Therefore, they contribute to the well-being of the people in Europe.

However, they are also the most affected by any changes, despite the difficulties they face.

Honourable speakers, we are aware of present risks in agriculture. Among other things, risks related to water scarcity, land degradation, losses of biodiversity. Unfortunately, I could continue listing risks that European farmers face in their daily life.

Therefore, we should be conscious of the urgent need for action to mitigate those risks in order to preserve and restore healthy ecosystems. Protecting these fragile and non-renewable resources is crucial to ensuring a healthy future. Our future.
The European Green Deal pursues wide-ranging actions to make Europe climate-neutral by 2050. It introduces new, sustainable and inclusive strategies to accelerate the economic transition that will allow for the improvement of the quality of life, of health, the care for nature, and leave no one behind.

Within its flagship strategy, the Farm to Fork, addresses the challenges of sustainable food systems and recognises the links between healthy people, healthy societies and a healthy planet. The Biodiversity strategy aims at reversing biodiversity loss and accelerating the EU's transition towards a resource efficient and green economy.

These two strategies have the same denominator - change. They both recognise that the change of current way of life is crucial and we have to act now.
Distinguished guests, our farmers need more options to respond to climate change to guarantee food security, and to help preserve biodiversity. This is when we should think about the innovation.

We are aware, that the research and innovation are the key drivers in accelerating any transition. I call to focus on the transition to sustainable, healthy and inclusive food systems from primary production to consumption.
We all know that with increasing digitisation and precision technique we can protect our environment by decreasing the use of fertilizers and pesticides without negatively impacting yields. It should never be a question of "either or" and rather a how do we protect our environment and climate while guaranteeing food security and production in Europe.

Moreover, the recent European Commission study has confirmed that the products of the New Genomic Techniques have the potential to contribute to more sustainable agri-food systems. The goals of the Green Deal and Farm to Fork are ambitious and new genome techniques will help achieving them. I hope that Europe will be more courageous when it comes to innovation and thereby not only support our farmers, but also our excellent scientists that developed the technology and its benefits. Therefore, I will dare to say that harnessing innovation and sustainability of food systems contributes to making our economy more competitive.
By investing in innovation, we are also meeting the objectives of the Green Deal and Farm to Fork Strategy, pursuing the EU's priorities and promoting visibility at global level.

Ladies and Gentlemen, the place to engage in the discussions on these matters is the Food Systems Summit that will take place in September 2021. This event is meant to seek ambitious policy outcomes for the future of farming and the global fight against hunger.

It is an excellent opportunity to launch new actions towards transformation of the world food systems into healthier and more sustainable. The EU has actively contributed to the preparation of the 2030 Agenda and has committed itself, to make the Sustainable Development Goals a guiding principle in all its policies and to promote them with its partners.

As AGRI and DEVE committee in the Parliament we jointly ask the Commission to put forward a renewed and enhanced EU commitment to achieve zero hunger and the right to adequate food. Furthermore, we need adequate financial commitments in order to reach the SDG 2 Zero Hunger given the current huge global funding gap. We also need to think of a new EU trade policy to support the global transition to sustainable agri-food systems. And also, how as EU we can support partner countries and their local farmers, fishers and foresters, as well as food producers in moving towards more sustainable practices in key areas such as animal welfare, the use of pesticides and the fight against antimicrobial resistance.
This is the chance for the EU to share its global vision and commitments with the world.

I am confident that by working together with the stakeholders, across all domains, we can move towards the transformation of the EU food systems to be more resilient, more sustainable, taking into account innovation and protection of biodiversity and natural resources. And let us among all questions not forget, that our farmers are in the middle of it all and produce daily our food on the table. I want take this opportunity and thank them for their work.

Ladies and Gentlemen, I wish you a good conference with constructive discussions and innovative ideas!

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OPENING SESSION

Mr. Christoph Ammann

Member of the Government of the Canton of Berne
and Minister for Economic Affairs, Energy and the Environment

Welcome to the Canton of Berne
Bienvenue dans le Canton de Berne
Herzlich willkommen im Kanton Bern
Ladies and Gentlemen

How can we produce our food more sustainably?

This question is extremely complex, and unfortunately there are no simple solutions.

I am pleased to be speaking to you today – to people who accept this challenge. Welcome to the 8th World Congress on Conservation Agriculture here in the Canton of Berne.

I am proud that the Canton of Berne, with its experts from the administration, teaching and research, can contribute to the strengthening and dissemination of a soil-conservation cropping system.

Switzerland, and the Berne region in particular, is predestined to host the World Congress – even if not all participants were able to travel due to the Corona pandemic. The Canton of Berne, with its diverse landscapes and different sizes and types of farms within a very small area, offers the best opportunities for Conservation Agriculture.

Switzerland, and in particular the Canton of Berne, has been researching and testing soil-conservation farming systems for many years. Today, 5 percent of the arable land is cultivated with direct seeding.

Efforts are also being made to introduce a soil-conservation cropping system in organic farming and vegetable growing.

In Switzerland, two of the basic principles of Conservation Agriculture – permanent soil cover and diverse crop rotation – have been legally prescribed since 1997. In the canton of Berne, many methods have been tested, and soil-friendly cropping systems have been promoted with financial incentives since 1993. Bernese agriculture has done pioneering work in this area.

The Online World Congress 2021 in Switzerland is intended to highlight the importance of soil protection. The public and political decision-makers should be made aware of this issue. I am sure that you will succeed in this endeavor.

As Minister of Economic Affaires responsible for agriculture, I am committed to ensuring that the Canton of Berne continues to move ahead in this area. The Canton of Berne will continue to work hard to find solutions for sustainable agriculture.

I would like to thank all those who contribute to this effort. I thank all those who build networks to exchange knowledge, share their results and support each other. I thank all those who have made this World Congress possible. A big thank you.
I wish you all a successful World Congress.

OPENING SESSION

Mr. Christian Hofer

Director, Swiss Federal Office for Agriculture

Dear participants of the Conservation Agriculture congress, dear organizers,

Also, from my side a warmly welcome to you to this outstanding event and many thanks for giving me the opportunity to address a few words to you.

When you think of Switzerland, you probably imagine snow-covered mountains, lush meadows and clear lakes. As diverse as our landscape is, so is our agriculture. Swiss farmers cultivate soils from the flat central plateau on 300 meters above sea level to steep mountain slopes up to 2'500 meters above sea level. They produce crops, fruits and vegetables on about 400'000 hectares, and use pastures either year-round on about 600'000 hectares or only in the summer months on more than 460'000 hectares.

Swiss agriculture is almost completely soil based. We have the advantage that we can produce our agricultural goods on young and very fertile soils. Therefore, we have to take especial care on this precious resource. The sustainable use of soils is even stipulated within the Swiss constitution. Already back in 1996, the Swiss population voted with almost 80 percent in favor of an initiative calling for a multifunctional agriculture. Therefore, Swiss farmers fulfill nowadays far more tasks than solely producing food, as they are also shepherds of our landscapes and our cultural heritage. Within our multifunctional agriculture, farmers ensure the maintenance of many services for our society and are well aware of their responsibility. More than in almost any other country, farmers are constantly under the scrutiny of the society and try to make people aware of the diverse demands on agriculture they have daily to deal with, and to create understanding for their practices.

With only 4 ares of arable land available per inhabitant, the pressure on the most fertile soils is tense. Around 1 square meter of arable land is lost every second in favor of settlements, infrastructure or forestation. In order to preserve the most fertile soils for agricultural cultivation, Switzerland developed a spatial development program almost 30 years ago which was renewed just last year. In this manner, each canton is obliged by law to protect a certain area of highly fertile cropland, based on its size and natural and climatic conditions.

To ensure that also future generations can also utilize soils according to their needs, the federal office for agriculture developed together with the federal offices for environment and for spatial development a national "soil strategy". This strategy pursues the vision that soil functions shall be conserved permanently and cultivated sustainably. To this end, various goals and paths have been defined that should lead to the preservation of the manifold soil functions. For the agricultural sector, the aims are – among others - the prevention of soil compaction and erosion, and the preservation of soil organic matter and soil biodiversity. As you can see, these are almost the same aims, which are in the focus of Conservation Agriculture.

However, knowledge about Switzerland's soils is still rather poor and very patchy. Therefore, the Federal Council created a center of excellence for soils. This center functions a national hub for soil information and provides all kinds of soil related services to as many user groups as possible. Detailed information on the state of soils and the functions they provide is highly needed on many different levels, from the political decisions makers to our farmers, who are working daily on their soils.

The conditions for Swiss farmers are quite different from the conditions for many other farmers in other countries. As Switzerland consists mainly of small-scaled landscapes and many fields are on rather steep slopes, cultivating the fields is labor-intensive. For these difficult production conditions, the high societal demands on production systems and the difficult economic environment for agriculture – Switzerland is not exactly known to be a cheap country - Swiss farmers are supported by the government with direct payments.

These direct payments are rewarded to farmers for their achievements in preserving the culture landscapes, food production and the responsible use of natural resources. In order to receive these payments, a number of conditions must be fulfilled, including an appropriate soil protection. This obligates farmers to take care of their soils, to maintain a balanced nutrient regime and to plant a broad crop rotation. Additionally, to this mandatory requirements, financial support programs are in place since 2014, which promote the application of soil conserving practices like no-till, strip tillage and mulch tillage. In addressing the conflict of interests between reduced soil tillage and the broad use of herbicides, the financial support is linked to the condition that a certain application rate of herbicides cannot be exceeded. Meanwhile, almost 20% of all Swiss farms participate in this soil conserving program.

Such programs for the sustainable use of agricultural soils are even planned to be extended in future agricultural policies. Additional reward programs will be set up that will stimulate not only reduced soil tillage but also a maximal duration of soil cover and an evenly balanced humus management on the farm level. Together with the already mandatory broad crop rotation, Swiss farmers will thereby be almost completely rewarded for the application of Conservation Agriculture practices.

You see, the sustainable use of soils is not only in the center of farmers daily work but also in the focus of many decision takers, and the resource soil with all its providing functions should be even much more appreciate in the future as it was so far. For this, we need your dedicated work on practices preserving our soils more than ever before, and I hope that we all can learn a lot by the outcomes of this conference. I wish you all very inspiring talks and fruitful discussions, and this not only for the duration of this congress, but also for your ongoing work.

Thank you very much for your efforts!

OPENING SESSION

Mr. Qingfeng Zhang

Chief of Rural Development & Food Security (Agriculture) Thematic Group
Asian Development Bank

Mr. Chair, Vice Chair, and moderator of this session; FAO Director General Mr. Dongyu QU, distinguished speakers, and respected participants; good morning, good afternoon, and good evening depending on where you are.
First of all, I would like to congratulate the organizers for successfully organizing the 8th World Congress on Conservation Agriculture in this difficult time. The theme of 2021 Congress -- **The Future of Farming: Profitable and Sustainable Farming with Conservation Agriculture**, resonates with ADB's strategy 2030 and our escalated focus on supporting our developing member countries (DMCs) for their green, inclusive, resilient recovery.

Asia has made remarkable progress in reducing hunger since the introduction of the Green Revolution in the mid-1960s. But despite that progress, Asia is still home to more than half of the total undernourished people in the world – an estimated 381 million people in 2019. Asia is also one of the most agricultural resource-stressed regions in the world. Agricultural land and water bases are declining, and the agricultural workforce is shrinking. The two-way nexus between agriculture and climate change is intensifying. Against these backgrounds, Conservation Agriculture to prevent losses of arable land while regenerating degraded lands is very important in Asia.

Recognizing the importance of Conservation Agriculture, Asia started to work to promote this but very slowly. A number of factors have hindered the progress, including the mind-set – overcoming the culture of the plough, need for local manufacture of the adapted equipment, lack of extension services throughout the region, and finally competition for crop residues which are sometimes also used as animal feed.

Despite of these difficulties, a number of DMCs in Asia have made good progresses in Conservation Agriculture. Countries like China, India, Pakistan, Bangladesh, Laos, Vietnam, Cambodia, and Philippines are not only very keen to transform their agriculture into a sustainable base, but also have research and extension activities on Conservation Agriculture. Among them, China and India have a significant area already under no-till crops. Up to 2016, Conservation Agriculture systems have been extensively implemented in China to reach an area averaging as much as 8 million ha. It was also reported that India's Conservation Agriculture programme saved USD 164 million with an investment of USD 3.5 million with internal rate of return of 66% which was the highest amongst all the CGIAR programmes. To promote knowledge sharing on Conservation Agriculture, regional networks for Conservation Agriculture for both South Asia and Southeast Asia have been established. These networks aimed at identifying the best practices and promoting the best policies and technologies among these DMCs.

Together with other development partners, ADB has assisted the DMCs in promoting Conservation Agriculture's research & development, knowledge sharing and demonstration. One example project was Dryland Sustainable Agriculture project that ADB had supported since 2009. This project covers 27 counties in Gansu, Henan, and Shandong provinces, and after 6 years, the project has delivered considerable number of outputs in terms of Conservation Agriculture techniques such as returning crop residues to the soil, and also facilities established and farmers engaged, showing promise in achieving its outcome.

ADB has also started to prepare another project in Indonesia with focusing on dryland farming as well. The project design includes soil and water conservation measures, retaining and increasing soil quality. The project will provide selected farmers with soil kit test equipment to independently monitor soil quality, analyze results, and decide on actions to improve fertility. In partnership with the International Rice Research Institute (IRRI), the ADB completed a field demonstration of direct seeding of rice in 2019 in Nepal and Cambodia to disseminate the benefit of minimum and zero tillage to farmers. In Nepal, labor shortage is a major problem in rice production as the primary method of crop establishment is transplanting, which requires a high labor input. The experiment showed direct seeding requiring zero or minimum tillage to reduce the total cost by 30-40%. This generated interests among the policymakers of the country to scale up Conservation Agriculture in the rice-based system of the country. At the field level, it created reliable local individual and institutional champions. Similar findings obtained from field experiments in Cambodia as well.

These are some of the examples of the ADB's initiatives to promote Conservation Agriculture in Asia. We need a lot to do to promote Conservation Agriculture in Asia which is dominated by the rice-based system. As I mentioned in the beginning, the ADB is committed to green, inclusive, and resilient rural recovery from the aftermath of the Covid-19 pandemic. Responsible production with minimum impact on nature, greening of the agricultural value chain with minimum carbon footprint, conservation of biodiversity through natural capital investment are the key priorities for us.

Finally, scaling up Conservation Agriculture in the region requires more profitability in adopting conservation practices and private investment in this area. ADB has established a working group to expand upon experiences in China and the Mekong subregion through a regional natural capital lab. The lab is designed as a living and virtual platform to incubate, accelerate, and expand natural capital investment, which will prioritize the support for greening of the agriculture value chain in developing Asia. The lab will leverage existing accounting tools to quantify the ecosystem service value of green agricultural value chains, strengthen eco-compensation or payments for ecological services to incentivize behavior change among small farmers, and establish a financial facility to convert ecosystem value or assets into the revenue model of agribusiness.

The lab will act as an enabler for blended financing to promote green, inclusive, and resilient solutions to build sustainable food system. I will invite you to join in this initiative which can potentially contribute to Conservation Agriculture.

I would conclude again thanking the organizers for organizing this very important and timely congress. Looking forward to a very interactive and useful discussions leading to pragmatic solutions to promote Conservation Agriculture.

Thank you all.

OPENING SESSION

Mr. Martin Kropff

Director General of the International Maize and Wheat Improvement Center – CIMMYT
Global Science Director for One CGIAR's Resilient Agri-food Systems science area

Colleagues,
It is wonderful to be part of the *8th World Congress on Conservation Agriculture*.
My name is Martin Kropff and I am the Director General of the International Maize and Wheat Improvement Center – CIMMYT – and the Global Science Director for One CGIAR's Resilient Agri-food Systems science area.

Across the CGIAR, many scientists already engage in Conservation Agriculture and I am happy to be here today to shed light on some of CIMMYT's success stories.

We all know that if not practiced sustainably, agriculture can have a toll on the environment.

It can introduce an unsustainable use of agro-chemicals. New insects and pathogens may become a serious problem and it reduces and alters wildlife habitats. Agriculture also contributes to greenhouse gas emissions linked to climate change.
Regenerative and nature friendly farming methods such as applied in Conservation Agriculture (CA) can help to combat these impacts and boost farmers' incomes.

Around CA, conducive decision making and business environment can create better income opportunities for entrepreneurs and innovators. It is not just a cost-cutting and resource-conserving concept. It is a strategy to address present and future challenges and reap opportunities in agriculture.

Over time, CIMMYT's research has moved from a plot to a landscape approach.
We consider the 3 principles of CA, minimum tillage, soil cover and diversification the base for the construction of an efficient and resilient production system. But we know that we need to go beyond those. We need to include precision, data driven, geo-spatial and digital agronomy inputs, as well as foresight and targeting and business models for scaling to generate real transformation of the agri-food system. The key for me is that we use science and evidence-based approaches in improving agricultural systems toward resilient livelihoods.

I would like to share a couple examples from our work and link them back to why CA is an excellent opportunity to address present and future challenges in agriculture.

CA methods can help to increase resilience to climate change.
For example, for maize, drought stress and extreme temperatures work together to reduce yields. Drought reduces the crop's ability to cope with excessive heat and, according to projections, this will only get worse.

I would like to share an example from our work in Africa.

Over 14 seasons and across 10 communities in Malawi, we tested if changes in crop management – based on CA – could make cropping systems more adaptive to climate stress. And indeed yes: results showed that by using stress-tolerant maize varieties, embedded in Conservation Agriculture that uses legume rotation, stover retention and minimum tillage, some of the negative yield effects of heat and drought stress were reduced.

The same thing is happening in Latin America.

Mexico is currently going through one of the worst droughts in decades. This will only become more frequent due to climate change.

In the summer of 2020, in our headquarters close to Mexico City, we experienced only two thirds of the usual rainfall. In those conditions, CA yielded twice as much maize grain than the conventional practice including tillage, monoculture and residue removal (5.6 t/ha vs 2.2 t/ha). For wheat the difference was even bigger. Wheat yields were four times bigger in Conservation Agriculture than when conventional practices were used (5.1 t/ha vs 1.3 t/ha).

CA methods can help to protect biodiversity. Let me tell you about our work on fighting the Fall Armyworm.
Fall Armyworm is an insect-pest native to the Americas and several years ago it began its march across the globe, eating everything in sight. Unfortunately, maize is one of its favorite foods.

CIMMYT and partners have studied ways to battle Fall Armyworm. In December 2020, we released 3 Fall Armyworm-tolerant elite maize hybrids for eastern and southern Africa. Currently, the varieties are undergoing the process of national performance trials across 14 African countries. The plan is to distribute these seeds to farmers in 2021.

But seeds *alone* won't increase farmers' yields.

You also need good agronomic practices such as the integration of legumes in climate-adapted push pull systems which will make CA systems a strong ecological response and solution against Fall Armyworm that is accessible to farmers.

In Zimbabwe, we integrated seeds with CA and the best diversification strategies adapted to the environment. By doing this, we experienced significant reductions in Fall Armyworm due to ecological control by ants and other predators. *Again*, this type of system is important because farmers often cannot afford to buy or access crop protection chemicals and, plus, they may pose risks to the environment and the farmers themselves.

In Mexico, where Fall Armyworm is native, we are integrating agroecological pest management into our work with farmers to address the pest, together with our national counterpart, INIFAP.

Fall Armyworm sex pheromones were first used to monitor populations to understand insecticide application needs and are now used for massive capture and mating disruption. Through capacity building with farmers and extension agents, we succeeded in reducing the application of broad spectrum or highly toxic insecticides. In fields in CIMMYT's projects, we went from 90% of registered insecticide applications in 2012 down to 40% in 2019.

CA methods sustainably use natural resources and improve incomes.
CA reduces soil erosion, improves soil water retention and nutrient availability for crops and gradually increases soil organic matter accumulation. While these are fantastic biophysical benefits, what convinces farmers to integrate CA in their fields is the fact that it reduces the *costs of production* and ultimately raises their incomes.

For many years, CIMMYT has worked with partners to transform the African landscape from manual to mechanized. It is super important to transform smallholder farming systems through small scale mechanization tools like 2-wheel tractors. Just recently, the Permanent Secretary in the Ministry of Agriculture in Zimbabwe initiated a new Strategic Alliance with CIMMYT and the private sector to out-scale access to mechanized Conservation Agriculture to a million of smallholder farmers by 2025. This will not only help to reduce drudgery of farming but create new business opportunities for women and youth.

Let's look at an example from Asia.

The rice-wheat rotation of the Indo-Gangetic plains is South Asia's food bowl, but it is becoming unsustainable. If status quo persists, the region will face complex agricultural sustainability challenges and implications on human health. All of this because of air pollution resulting to crop residue burning, inefficient water and agro-chemical uses.

Integrating CA with adapted varieties has shown tremendous potential for resource conservation, adapting to climatic risks, reducing greenhouse gases and increasing yield and farmers' incomes across the Indo-Gangetic plains.

Our work with partners in West Bengal has seen integration of various CA implements become compulsory in any government-supported custom hire center which is seeing substantial leaps in uptake across the state.

In India, by using a tractor attachment called the Happy Seeder instead of conventional tillage tools, farmers are making 20% more profit while applying less fertilizer and less water with significant reduction in greenhouse gases.

How does it work? The Happy Seeder cuts and lifts rice straw, sows wheat into the soil, and deposits the straw over the sown area as mulch with little disturbance to the underlying soil. This eliminates the need to burn straw residue thus removing the main source for air pollution in parts of India where the air quality level is 20 times higher than the safe threshold defined by the World Health Organization.

Given the depletion of aquifers and labor shortages, the development of direct seeding technologies is leading to increased investments and adoption of direct-seeded rice. This is a win for the farmers *and* the environment.

Recent work has also highlighted how CA is linked with improved gendered outcomes and livelihoods in South Asia, with women often benefiting more in terms of time saving than their male counterparts. They are able to use that time differently. Some women chose to use it for household responsibilities or further diversifying their agricultural production and non-farm activities. This is beneficial to their food, nutritional and economic security, as well as links to potential improved educational outcomes for their children.

In conclusion, challenges still remain for the widespread adoption of new methods and techniques to make farming systems more sustainable. Because of this, we need to work on the socio-economic interface with farmers and at the policy level. There is no one silver bullet for making farming more sustainable. But as we will hear throughout this conference, it is not a choice. We must increase food production and we cannot allow agriculture to continue to destroy the environment and the natural resources we depend on.

The development and use of agroecological approaches, as I call them, based on biological scientific evidence, is not only a smart investment for people and nature – it is an *imperative* for sustainably feeding the anticipated global population of 9.1 billion by 2050.

But there is much we still need to know.

There are considerable knowledge gaps that need investment, collective efforts, and joint research:

- Suitable and profitable crop diversification options for a variety of cropping systems that can sustain healthy diets
- Residue retention – the processes in the soil and its real potential for climate mitigation under tropical and sub-tropical conditions
- Soil health dynamics when changing from conventional tillage to Conservation Agriculture (bacteria, mycorrhiza fungi, etc.)
- The role of intercropping systems in the suppression of pests and diseases and in offering financial entry points for short term benefits
- Integration of green manure cover crops into smallholder farming systems and its integration with livestock
- Weed management and the reduction of herbicide dependency in CA because no till results in more weed pressure; factors affecting the feasibility, profitability and viability of weed management practices
- Smallholder mechanization and developing successful and viable business models for scaling.
- Nutrient management and the management of organic inputs.

I hope that together we can work on finding answers and filling knowledge gaps and scaling of technologies that are based on scientific evidence together with our stakeholders, in the first place the farmers!

Thank you for your attention and I wish you a successful 8th World Congress on Conservation Agriculture!

OPENING SESSION

Ms. Mary Boote

Global Farmer Network

Good morning,

I bring greetings to you from the Global Farmer Network, who I serve as CEO. Currently comprised of 207 farmers hailing from 60 countries, 6 continents, the farmers who ARE the GFN are committed to a mission of "amplifying the farmers' voice in promoting trade, technology, sustainable farming, economic growth, and food security".

I would have enjoyed being with you in person. In the past 16 months, we have all experienced unexpected challenges, regardless of where we live, including a need to adapt and learn how to communicate with each other differently.

For an audience focused on using technology and strategies for the benefit of society and the environment, the ability to use technology to speak with you today is humbling and another example of how it can be used to share knowledge, support, connect, and encourage. Thank you to the delegation leadership for allowing me to connect with you in this manner.

Your theme: The Future of Farming – Profitable and Sustainable Farming with Conservation Agriculture lays out very succinctly the challenge and opportunity in front of us. We know that profitable and sustainable are reachable goals that can be achieved in tandem. The data to support that truth is available. The **challenge** before all of us is to make the case, share the information, support agriculturalists globally and work together. Collaboration is an imperative. As I look at today's agenda, I see an important session highlighting the farmer's role, followed by one focused on private sector innovation and engagement, to one that discusses the enabling role those public institutions play and followed by a session that is focused on civil society contributions. All very important in their own right. To drive action – collaboration between all is necessary.

Global Dialogues

Today, discussions regarding what a resilient global food and agriculture system looks like and how it should operate are being held on global and regional platforms from the UN and the Food Systems Summit to the EU Commission and its discussions around the Green Deal to the United States where President Biden, focused on climate change, endorsed cover crops in his State of the Union Address this past February to Africa, India, Latin America and SE Asia where the challenges of climate, pest, disease and policies are the focus of governments, NGOS, public and civil society, we have the opportunity – the responsibility - to speak up, reframe and foster constructive global dialogue.

Farmers are leading the way

One of the silver-linings uncovered by the global pandemic was the determination by every country in the world that agriculture is an essential industry. In addition to allowing the continuation of agriculture production without pause, it has provided farmers a unique window of opportunity to talk about what you are doing and why. Explaining that a farmer's basic duty is to protect the soil – not because the government tells them to – but because the economic, environmental, and social sustainability of his farm demands it. Farmers are leading the way in food production, protection of the soil, preservation of biodiversity, and meeting the global challenges of climate change. Their experience and practical expertise are needed to bring a sense of reality to policies discussed and created a long way from the field, in an ever-increasing virtual world.

People who are not engaged in farming often lose sight of this important fact. We, in this room, know that farmers are innovators who are applying technologies to the challenges of this moment in time. Conservation Agriculture is a tool that supports and is foundational to our joint efforts to build and maintain a science-based resilient, sustainable global food system. Unfortunately, the true results of Conservation Agriculture are invisible to many. You have to dig down- literally – to see evidence that Conservation Agriculture combined with other technologies and practices is improving soil health, nutrient cycling and water efficiency, storing carbon and as one of the GFN farmers from Iowa stated recently – "I'm growing more livestock under the soil than on top of it these days!" For many, this has required new thinking and conscientious planning. And as farmers, researchers, policy leaders and more in the Conservation Agriculture space, you have a positive story to tell about the role you are playing, together.

Exporting Knowledge

Global meetings like this Congress serve an important purpose – bringing together all stakeholders in the Conservation Agriculture sphere to share information, exchange ideas, develop new concepts, encourage, support, become re-engaged and for many of us, re-inspired to do more.

One of our Argentinian farmers and an Aapresid member shared a concept with me that I think bears repeating for this important audience: "Nobody knows more than we all know together". The positive impact driven by Conservation Agriculture is exponentially increased when that knowledge is exported. Farming is different everywhere but many of you have observed or benefitted directly from putting to use information others have shared, adapting to fit local conditions. In a world with a growing population and rising environmental pressures, sharing the strategy, techniques and technology of Conservation Agriculture to areas of the world under additional stress like Africa and India – have never been more important. Sharing not just the winning results but also the mistakes made – lessons learned – so they don't have to be made again. The exchange of information and experiences makes everyone better and our world enriched.

The power of collaboration

In January 2021, entrepreneur Elon Musk, the visionary talent behind Tesla, tweeted that his foundation would give $100 million for a break-through in carbon capture technology. On Earth Day 2021, the details for Musk's Carbon XPrize were released, offering an award for the creation of a technology that would annually remove 10 gigatons of carbon from the atmosphere and store it in the ground by 2050. Climate change and the challenges it is presenting around the world concerns Mr. Musk – it concerns all of us.

As participants in this World Congress for Conservation Agriculture, we know, that in addition to building soil health, retaining moisture and nutrients, boosting yields, and ultimately increasing a farms resilience, the impact of Conservation Agriculture is turning fields into factories of carbon sequestration.

A single farm using Conservation Agriculture cannot solve the challenge of climate change but imagine what is possible if all of the farms of the world were to work together. Farmers' every day actions are uniquely important, and as a collaborative force, they are a force for good. When you see and share with the world that part of the solution to our building and maintaining a sustainable, resilient global food system while dealing with the challenge of climate change, is below our feet, the power of Conservation Agriculture can be a game changer.

I appreciate the opportunity to address you this morning and look forward to joining you in person soon. I wish you a successful and impactful Congress focused on sharing information with each other, learning, encouraging, and laying out a future of farming that is truly profitable and sustainable for all.

Thank you.

The future of farming
Profitable and Sustainable Farming
with Conservation Agriculture

8 WCCA
8th World Congress on Conservation Agriculture

INAUGURAL SPEECH
BENEFITS OF CA FOR FARMERS, SOCIETY AND ENVIRONMENT

Prof. Amir Kassam

Moderator, Global Conservation Agriculture Community of Practice (CA-CoP), amirkassam786@googlemail.com

Friends,..

This is an historic day for the CA movement. It was twenty years ago that ECAF, the European Conservation Agriculture Federation, organized the First World Congress on Conservation Agriculture in partnership with FAO. Today, thanks to continued support from FAO and ECAF as well as other sponsors and especially SWISS NO-TILL, we are gathered together here in Bern and all around the world to celebrate our success as the drivers of the biggest farming revolution to have occurred in our lifetimes.

Let us celebrate our joint engagement and contribution to transforming farming from being the main source of land degradation globally, to becoming a driving force for conserving and rebuilding healthy soils and agroecosystems so that they can sustainably meet the world's future needs for food and other farm products while helping to slow the pace of climate change and ecological breakdown. Let us celebrate our part in the transformation of farming, from being a contributor to the many interconnected crises facing the world, to being a key part of the solution.

It is no exaggeration to claim that our achievement in engaging millions of farmers across every continent in what has become known as Conservation Agriculture –or CA– has been a massive game-changer.

We can and should take great pride in all we have done but we still face huge challenges to complete our revolution so that what we have pioneered is steadily improved and becomes the global norm in farming. Our task during these 3 days on-line, and in the field days, is to shape the future directions in which we need to move together to achieve this in the shortest possible time. For this, we must apply lessons from our collective experience over the past 50 years or so.

We have come this far because of the foresight and determination of some remarkable visionaries and pioneers –mostly farmers– in the USA, South America, Asia, Africa, Europe and Australia. These pioneers saw that conventional tillage, involving frequent inversion of the topsoil, was damaging the structure of soils, reducing their organic matter content, and making them susceptible to erosion by wind and water. They showed us that we could grow productive crops without digging or ploughing, and they devoted their lives to improving CA technologies and sharing them with others in their own countries and beyond.

Rather than list these pioneers by name, I invite each of you to think back to the beginnings of CA in your own country and to reflect on the exceptional people who challenged conventional wisdom and put their ploughs aside.

One of the most notable of the early CA pioneers in the Global South was Dr. Herbert Bartz who sadly died recently. In 1972, with encouragement from Rolf Derpsch from GTZ, he became the first Brazilian farmer to throw away his plough. From then on, he devoted his life to improving CA techniques and promoting CA in Brazil and globally. Now, Brazil has become a leading CA nation with 43 million ha – or nearly 80% of its annual cropland - under various forms of no-till agriculture.

Herbert was hoping to be with us today and had prepared a brief video message to inspire us to follow in his footsteps. I am delighted that his daughter, Marie, has joined us in this Congress, and she will have more to say abou t her father this evening at the Social event where she will be showing the video.

I invite you to watch another video now which Herbert made not long ago for a CA Congress in Africa.

https://www.dropbox.com/s/7sy1hu5kfv54q3m/chamada%20herbert%20bartz-v2.mp4?dl=0

Let me now briefly touch on our achievements.

When the pioneers of No-Till said that good crops could be grown without digging or ploughing, most farmers laughed in disbelief and dismissed them as dreamers. Now, just half a century later, millions of farmers all over the world have taken them seriously. They have embarked voluntarily on all kinds of CA systems, no longer carrying out any tillage on their farms.

The global area farmed using CA systems has risen from less than 1 million ha in 8 countries in 1970 to 205 million ha in 102 countries in 2019. This is 15% of the world's cropland area. In Argentina, Australia, Brazil, Canada, Paraguay, South Africa, Uruguay and the USA, CA methods are applied on more than half their cropped area.

From 1990 to 2009, the CA area globally increased at an average annual rate of 5.2 million ha, reaching about 100 million ha in 2008. From then on until now, the CA area expanded at double that rate, attaining an average of 10.5 million ha per year. This was largely because the global CA Community of Practice (CA-CoP) was established in 2008, with its own communication and networking platform, and began to globalize CA through the farmer-led CA movement worldwide.

The CA-CoP, of which I am Moderator, is a fast-growing open-ended community in which any person or institution interested in CA is welcome. While its network and mailing lists extend its reach, it has no list of members, no membership fees, no hierarchical structure and no officers with executive powers. It is glued together by its adherents' commitment to farming without soil tillage, their natural inclination to innovate and their enthusiasm to share their experiences. This has led to the formation of many local CA groups which, in turn, are linked to regional groups in regular contact with the Moderator.

With the valuable patronage of FAO and much goodwill and support from other international entities, the Global CA-CoP has come to play an important catalytic and facilitating role, including the promotion of regional programmes and national activities, sharing experiences, making information, especially on innovations, widely accessible, and engaging donors and financing agencies in funding local CA programmes.

All of this has been done with the intent that farmers remain in the driving seat. The triennial Congresses provide the opportunity for all interested parties to take stock of progress, to share experiences and ideas, and to chart the future directions in which the Community will seek to move.

This has clearly succeeded! CA is now practiced in all major climate zones in which there is farmed land – from the warm humid tropics to the cool temperate areas. And it is applied in all the world's main farming systems. It has taken hold in rainfed and irrigated areas, short-term and perennial crops, mixed crop-animal farms and organic systems. It has been adopted by large-scale mechanised farms and by smaller farms where most of the work is manual.

CA has also evolved into a wide range of complex farming systems which make the most of the improved soil conditions created by the absence of tillage.

But in spite of all of this, our movement remains vulnerable to possible changes in the governance of our global food system.

A surprising threat could come from transnational corporations, convened by the World Economic Forum in Davos, which have declared a 4th industrial revolution. This would be based on harnessing 'big data' to tell every farmer what to grow and when to plant, and to manipulate consumers' food choices. While they claim that this will cure the ills of the global food governance system, I feel bound to ask: Will this address degradation of our common resources and the planet? Will this meet the needs of small-scale farmers and protect their seed, land and food sovereignty? Will this change our food distribution system to a more equitable one that would eliminate hunger and lead us to healthier diets?

In raising these questions, I am not denying that there are many valuable opportunities for widening the use of digital tools to empower farmers and consumers to make better choices – but without infringing on their rights to make their own decisions.

The reality is that we are the great farming revolutionaries of our time for large- and small-scale farmers. Together, by translating our knowledge and convictions into practical action on the ground, we are leading the most transformational revolution in how land is farmed since the inversion plough was invented in the mid-17th century. We have successfully challenged the universally held assumption that most land has to be regularly and intensively tilled and chemicalized to be productive and profitable. We are also proving that the widely held view that smallholders have no future is nonsense.

We do this because we believe in it, based on the evidence generated by the early no-till farmers. Nobody has had to order us to stop ploughing and digging and nobody has had to pay us to change our ways!

Farmers are the initiators and drivers of the CA movement, its main innovators, and its main promoters. Their success, including spreading and adapting CA into new ecologies and farming systems, has led to the growing involvement of scientists and created a demand for specialised equipment and inputs that has expanded the participation of the private sector in our revolution.

The main motivation for farmers' engagement has been CA's potential for net gains in productivity and incomes. By eliminating tillage, larger farmers have cut spending on farm machinery, inputs and fuel, while small-scale farmers have not only made big savings in time and human energy from excluding deep hand-digging, but they have also found that they can move into CA with few purchased inputs and rely on their own seeds.

Formal research systems have become increasingly engaged in comparing the impacts of different CA interventions especially on soil structure and biology, moisture retention, carbon sequestration and pesticide-free weed and pest-management. There is now a huge raft of easily accessible scientific studies on almost every dimension of CA applications. Thanks to the expanding databases of CA networks, FAO and Cornell University, information is easily accessible on almost every dimension of CA in text-books, and in scientific and technical studies. In future, however, researchers and farmers must do much more to team up in generating new CA systems knowledge.

One feature of CA is that its adoption and spread does not follow traditional linear agricultural extension models that transfer the findings of researchers to farmers. Instead, farmers themselves play the major role in innovation through CA Farmer Associations, Farmer Field Schools, Clubs and Networks as well as through community engagement. These social institutions offer opportunities for sharing knowledge and for cultivating solidarity that stimulate change and self-empowerment. This works effectively for all farmers when their skills, and needs for seed, land and food sovereignty are respected and supported by governments and stakeholders in the public and private sectors.

True, the private sector has responded well to demand especially for machinery and inputs, but in many places, CA farmers call the shots and the private sector has to offer a mutually beneficial service support along the value chain.

We are pushing ahead with CA and improving it as we go, mainly because we have found our incomes rising and the quality of our farmland improving.

CA differs from the dominant ‘industrial’ approaches to tillage farming that have been driven by the goal of ever greater intensification, aimed at maximising yields. They use more and more inputs and need ever bigger investments. Over time, they all too often damage or destroy the soils and environment that provide the foundations for food production and environmental or ecosystem services, and also put human health at risk of nutritional disorders.

In spite of CA’s rapid spread, tillage-based agricultural intensification continues to cause vast physical and biological soil degradation and erosion, forcing the abandonment of once productive agricultural lands, increasing the frequency of flood damage, polluting our environment with toxic chemicals, releasing high levels of greenhouse gases, wiping out biodiversity, and reducing adaptability and resilience to biotic and abiotic stresses as well as fostering resistance to antibiotics.
It seems to come naturally nowadays for humans, at least in so-called ‘developed countries’, to think that more is better. We now realise that satisfying the desire for more and more material things without considering their environmental impact is putting at risk the future of our children and grandchildren, and of all those with whom we share the planet.

CA’s success comes from deliberately moving in exactly the opposite direction. We are getting more from less and bequeathing a healthier planet to future generations. We have already shown the ability of CA’s core practices of no-till, soil mulching and crop diversification to provide an effective foundation for integrated biological pest management and for drastically reducing agrochemical use. We have also shown in several environments with smallholders and large-scale farmers the avoidance of the use of pesticides for controlling weeds, insects and pathogens through for example Push-Pull strategies, techniques of planting green involving green manure cover crop mixtures, and manipulation of soil fungi-to-bacteria ratios. And many smallholder farmers are practicing CA without the use of any agrochemicals. This is why FAO placed CA at the core of their ‘Save and Grow’ global strategy for sustainable production intensification.

CA is good for all farmers, good for the land, good for the planet and good for people.

Let us now look to the future of CA

There is no doubt that CA is a success story that is here to stay and that it will continue to grow fast. But what about our expectations for the outcomes of this Congress?

The organizers of the Congress are convinced that CA must be the mainstay of the shift that the world has to make urgently towards sustainable farming and food systems. This is because we know that, for as long as most soils continue to be damaged by tillage, the world cannot reach the goal of making food systems sustainable.

But we also recognise that some aspects of No-Till systems, as they are now generally practiced, are restricting sustainability. Specifically, some No-Till systems with poor cropping diversity still remain too dependent on pesticides (especially herbicides), on mineral nitrogen fertilizers, and on unduly heavy farm machinery driven by fossil fuels.

I am sure that you will all agree that this has to change.

Within our global Community there are many precedents for moves in the right directions, but we need to throw our weight behind accelerating their enhancement and uptake, so that CA becomes synonymous with sustainable farming for the future.

We also know that we cannot go it alone. We must engage globally and locally with the champions of other essential elements of sustainable farming, especially those engaged in organic farming, integrated pest management, agroecology and regenerative farming systems in their various guises. In return, all these farming systems can be helped to harness CA principles and practices. If we do not share our experiences, help each other and pull together, many of the international Sustainable Development Goals – the SDGs – relating to food, natural resources management and climate change will be unattainable. We also have an important role to play in the recently launched UN Decade on Ecosystem Restoration 2021-2030.

I also suggest for your consideration that the time may have come for our Community to begin to help to shape food consumption patterns in ways that will relieve pressure on the world's finite area of cultivable land rather than destroy forests and other vulnerable ecologies to expand farmed land, with doubly negative effects on the rate of climate change. Fortunately, we are faced with a win-win-win opportunity, as the area under farming can be greatly reduced, environmental damage curbed and human health improved by inducing a shift towards predominantly plant-based diets: this, in turn, would cut demand for livestock feeds which has been a main driver of the recent damaging expansion in cropped areas especially in tropical regions.

It is against this background that I suggest that this Congress may wish to signal its support for a notional goal of having good quality CA-based systems fully applied on at least 50% of the world's annual cropland area or 700 million ha by 2050.

I believe this is an attainable goal given that the global CA movement doubled the rate of uptake of CA during the last decade. The big challenge will be to graft the other essential elements of sustainable farming into all our programmes – including those in the existing 200 million ha already applying CA.

Achieving this goal would require a massive boost to the momentum of our Community's activities with a concentration on the following six themes:

1. Catalysing the formation of additional farmer-run CA groups in countries and regions in which they do not yet exist and enabling all groups to accelerate CA adoption and enhancement.
2. Greatly speeding up the invention and mainstreaming of a growing array of truly sustainable CA-based technologies, including through engaging with other movements committed to sustainable farming.
3. Embedding the CA Community in the main global efforts to shift to sustainable food management and governance systems and replicating the arrangements at local levels.
4. Assuring that CA farmers are justly rewarded for their generation of public goods and environmental services.
5. Mobilizing recognition, institutional support and additional funding from governments and international development institutions to support CA programme expansion.
6. Building global public awareness of the steps being taken by our CA Community to make food production and consumption sustainable.

To move forward with this, strengthening of the Moderator capacity within the CA Community is now needed. Much thought must still to be given to this, but one thing is clear: we must retain the concept that, as now, our future actions must be guided mainly by a growing team of volunteers coming from within our midst who are committed to giving their expertise, time and energy to enhancing and spreading CA systems.

Earlier, I paid tribute to our pioneers and champions. With millions of farmers now applying CA in its many variants across the world, I feel confident that plenty of people will signal their willingness to dedicate themselves to moving our activities forward.

One of the few positive by-products of the COVID pandemic is that it has stimulated great advances in information and communications technology. We are applying some of these in this largely virtual Congress. Any new actions need to take the fullest possible advantage of these innovations. One important implication is that all those involved in any new programme moderation arrangements can make most of their inputs from where they live.

Of equal significance is the huge opportunity that these technologies offer for accelerating the spread of advances in knowledge across our Community and beyond. The Community's strength has been built on farmer-to-farmer sharing of experience, usually within their own localities and sometimes through country exchange visits. Now these farmer-to-farmer exchanges can instantaneously become global.

And so, we shall nurture the emergence of a stronger moderating mechanism that will function almost entirely virtually. It would enjoy the guidance of an advisory panel, representing regional and national interests and those of cooperating institutions. It would have the capacity and power to set up task forces to push forwards on each of the 6 main themes – and any more that might be added. And it would need to have a permanent IT systems development and operating capacity. It would also oversee and support future processes for convening CA World Congresses. Finally, it would have to be set up as an entity – perhaps as a non-profit organisation -- with sound financial management, programme monitoring and reporting capacities.

Finally, though this may seem a minor issue, I also propose that we convene a small working group to set up arrangements for honouring our pioneers through creating a CA Hall-of-Fame in time for the 9th Congress.

To get started immediately on this expanded agenda, ECAF has generously agreed that elements of the Congress Secretariat can continue to assist the Moderator in moving ahead with these new arrangements. I hope that we can also continue to benefit from the patronage offered by FAO since our work began.

I am confident that this Congress will, like earlier ones, give a great boost to our efforts and set the stage for a very bright future – a future in which our Community will play a hugely important part in the race to make the world's food systems properly sustainable.

Thank you all for joining us at this challenging moment in our history.

My very best wishes to you all for a truly inspiring Congress.

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FARMERS´ ROLE IN MAINSTREAMING CA WORLDWIDE

Mr. Kofi Boa

Farmer

Farmers, big or small are the exhibitors of the real value of CA and so for the technology to attract the attention of all other groups of people, we farmers must assume the role of the protagonists and play the advocacy role.

Come to think of it this way. How many agricultural researchers are farmers themselves and are applying their own recommendations at scale? And how many agricultural extension officers out there are also farmers farming themselves? Majority of them are mostly people who are doing research and extension as a means of earning a salary and especially in most developing countries, they continue to enjoy salaries and fringe benefits whether the soils are still eroding or not. They only provide knowledge and guidance to keep our CA candles burning.

The realization is that, it is the one who has seen the light and carrying the light around that can lead other people out of darkness and so those of us farmers who either by dint of tragedy, by trial and error or out of perseverance that have seen the real value of CA should without any reservation, be the ones to show up the worth of CA to the whole world for we will never ever sound convincing enough and win the attraction of the world if we have nothing visible to show.

When we commit ourselves to exhibit CA in terms of its impacts on our food systems, on our health and other ecosystem services we will surely attract the attention of everybody and therefore push CA to the heights. We at the CNTA are doing this, Gabe Brown is doing it and farmers in Brazil, Argentina and elsewhere are doing it. AND what about you my dear CA farmer?

We need to come together and encourage knowledge sharing and exhibition of the benefits and evidence of CA not just at big sessions like the WCCA, ACCA and others but right from the community level to start blowing the horn. More so in Africa, it is at that level where the bulk of the food is produced and so if you are out there thinking that you are not a farmer and therefore you don't care much about what happens on the farmland, farmers will in the first place lose their job and, in the end, everybody including you will die out of hunger.

CA is helping to build healthy soils to support the growth of healthy plants to produce abundant food to feed healthy people like all of us at this congress so no matter what you do for a living, help us the farmers to push our governments all over the world to institutionalize CA in national agricultural systems because no single nation can do it and think that it is safe.

The shift to CA will require not just value-aligned capital but also technical expertise and partnership especially for the growth-stage CA farmers and related companies. These will be the drivers to move the CA train from the North to the South and from the East to the West for the benefit of mankind and society.

Thank you

PRIVATE SECTOR INNOVATIONS & ENGAGEMENT FOR CA DEVELOPMENT

Mr. Juan González Valero

Head Sustainable and Responsible Business, Syngenta Group

Syngenta has always invested significantly in biodiversity and soil health. In 2013 the company began a major global programme of investment into innovation for sustainable farming. 2019 saw a move to seek more specific approaches to enhance farmer innovation and uptake, seeking increased farm productivity and sustainability.

Major investment areas in this programme are:

- Soil health, based on bio-stimulants, to improve nutrient uptake, plant stress resilience and water-use efficiency.
- Nutrient efficiency
- Root health development through genetics and seed dressing

Syngenta continues its major long-term commitments and co-operation in Europe on biodiversity and sustainability but has also committed an investment of 2 billion euros over the next 5 years to global programmes. One example of their large-scale field programme, called Reverte, is in the Cerrados of Brazil. This aims to recuperate I million hectares of degraded soils via integrated cropping and livestock.

The Syngenta Resource Efficiency Programme aims to improve biodiversity monitoring with emphasis on:

- Indicators and sensors and to make these technologies more precise and available to a wider range of users to improve productivity and facilitate scale-up.
- New molecules and biological compounds to meet challenges and replace old technologies.
- Precision application of crop protection products and precision seeding and new genetic material.

Current policy is to continue to invest heavily in research and development in the above areas to assist the performance and adoption of improved farming systems and support Conservation Agriculture.

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CIVIL SOCIETY CONTRIBUTIONS TO SCALING CA

Mr. David Traynor

Concern Worldwide

Who are Concern Worldwide?

- Concern founded in 1968 in response to the Biafra crisis in Nigeria, has since grown with Concern working in 27 countries, and has a dual humanitarian and development mandate.
- These are either impacted by protracted humanitarian crises, and/or in the bottom 40 of the HDI.
- Concern launched its new strategic plan and involves responding to the climate, conflict and hunger crises in the poorest and most fragile contexts.
- With regards to Concern's Livelihoods programmes, they focus on livelihoods security for vulnerable households affected by disasters and shocks and extreme poor with both hunger and nutrition outcomes.

Why should an CSO do Conservation Agriculture?

- Many of the countries Concern works in are extremely fragile and are located in regions that have been disproportionately impacted by climate change. Four of these countries are in the Sahel, including Burkina Faso, Niger, Chad and Sudan.
- There have been major disasters in the Sahel, including escalation of conflict in Burkina Faso and Niger, prolong dry periods, erratic rainfall patterns. However, many of these "major disasters" often distract from the small shocks that smallholder farmers in the Sahel that rely almost exclusively on agriculture or livestock for their livelihoods, experience day to day.
- The Sahel is an extremely vulnerable agro-ecology.
- In the Sahel, insufficient or late rains, soil erosion, deforestation and degraded soil, pest and disease outbreaks can affect the performance of crops. Smallholders lack the means to purchase agricultural inputs, hire labour to prepare land and face inequality barriers based on gender, ethnicity, etc to build livelihoods.
- As Concern works in some of the most fragile countries, the state may lack the resources to provide sufficient extension and training services.
- This is where a civil society organisation such as an international or national NGO to a community group can fill these gaps. Concern has had Conservation Agriculture as its key element in its food security and livelihoods programmes throughout the Sahel.

How do we do it?

- In the Sahel, farming practices have been adapted to the semi-arid agro-ecologies over centuries and hence it is vital that local knowledge is incorporated when planning extension. Concern has used the lead farmer approach as a peer-to-peer extension method.
- This involves training female and male farmers selected by communities based on criteria such as having a good knowledge in farming, being able to teach others and having resources to take risks in new approaches.
- Lead farmers are then grouped with student farmers who are selected based on community-defined criteria, such as being from extreme poor socio-economic groups, more than three children under five, children enrolled in a malnutrition treatment programme, female headed households, vulnerable households caring for elderly, disabled, etc.
- A lead farmer is trained by Concern in the three principles of Conservation Agriculture, many of these such as *zai* holes or tools such as *hilaire* that can be used for minimum tillage have been used for centuries.
- Often the local state extension agencies has been contracted to provide the training to create a link with farmers and these services. These trainings are best done in a field nearest to the villages that reflect the local agro-ecologies rather than a demo plot in an extension centre that can be a more sanitised field with good fertility and free of pests and diseases.
- Follow-up after trainings is essential, using staff from the area who have good connections with local authorities and customary leaders for acceptance of the NGO. Recognising indigenous farming methods adapted to the Sahel is essential to support integrating with more improved Conservation Agriculture practices.
- In Niger, Chad and Sudan, we focus on smallholders famers and I think we can see that Conservation Agriculture provide very significant results in a context where yields.
- Conservation Agriculture by its nature, requires less inputs, less labour and can have impacts on protecting soil ecosystems.
- Civil society also need to consider other areas as well with Conservation Agriculture, such as:
    1. Environmental regeneration.
    2. Gender (addressing the barriers to livelihoods improvement).
    3. Protection (safety of female and male farmers in fragile contexts).
    4. Nutrition and health (preventing malnutrition and disease).
    5. water, sanitation and hygiene promotion (reducing disease and improving irrigation).

This is to have the maximum impacts for resilience of poor and vulnerable households.

What can we do after we finish our work?

- In many of the more fragile contexts, sustainability can be compromised by lack of extension services once the NGO finishes the programme.
- This is where an alternative is needed, and can involve supporting producer groups, farmers groups or federations and other grassroots community groups who can develop Conservation Agriculture techniques through trials in something like a Farmer Field School.
- Concern has been focusing on smallholders famers and I think we can see that Conservation Agriculture provide very significant impacts in the Sahel. I think there is a need for more evidence in terms of results and to study how far Conservation Agriculture can reach (communication channels, dissemination techniques, etc.) the most vulnerable households in an effective and efficient way.
- We also need to look at specific groups, such how it enables women and men and marginalised smallholders in the Sahel to have more secure livelihoods.

SUBTHEME 1

SUCCESSFUL EXPERIENCES AND LEARNINGS FROM CONSERVATION AGRICULTURE WORLDWIDE

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Successful experiences and learnings from Conservation Agriculture worldwide

A. Kassam[1], T. Friedrich[2] and R. Derpsch[3]

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Since 2008/09, Conservation Agriculture (CA) has been expanding globally at an annual rate of more than 10 M ha of cropland. In 2015/16, the total CA cropland area was more than 180 M ha, corresponding to 12.5% of global cropland area. The spread of CA is expanding in Asia, Africa and Europe in recent years because more resources are being allocated towards supporting farmers to adopt CA. Perennial CA systems such as orchards, plantations and agroforestry are expanding worldwide. Globally, expansion of CA is largely farmer-driven and has become a multi-stakeholder movement comprising formal and informal CA networks at national and international levels, with support from individuals and institutions in public and private sectors.

Successful global experiences about CA are many. They show:

- The interlinked CA principles are universally applicable in all land-based production systems in all continents for all farm sizes and types of farm power.
- The core CA practices serve as underpinnings for ecological sustainability upon which a range of integrated crop, soil, nutrient, water, pest, energy management practices and benefits can be built.
- CA is a valid alternative agricultural paradigm that can address the weaknesses of the dominant tillage-based Green Revolution paradigm.
- CA is considered to be the best example of climate smart agriculture, but CA is also smart in several other ways including ecologically, economically and socially.

Learnings arising from CA experiences are also many. They show:

- Why CA works as a basis for sustainable intensification, i.e. the underlying science as to why CA systems are more stable, productive, profitable, efficient, resilient, regenerative, deliver a wide range of ecosystem services and are climate smart.
- The productivity, environmental, economic and social contributions being made by a large diversity of CA systems globally across a whole variety of agroecological zones, including at watershed and regional levels.
- The growing range of learnings related to CA system practices and benefits in terms of the role of crop and soil biodiversity, of soil biology, of cover cropping, and of integrated pest (weeds, insect pests, pathogens) management.
- New ways forward that are making it possible for CA systems to operate more biologically and organically, thus reducing or minimizing the use of agrochemicals.
- The important role played by CA systems in pro-poor agricultural development strategies.
- The role of farmer-led stakeholder networks in accelerating and sustaining the spread and quality of CA systems.

Several of these successes and learnings will be elaborated in the full paper and in oral presentation at the Congress, along with the latest information on the global adoption and spread of CA.

Keywords: *global, paradigm, adoption, climate smart, networks*

1. Introduction

This paper provides an update on the uptake and spread of CA around the world and elaborates some of the successful experiences in the different regions that confirm that CA principles are universally applicable in all land-based agro-ecologies. The successful experiences offer lessons or learnings, and these are elaborated in terms of: what makes CA principles universally applicable? What makes CA systems perform better than conventional tillage-based systems. The paper highlights some of the important technical and organizational areas that need or should be given greater attention to accelerate the uptake and spread of CA systems.

2. Successful experiences

2.1 Global and regional spread

The information on the global spread of CA cropland area in 2008/09, 2013/14 and 2018/19 is shown in Table 1. The CA information regarding its area at the national level has been updated up to 2018/19 and will be finalized soon. The interim updated information for 2018/19 is presented in this abstract applies only to annual cropland and is based on several sources: official statistics; no-till farmer organizations; Ministry of Agriculture, NGOs, and well-informed individuals from national and international research and development organizations. It has been possible to update the information base for most countries. For those countries whose area has not been updated, the information from the update in year 2015/16 is used in this abstract.

Table 1: Global spread of CA cropland area (M ha) in different regions and the percent change since 2008/09 and 2013/14.

Region	CA cropland area 2008/09	CA cropland area 2013/14	CA cropland area 2018/19	Percent change in CA area since 2013/14	Percent change in CA area since 2008/09	CA as a percent of cropland area in the region 2018/19
S&C America	49.6	66.4	83.0	25.0	67.3	68.7
North America	40.0	54.0	65.9	22.2	64.7	33.6
Australia&NZ	12.2	17.8	23.3	30.5	91.0	74.0
Russia&Ukraine	0.1	5.2	6.9	32.7	6800.0	4.5
Asia	2.6	10.3	17.9	74.3	588.5	3.6
Europe	1.6	2.0	5.2	154.9	225.0	5.2
Africa	0.5	1.2	2.7	120.3	440.0	1.1
Total	**106.5**	**156.7**	**205.0**	**30.8**	**92.4**	**14.7**

The global total CA cropland area in 2018/19 is about 205 M ha, corresponding to about 14.7% of the total global cropland, with the spread being more or less equally split between the developing regions (50.5%) industrialized regions (49.5%). Overall, the increase in the global CA cropland area since 2008/09 has continued at an annual rate of about 10 M ha, from 107 M ha in 2008/09 to 205 M ha in 2018/19. The global CA cropland area increased by some 92% since 2008/09, and 30.8% since 2013/14. The change in the CA cropland area in the different continents since 2008/09 has been: 67.3% (from 49.6 to 80.0 M ha) in South America; 64.7% (from 40.0 to 65.9 M ha) in North America; 91% (from 12.2 to 23.3 M ha) in Australia & NZ; 600% (from 0.1 to 6.9 M ha) in Russia and Ukraine; 588.5% (from 2.6 to 17.9

M ha) in Asia; 154.9% (from 1.6 to 5.2 M ha) in Europe; and 440% (from 0.5 to 2.7 M ha) in Africa.

The historical chart of CA uptake at the global level is shown in Figure 1. The transformation of conventional tillage-based agriculture began in the 1930's after the 'Dustbowl' that shook the farming communities in the mid-west of USA and the scientific community to rethink about what was not going right with farming, particularly with regards to soil conservation.
Minimization of soil disturbance with stubble mulching was a major breakthrough in the understanding of how the objective of crop production intensification could be combined with the objective of soil and water conservation at the practical level by farmers. Although initially an umbrella term of conservation tillage became popular to describe practices that allowed a reduction in soil mechanical disturbance and provide protective soil cover, it took few more years before it was established in the late 1960s that no-till seeding through stubbles and crop biomass cover was the way to avoid or eventually reverse soil degradation and erosion.

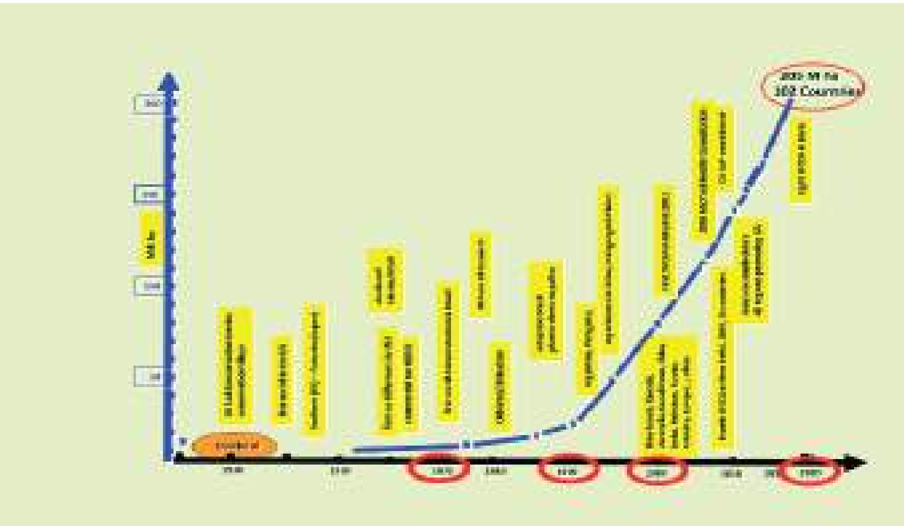

Figure 1. Historical uptake of CA cropland systems worldwide

No-till seeders began to be produced first in the USA, and then in South America and UK in the 1970s. It was during the following two to three decades that the three practices which now comprise the ecological foundation of Conservation Agriculture systems began to emerge. By the mid-1990s, some 35 M ha of cropland area was under no-till systems in North America in USA and Canada and in South America in Brazil, Argentina, Paraguay and Uruguay where on large farms it was possible to manage weeds with chemical means. In 1997, the term Conservation Agriculture (CA) was used for the first time in Spanish at a FAO supported conference of the Regional Conservation Tillage Network in Mexico. The modern version of CA as we know it today was conceived and defined in 1998 at an FAO Workshop in Harare, Zimbabwe (Kassam et al., 2020).

2.2. CA adoption at national level

Historical development of no-till systems and the modern version of CA that has been promoted over the past three decades are documented in Kassam et al. (2020).

Pre 1970: The history of agriculture has been essentially a history of tillage in agriculture, and the culture of ploughing or tilling the soil to establish crops and to manage weeds has been part of history of agricultural development worldwide. However, after the WWI, agriculture began to be intensified to achieve greater output. This was essentially based on the intensification of the use of tillage and agrochemicals as part of crop nutrition and protection management of higher yielding crops under standardised mechanized systems. Initially, this change process began in North America but after WWII, it spread to other industrialized countries in Europe and Eurasia as well as in Australia and New Zealand and in the independent countries of the tropics with emerging economies such as in Latin America and South Asia as part of Green Revolution drive from the West.

1970-2010: From 1970 to 2000, no-till production was being tested in all continents by researchers and larger-scale mechanized farmers, and limited scaling began in the 1980s and 1990s mainly in few countries such as the USA, Canada, Australia, Brazil, Argentina, Paraguay, Uruguay, Bolivia, Venezuela, UK, Australia, New Zealand, Spain, Germany, Kazakhstan, Zambia and South Africa. By 2000, these countries together covered some 65 M ha of CA cropland systems.

The decade of 1990s is considered as the decade when CA took off. During the first and the second decades of the new millennium, CA uptake by farmers spread out to Africa and Asia, while it continued spreading in the Americas, Europe and Australia. Smallholders had already been adopting CA systems, both manual and mechanized, in the tropics in South America in the late 1980s and 1990s, and smallholders in Africa and Asia also began to adopt CA systems during 1990s and the first decade in the new millennium.

The millennium opened with the first World Congress on Conservation Agriculture which was held in Madrid, Spain. This helped to globalize the concept and principles of CA, and CA was promoted as part of sustainable production intensification by FAO and some donor agencies. Some centres of the CGIAR particularly CIMMYT and ICARDA began to conduct research on CA, and a number of national research systems also began to initiate CA research. More regional and national CA organizations and networks were established. Focus of attention also expanded to West Asia, South & South-East Asia, East Asia and Africa with countries such as Iran, Syria, India, Pakistan, China, South Africa, Mozambique, Zambia, Kenya, Ghana and Morocco making significant progress in the expansion of CA area as well as in CA research to facilitate the effective application of the CA principles in specific contexts.

In July 2008, an international Consultation was organized by FAO in Rome to take stock and discuss what were the conditions that were necessary to achieve scaling of CA cropland systems. Experiences from all continents were discussed and a global action plan was formulated to globalize the adoption and uptake of CA. To facilitate the implementation of the plan, a communication platform of Conservation Agriculture Community of Practice (CA-CoP) was established in early January 2009. The platform has enabled global CA stakeholders to be connected and exchange information on all aspects of CA from science and practice to sustainable agriculture development and conservation and regeneration of natural resources and ecosystem functions.

By 2010, more than 105 M ha (7.0 % of global cropland) were under CA cropland systems across 36 countries, covering all continents and most land-based agroecologies. Three more World Congresses had also taken place in Brazil (2003), Kenya (2005), and New Delhi (2009). During the period 1990 to 2010, global uptake of CA was about 9 M ha per year.

2010-2020: During the decade the rate of global uptake increased to 10.5 M ha per year, reaching more than 205 M ha (14.7% of global cropland) in 2019 across 100 countries. CA area in Africa, Asia and Europe expanded more rapidly as more attention and resources were directed to promoting and supporting the uptake of CA cropland systems. During the decade three more World Congresses were held, in Australia (2011), in Canada (2014) and in Argentina (2017).

The expansion of CA uptake continues to be largely farmer-driven and increasing number of governments are now providing policy and institutional support along with private sector machine and service companies to the uptake of CA cropland systems.

3. Learnings

The following are some of the significant learnings based on scientific and empirical evidence from CA-based cropland systems. Similar results are being obtained with perennial systems such as orchards, plantations and CA croplands with trees. The list of learnings is long and there are many variations about these learnings, reflecting variations in biophysical, economic, environmental, social, institutional, research and political conditions. We have selected the following three key learnings which are elaborated in the following sections: (i) The reasons why the three CA principles are universally applicability; (ii) What makes CA operate sustainably and optimally?; and (iii) CA is a valid alternative agricultural paradigm for sustainable development.

3.1. Universal applicability of the three interlinked CA principles

The three interlinked principles of CA have been shown to be universally applicable in all land-based crop production systems in all continents on all farm sizes and with all types of farm power. These CA systems include rainfed and irrigated annual crop systems including horticultural crops involving root and tuber crops, and rice-based systems; perennial crop systems including orchards, vineyards, annual crops with trees and shrubs or agroforestry, plantations; and pasture, rangelands and mixed systems. CA systems are being managed organically or biologically as well as with synthetic inputs (Kassam, 2020).

This is because the three principles emulate nature in which mechanical soil disturbance does not occur for vegetation to propagate and establish. Where vegetation growth is possible because of moisture availability, biomass produced always covers the ground and organic matter is converted into compost mulch on the ground surface and is incorporated into the soil through the microorganisms including mesofauna. Earthworms and termites play an important role in ingesting the biomass and mixing it with soil mineral particles to churn the soil and produce nutrient rich worm casts and excreta. Microorganisms also produce their own compounds carbon-rich compounds which help to bind soil mineral and non-mineral particles into stable aggregates that improves soil structure and porosity, water infiltration and retention and soil aeration.

CA is described as an ecosystem approach to regenerative sustainable agriculture and land management based on the practical application of three context-specific and locally-adapted interlinked principles. They are often referred to as the three 'pillars' of CA that provide the foundation for CA's ecological sustainability without which economic and social sustainability are not possible.

The application of the three interlinked principles into practices provides the underpinnings for ecological sustainability and have been shown to have a robust ecological science foundation, providing a base upon or into which complementary practices can be integrated thereby further strengthening the biophysical and biochemical processes of the system that nourish and protect the plants, as well as facilitate the functioning of the ecosystem. Thus, ecosystem functions at the field level as well as at the landscape level are enabled or mediated satisfactorily. Growing conditions for efficient growth are established and resilience against biotic and abiotic stresses is also enhanced.

3.2. What makes CA operate sustainably, regeneratively and optimally?

- CA systems operate sustainably, regeneratively and optimally because CA promotes the following conditions and outcomes for the whole production system.
- CA has ecological and biological foundations for sustainability
- CA generates enhanced soil health status, biology and functions
- CA enhances biodiversity
- CA has diverse plant root systems and their relationship with soil systems
- CA enhances environmental and ecosystem functions and delivers benefits to farmers and society
- CA develops maximum efficiency and resilience
- CA is able to regenerate and rehabilitate degraded agricultural lands

Each of the above features of CA works synergistically with each other at the process and outcome level levels in ensuring superior and optimal overall performance. CA opens up the possibility for the farmers to transform and regenerate the resource base and conserve the gains and sustain the biological outputs as well as the ecosystem service outputs, allowing the system to operate at its optimal capacity.

3.3. CA is a valid alternative agricultural paradigm for sustainable agriculture

Global scientific and empirical evidence shows that CA is a valid alternative agricultural paradigm that is capable of addressing the weaknesses in the dominant tillage-based Green Revolution paradigm. CA has shown the fuller potential of agricultural land use for the farmers and their households and communities, for the greater society, and for the planet.

Increasingly, CA is seen as a sustainable production base for climate smart agriculture and for carbon sequestration, responding to food security needs and to adapt to and mitigate climate change. The private sector corporations appear more and more to provide support to agricultural transformation towards CA whenever it makes good business sense.

However, it seems that local manufacturing companies would need to become more and more involved in producing the needed on-farm and off-farm equipment for CA systems. Many of the equipment and post-harvest processing used in conventional agriculture are relevant for CA systems. However, no-till direct seeders suited for all farm power and particularly for smallholder systems is an important area requiring further development. The same accounts for non-chemical, non-soil engaging tools for weed management.

The global CA movement is beginning to focus more and more on understanding the conditions necessary for mainstreaming CA which involves the alignment of national policies and institutions towards supporting the transformation of tillage agriculture to CA systems but also engaging in strategic research for improving the quality and performance of CA systems. Where mainstreaming is occurring, such as in countries like Canada, USA, Brazil, Australia and South Africa, CA systems are able to play a bigger role for society in terms of sustainable food system and environmental management. This includes increasing farmers income and creating greater wealth from agriculture, reducing cost of production and consumer price of food, and enabling pro-poor development involving smallholder farmers and their communities. Improved environmental management include providing ecosystem services such as cleaner water, carbon sequestration, enhancing biodiversity and lowering pollution levels and flooding risks.

4. Concluding remarks

The global burden of chronic crises includes food insecurity, climate change, loss of biodiversity, environmental degradation and unsustainable diets and human ill health. CA systems have a role to play in contributing to addressing all these crises. Increasingly, CA must be seen to be a central part of sustainable food systems and sustainable environmental management.

CA global community must continue its effort to improve the quality and performance of CA systems but also undertake strategic research that would allow CA systems to operate biologically or organically, utilizing minimum input of synthetic agrochemicals or avaoiding them. Already there are promising signs that such CA systems are possible, thus making it possible for farmers to adopt CA-based organic farming.

Equally important is the need to support smallholder farmers transform their conventional systems to CA systems with improved returns and environmental benefits. Already more smallholders are practicing CA than large-scale farmers. However, the needs of smallholder farmers need to be given greater attention than in the past. Equally important is the need to make farming an area of opportunity for women and youth, and transformation of conventional agriculture to CA has much to offer towards this goal, particularly when integrating precision GPS based practices and robotics in making farming more efficient and profitable

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A role of Conservation Agriculture practices under salt affected regions of Uzbekistan

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Salinity is becoming a major problem in Uzbekistan, which is increasing year after year, and thereby adversely affecting crop yields. About half (2.1 million ha) of the irrigated area in Uzbekistan is affected by secondary salinization: 31 percent is slightly saline, 18 moderately saline and 4.5 percent strongly saline. We have to tackle this problem scientifically by adopting best practices so that younger generations could also use available land resource more effectively. There are different options by which salinity problem could be managed; these include salt tolerant varieties, conservation tillage, and rice-wheat cropping system. CA is one of the most promising land use options that have been developed in our times. It is very clear that soil, crop and water management is very important for sustainable agriculture in Uzbekistan. Lot of work has been done to improve soil and water related aspects. Current research evidence from the irrigated conditions of Uzbekistan shows that CA practices are promising to combat salinity in the existing cropping systems. CA practices such as permanent no-till beds have shown their effectiveness in lowering the rate of land degradation caused by soil salinization. Site specific research is needed to assist farmers in responding to CA-based soil management and production system changes such as in nutrient requirements, and in pest, disease and weed dynamics, as well as in green manure cover crop options to be incorporated into crop rotations.

Keywords: *salinity, Conservation Agriculture, soil, irrigation and yield*

Introduction

Salinity is becoming a major problem in Uzbekistan, which is increasing year after year, and thereby adversely affecting crop yields. About half (2.1 million ha) of the irrigated area in Uzbekistan is affected by secondary salinization: 31 percent is slightly saline, 18 moderately saline and 4.5 percent strongly saline. We have to tackle this problem scientifically by adopting best practices so that younger generations could also use available land resource more effectively. There are different options by which salinity problem can be managed; these include the use of salt-tolerant varieties, cropping system diversification, and adopting Conservation Agriculture (CA) which can also include salt-tolerant varieties and diversified cropping such as cotton-wheat-legume cropping system. Mulching or crop residue retention is one of the simplest and most beneficial practices. Manure application has been used from ancient time in Uzbekistan as a fertilizer for crop cultivation, as it is rich in nitrogen and other nutrients which facilitate the growth of plants. It is very clear that soil, crop and water management is very important for sustainable agriculture in Uzbekistan. The CA practice of permanent no-till beds with mulch cover has shown its effectiveness in lowering the rate of land degradation caused by soil salinization (Nurbekov, 2008). The objective of this research was to study effect of different mulching rate on productivity of winter wheat yield under no-till method.

Materials and methods

The experiment conducted in 2016-2018. Salt tolerant winter wheat variety Dostlik was sown using no-till method in the experiment. Preceding crops were cotton and mungbean. In this experiment, different rates of manure as mulching materials (10 t ha^{-1}, 15 t ha^{-1}, 20 t ha^{-1}), also mungbean (10 t ha^{-1}) and sorghum straw (10 t ha^{-1}) were applied. The wheat grown in the salt-affected field and soil salinity was 5 DSm moderately saline.

The experimental design was a randomized complete block with four replications. Plot size was 200 m^2 (25x8 m). Data analysis was performed using the GenStat program 18th edition.

The method of Mishustin et al., (1968) was used to assess soil fertility and to determine the soil biological activity. Fresh cleared soil profile was stuck to the flat emulsified side of photo paper and was covered with the soil which would be packed up to ordinary position. Extracted photo paper was washed to remove from the contaminations and was dried in the shade.

Results

Salinity acts to inhibit plant access to soil water by increasing the osmotic strength of the soil solution (Nurbekov, 2008). As the soil dries, the soil solution becomes increasingly concentrated, further limiting plant access to soil water. Soil mulching is an agro-technical operation in which the soil surface is covered with materials in order to conserve water, prevent soil salinity, exterminate weeds, etc. Egamberdiev (2007) showed that mulching with crop residues improved soil micro-aggregation in the irrigated areas of Uzbekistan. Our research shows that the protease activity of the soil was higher in the soil with crop residue than in the field without crop residue (Figs 1~2).

Fig. 1. Protease activity of soil without crop residue.

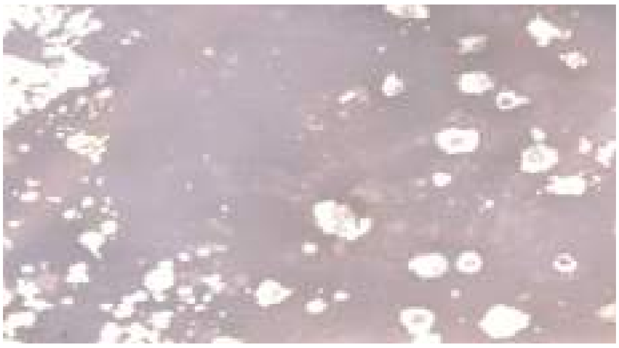

Fig. 2. Protease activity of soil with crop residue

The main terms in CA practices are creating of crop residue in the field with stubble stems and chopped straw, which provide full effect of mulching. Consequently, the salts will not be accumulated in upper layer of the soil due to decreased evaporation. Mulching with sorghum, mungbean crop residues and with organic manure are decreasing the dry salt contents in 0-10 cm soil layer. Soil mulching with crop residue and manure decreased the salt content in 0-10 cm soil layer up to 1.9-3.2 times (Fig 3). Current research evidence from irrigated production in Uzbekistan shows that mulching with crop residue retention are effective in combating salinity. In long-run, no-till method with retention of crop residues helps in lowering down the salinity levels due to combined effects of reduced evaporation and recycling of organic matter.

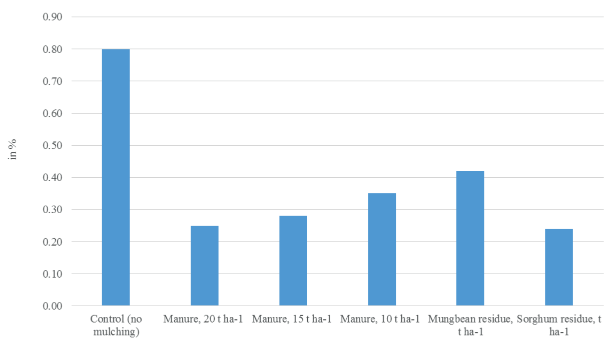

Fig. 3. Dry salt content as affected by mulching

Tursunov (2009) reported that the effect of crop residues on cotton growth was insignificant while Nurbekov (2008) reported that the application of mulch or mungbean and sorghum resulted in significantly higher content of soil moisture in 0–15 cm soil depth as compared to the control which was simultaneously reflected in yield and yield contributing characters. Similar results were found in our three-year (2016-2018) studies with winter wheat cultivation using no-till method have revealed that the application of manure brought a significant increase in grain yield. The significant effect was also noticed on such yield contributing traits like plant height, spike length and number of grains per spike (Figs 4~6).

The increase of manure level from 10 t ha^{-1} to 20 t ha^{-1} also brought a significant increase in yield and yield contributing traits (fig. 7). Significant yield difference was found planting method (<.001). Coefficients of variation was 10.8. Winter wheat yield under mulching treatments was numerically higher than control

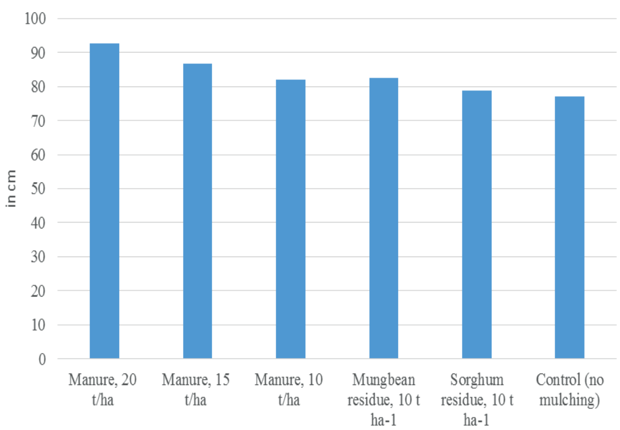

Fig. 4. Plant height as affected by mulching.

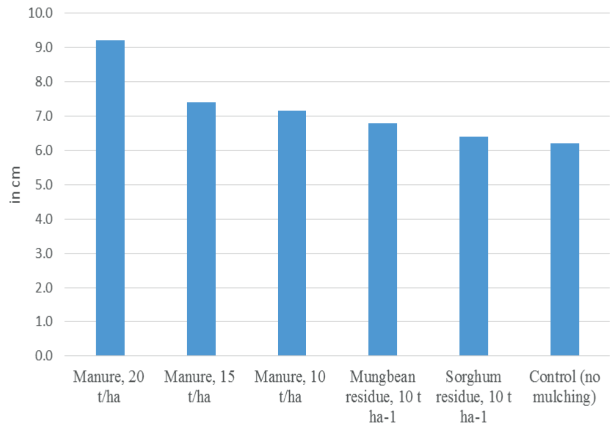

Fig. 5. Spike length as affected by mulching.

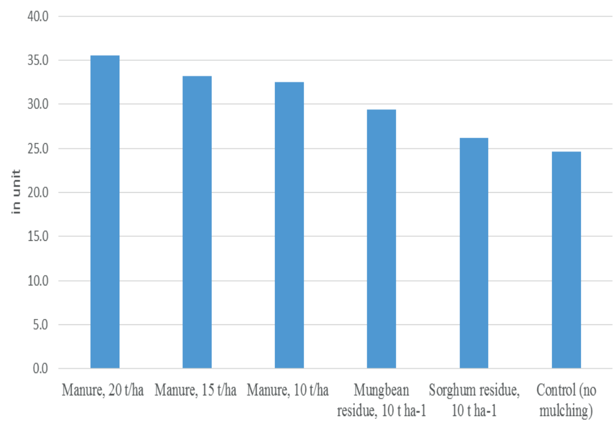

Fig. 6. Grains per spike as affected by mulching.

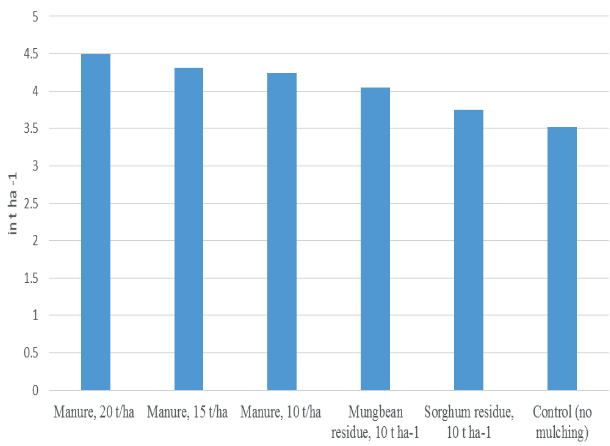

Fig. 7. Wheat grain yield as affected by mulching.

treatment. Wheat yield in treatments with manure application was 0.23-0.97 t/ha higher than in control plots, which was 3.52 t ha^{-1}. This can be explained as the evaporative losses of water f rom mulching plots are lower than that of without mulching plot and with reduced evaporation, the accumulation of salts in root zone decreased that facilitates in proliferation of roots and in turn greater yields.

Conclusions

A study on the protease activity of the soil was showed that, protease activity of the soil with crop residue was higher than in the fields without crop residues.

Yield of wheat was increased with mulching plots compared to without mulching or control plots. We also emphasize the necessity of taking into account the crop residue retention under no-till method in the cultivation of winter wheat in the salt-affected region to stabilize wheat production in Uzbekistan.

We clearly realize that some residue retention will be essential before they attempt to adopt CA practices even though the primary goal may be to simply realize lower production costs which is common with tillage reductions.

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25 years of « Oberacker » for a climate-friendly and soil-conserving agriculture of the future

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The 25-year's studies of the long-term field experiment Oberacker in Switzerland reveal that Conservation Agriculture in line with a long-standing continuous no-tillage system is a suitable alternative to the conventional plow system.
Plowed topsoils do indeed create better germination and development conditions shortly after sowing, which is particularly beneficial for tuber and root crops. At the same time, however, the risk of compaction increases in the subsoil, especially under wet conditions. In contrast, higher nutrient availability in the topsoil, enhanced aeration of the subsoil and greater supply of plant available soil water under no-tillage result in higher yields for legumes and cereals. Cost accounting shows that no-tillage is still economical compared to other cropping systems as a result of increased yields and ecological contributions. It also contributes valuably to erosion control.

The Corg- and Ntot-contents under no-tillage are significantly higher in the topsoil layer than after plowing. Over the entire profile no higher C-sequestration was observed in no-tilled than in plowed soil.

Despite higher application rates in the no-tillage than in the plow system, neither more glyphosate nor more of the breakdown product AMPA was detected in the soil. Merely an accumulation was found in the uppermost 5 cm of the no-tilled soil. But no reduction in the amount and species diversity of earthworms and arbuscular mycorrhizal fungi could be observed – on the contrary: in all crops there are significantly more species under no-tillage (ø 18.5) as compared to plowing (ø 13.2). An important and simple figure for enforcement is the maximum carrying axle load. Loads >5 t mean that, especially in wet growing seasons, the number of
trafficable days without risk of subsoil compaction is counted.

Overall, the aim for the future is a low-input (relay) cropping system based on N- and P-recycled fertilizers with maximum energy and resource efficiency by means of a minimum use of auxiliary substances. This requires changes in the way how to drive on and till the soil. In order to preserve the functionality of our soils and to keep more of the environmental compartments intact, a holistic approach is needed that takes several concerns into account simultaneously: protecting the climate, conserving the soil, maintaining the landscape, reducing natural hazards, keeping waters clean and – last but not least – producing our food.

Keywords: *no-tillage, moldboard plowing, soil ecosystem services, yield, glyphosate substitution*

1. Introduction

Since the late 1950s agricultural production on arable land has been strongly intensified. Switzerland is characterized by sloping and undulating areas as well as a cool and wet climate with annual precipitations of 1000 mm and more. Therefore, soil erosion is a major concern in arable farming. In addition, axle-loads of farm machinery have increased significantly during the last decade resulting in pronounced soil compaction and decreased soil quality. A strategy of action introducing a practicable cropping system, which combines the conservation of natural resources with economic benefits, was required. Conservation Agriculture (CA) – in particular no-tillage (no-till; NT) based on Manitoban experiences from the early 1980s (Sturny W.G.) – fulfils both these criteria.

In the Canton of Berne, CA is being encouraged with financial incentives since 1993 also, but not exclusively, in areas being prone to erosion (Schwarz, R.; Chervet A.; Hofer P.; Sturny W.G., Zuber M.) – including a farmer-to-farmer approach. Innovative private contractors made a valuable contribution to promoting NT techniques among farmers. At the same time, countrywide awareness about NT was successfully raised through consulting, publications, field trials and demonstration plots, field days as well as the national discussion platform SWISS NO-TILL (www.no-till.ch).

2. Materials and Methods

NT and conventional plough (PL) tillage have been compared without fallow period and application of mineral fertiliser only, in the long-term field trial "Oberacker" at INFORAMA Ruetti in Zollikofen (near Berne) since 1994. The slightly humic sandy loam is a deep and nutrient-rich soil. Crops were grown in a six-year crop rotation (peas, winter wheat, field beans, winter barley, sugarbeets, silage corn) in a strip trial with six adjoining plots. The objectives are to demonstrate advantages and disadvantages of a NT and PL system and to work out solutions for perceived problems.

3. Results and discussion

3.1. Soil and water

Chervet, A.; Ramseier, L.; Sturny, W.G.; Weisskopf, P.; Zihlmann, U.; Müller, M.; Schafflützel, R. show a threefold increased infiltration rate for NT as compared to PL. The main causes of delayed infiltration on PL plots are destroyed earthworm channels and layer boundaries, which have been formed by compaction and smear layers on the furrow bottom, as well as by "straw mattresses", and silting due to intensive soil tillage. In particular, large earthworm species such as *Lumbricus terrestris* increasingly dieback by soil loosening, and the number of water-conducting channels is diminished (Maurer-Troxler C.; Chervet A.; Ramseier L.; Sturny W.G.). In the PL system, plant residues are ploughed in so that evaporation rate of the soil surface is increased, while the NT system has a higher water-holding capacity (Fig. 1): with little evaporation – in particular in dry periods – more water remains for transpiration. This results in better crop yields and a more active soil life in harmony with the accumulation of organic matter. Although the distribution of C_{org} and nutrients differed significantly between NT and PL, stocks of C_{org} and of all investigated nutrients were similar in both systems. Unlike in the PL system, C_{org}, N_{tot}, K and Mg were concentrated in the surface layer in the NT system; in addition, the pH was lower and P and Ca had slight concentration maxima at around 20 cm depth (Martinez, I.; Chervet A.; Weisskopf, P.; Sturny W.G.; Etana A.; Stettler M.; Forkman J.; Keller T.). If the predicted climate changes really occur, there will be a redistribution of an-

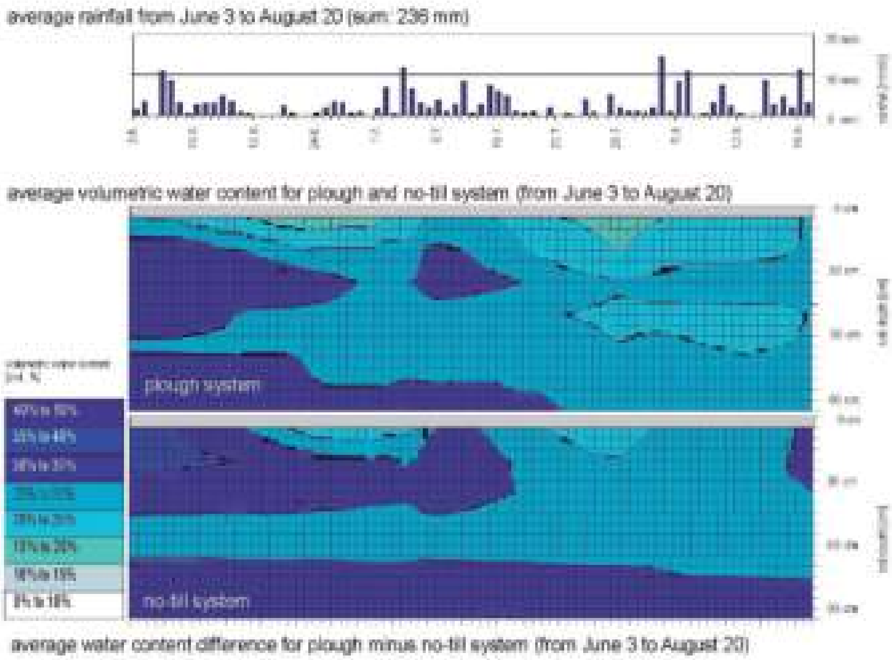

Fig.1. Water content differences for no-till (NT) and plough (PL); long-term field trial Oberacker

nual precipitation and an intensification of individual precipitation events: in the future, with a roughly equal total amount of precipitation, more rain will fall in winter, while there may be more frequent pronounced dry periods in summer. Under such conditions, the higher infiltration and storage capacity as well as the continuous water supply in the no tilled, undisturbed soil use the water resources more sparingly than a production system with intensive, full-inversion tillage.

3.2 Fertilisation

Precision placement of mineral nutrients is of particular importance in CA, since fertiliser is not being incorporated into the soil. Yield losses due to lack of nutrients or toxicity problems are only possible with the use of non-specialized implements. With correct placement, no losses in yield were found after a longer transition phase according to a New Zealand study (Baker, C.J.; Afzal, C.M.). Zihlmann U.; Weisskopf P.; Müller M.; Schafflützel R.; Chervet A.; Sturny W.G. showed NT soils being similar to PL soils with respect to nitrogen supply. However, in the case of NT a lag phase in nitrogen mineralisation was observed, which may be related to reduced aeration of the topsoil. Nitrogen losses to groundwater (nitrate) and to the atmosphere (nitrous oxide) should be cut down by an ammonium-based N-fertilisation strategy, especially in spring crops such as sugarbeets and corn. It was also shown that the application amount of nitrogen fertilisation in the case of NT with adapted crop rotation can be lowered for winter cereals.

3.3 Plant protection

With the abandonment of intensive soil tillage in CA and particularly in NT, weed control becomes a key issue: in general, monocots and perennial weeds develop better than dicots and annual weeds. Long-term NT, combined with adequate weed control, is supposed to lessen weed infestation as compared to PL (Linke C.).

In contrast, the PL system provides improved emergence conditions to the field crop, but also the perfect setting for the development of weeds. Soil disturbance through tillage transports seeds of past vegetation periods to the surface and will accelerate the vegetative propagation of light induced germination. Ploughing is not necessarily a permanent solution to weed problems. That’s why development and application of alternative cropping systems, combining different measures and techniques, is urgently needed and has the potential to reduce herbicide applications. The most effective and non-chemical method for environmentally sound plant production is based on green manure and crop rotation (Fig. 2, left) – if need be on "electro herbicide" (Fig. 2, right). Chervet A.; Gubler L.; Hofer P.; Maurer-Troxler C.; Müller M.; Ramseier L.; Streit B.; Sturny W.G.; Weisskopf P.; Zihlmann U. showed a significant reduction of glyphosate use gradually decreasing towards zero (Fig. 3) in the 25 years of the long-term field trial Oberacker: thanks to a competitive, appropriate mixture of green manure species, consistent shift between grain and foliage plants, permanent soil cover and root penetration. The detected residues were only slightly increased in the upper 5 cm of the NT topsoil. Such a longstanding NT system is economical (Chervet A.; Sturny W.G.; Tschannen S.; Fehr M.; Keller M.) and ready to be put into continuous agronomical practice. Both systems are being established further and optimized with regard to environmental sustainability and by significantly reducing the application of glyphosate (Sturny W.G.; Chervet A.; Maurer-Troxler C.; Ramseier L.; Müller M.; Schafflützel R.; Richner W.; Streit B.; Weisskopf P.; Zihlmann U.).

Fig. 2. No-till (NT) in frost-sensitive green manure mixtures is conducted without use of a total herbicide such as Glyphosate (left). A prototype based on electricity should enable weed control with abandonment of non-selective herbicides (right); both pictures from long-term field trial Oberacker.

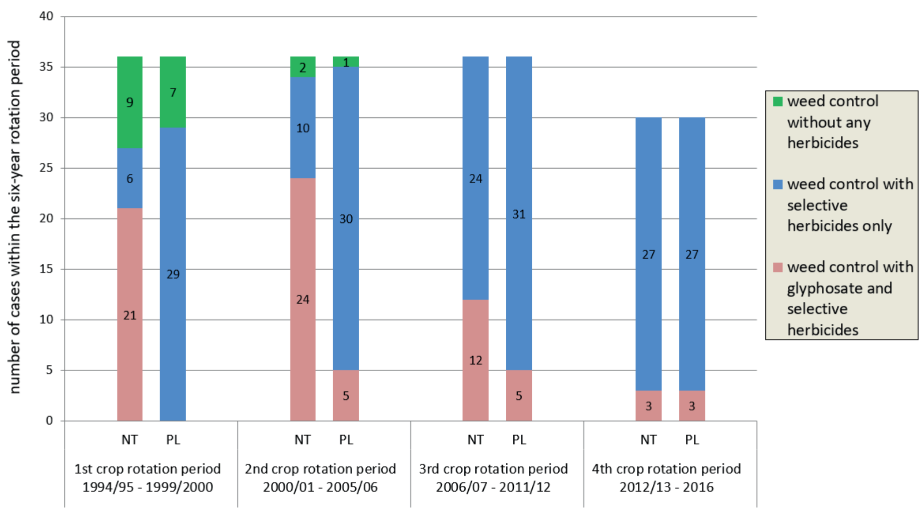

Fig. 3. Weed control herbicide strategy for no-till (NT) and plough (PL); long-term field trial Oberacker

3.4 Crop yields

The average yields of the various crops in the selected experimental years from 1995 to 2014 are represented in Table 1. Considering all crops over 20 years, the average yield in NT was 102.6% of that in the PL system; but this difference was not statistically significant (p=0.28). Winter cereals (winter wheat,winter barley) and legumes (field beans and peas) had significantly higher yields in the NT system than in PL soils,but lower for root and tuber crops (sugarbeets, potatoes). The difference in corn yield between NT and PL was marginal. We conjecture that one of the reasons for the high crop yields in NT in the Oberacker long-term field experiment was the well-balanced crop rotation, including cover crops; another reason is more supply of plant available soil water in dry periods (Martinez, I.; Chervet A.; Weisskopf, P.; Sturny W.G.; Etana A.; Stettler M.; Forkman J.; Keller T.).

Table 1. Average crop yields (1995-2014): all crop yields are given in dt ha^{-1} (cereals: 14% moisture content; grain legumes: 15% moisture content; corn: dry matter; potatoes: fresh weight; sugarbeets: Mg sugar ha^{-1}). n: number of experimental years; cropping system: no-till (NT) vs. plough (PL). Values followed by different letters are significantly different (p <0.05); long-term field trial Oberacker.

Crop	n	NT	MP	% (MP=100)
Winter barley	20	65.9 a	62.2 b	105.9
Sugarbeets	20	11.5	11.9	96.6
Silage corn	20	199.9	198.7	100.6
Winter wheat	19	55.0 a	51.9 b	105.9
Spring peas	8	42.5 a	37.3 b	113.7
Spring field beans	6	30.9 a	26.3 b	117.3
Winter rye	6	59.5	58.6	101.5
Winter peas	5	32.1 a	26.6 b	120.9
Potatoes	5	341.1 b	399.5 a	85.4
Hay meadow	2	1)	1)	1)
Soybeans	2	26.3	29.4	89.7
Winter field beans	1	23.6	29.0	81.2
Spring wheat	1	60.5	49.7	121.5
Average all crops				102.6

[1)] not evaluated

3.5 Profitability and Sustainability

Yields and archived records of the field operations provide the basis for cost-effectiveness calculations. For each crop grown from 2009 to 2014, the direct costs (seed, fertilizer, and plant protection products) as well as the machinery costs and the employment of third parties were compiled. Soil tillage, seeding, crop maintenance and harvesting are carried out with commercial machines by contractors. The profit margin I is obtained by subtracting the costs from the revenues. The profit margin II includes the profit margin I plus ecological contributions such as proof of ecological performance, extenso, resource efficiency and integrated production (Fig. 4).

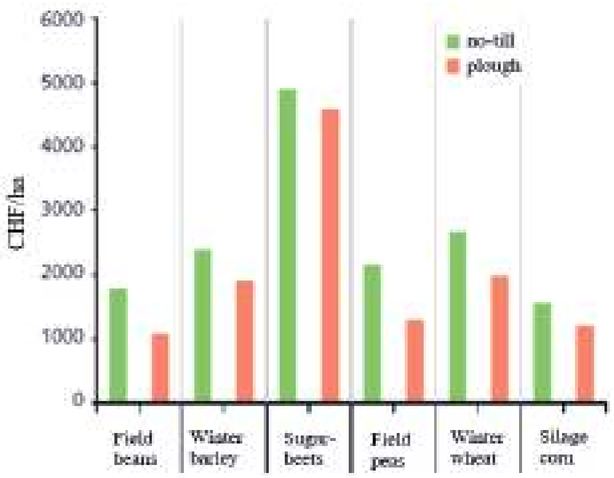

Fig. 4. Average profit margin II (CHF/ha) of crops grown between 2009 and 2014 with regard to cropping system (no-till [NT] vs. plough [PL]); long-term field trial Oberacker

3.6 Ecology and Economy

Taking into account a wide range of energy requirements, West, T.O.; Marland, G. developed net carbon balances for different crops and determined CO_2 emission of 72 kg ha^{-1} for ploughing, 45 kg ha^{-1} for reduced tillage, and 23 kg ha^{-1} for NT. The economic potential of CA has been recognized for quite some time, still the percentage of not permanently ploughed acreage remains low in Europe (Chemnitz, C.; Weigelt, J.). For economic assessments lower labour and machine costs are essential and – in the case of CA – offer remarkable advantages especially in the areas of PL and NT (Hollmann, P.); (Tebrügge, F.). This is due to a reduction in energy use and of wear through lower soil tillage intensity.

4. conclusions and outlook

The 25-year's studies of the long-term field experiment Oberacker in Switzerland reveal that CA in line with a long-standing continuous no-till (NT) system is a suitable alternative to the conventional plough (PL) system. Lack of soil mixing under NT leads to changes of chemical, physical, and biological soil properties. In a continuous long-term NT system, nutrient availability in the topsoil, soil aeration in the subsoil, supply of plant available soil water and biodiversity of earthworms and arbuscular mycorrhizal fungi increased. Partially higher yields, labour saving and more frequent remunerations make the NT system profit-able. It also contributes valuably to erosion control. Cost accounting shows that NT is still economical compared to other cropping systems as a result of increased yields and ecological contributions.

Despite higher application rates in NT than in the PL system, neither more glyphosate nor more of the breakdown product AMPA was detected in the soil. Merely an accumulation was found in the uppermost 5 cm of the NT soil. But no reduction in the amount and species diversity of earthworms and arbuscular mycorrhizal fungi could be observed – on the contrary: in all crops there are significantly more species under NT (ø 18.5) as compared to PL (ø 13.2). An important and simple figure for enforcement is the maximum carrying axle load. Wheel loads >5 t mean that, especially in wet growing seasons, the number of trafficable days without risk of subsoil compaction is counted (Gut, S.; Chervet, A.; Stettler, M.; Weisskopf, P.; Sturny, W.G.; Lamandé, M.; Schjønning, P.; Keller, T.).

Overall, the aim for CA and the future is a low-input (relay) cropping system based on N- and P-recycled fertilisers with maximum energy and resource efficiency while pollutant inputs are reduced to the max. This requires changes in the way how to drive on and till the soil. In order to preserve the functionality of our soils and to keep more of the environmental compartments intact, a holistic approach is needed that takes several concerns into account simultaneously: protecting the climate, conserving the soil, maintaining the landscape, reducing natural hazards, keeping waters clean and – last but not least – producing our food.

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The future of farming
Profitable and Sustainable Farming with Conservation Agriculture

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8th World Congress on Conservation Agriculture

Conservation Agriculture in Central America and Peru

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This paper aims to appreciate the actual Conservation Agriculture (CA) adoption in Central America (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama) and Peru. Severe land degradation affects large proportions of the land areas of the countries. The estimated total area under different forms of CA in Central America is about 557,732 ha: El Salvador (1,950 ha), Guatemala (10,000 ha), Honduras (543,087 ha), Nicaragua (2,695 ha). The total area under CA systems in Peru is currently 200,540 ha. The CA principles apply to agricultural production systems' diversity resulting from a range of topography, soil types, and climates. These systems vary not only in the crops cultivated or the animals raised but also in the plot or farm sizes, types and intensities of management, the arrangement in the landscape, orientation for export or internal markets, agroecological conditions, and their location. In the region, CA annual cropping systems do not disturb the soil, leave stubble biomass on the surface, and include diversified crop rotations or associations, including cover crops and a varied mix of legumes, grasses, and other species. In the hillside areas in the region, there are traditional systems that follow the principles of CA. These include agroforestry with annual crops, cocoa and coffee plantations, pasture restoration with mixtures of gramineous and legumes plants, and controlled grazing to maintain proper soil cover and fodder supply (high Andean of Peru). There is also increasing adoption of fruit trees with cover crops and establishment of managed forests with various undergrowth strata to increase soil cover and to prevent erosion problems during the establishment phase (Quesungual system in Honduras). CA also provides governments opportunities to harmonize specific national objectives - notably better management of natural resources and the development of sustainable agriculture and livelihoods - with the primary purpose of benefiting rural families. Lack of or insufficient access to machinery for planting, fertilizing, and spraying pesticides limits CA's adoption and spread. Besides knowledge, technologies, and supplies, CA's adoption needs a favorable policy environment, targeted research, motivation, and participation of farmers and their communities. There is still a long way to go in the region, from the old approach of soil conservation in agricultural land based on physical structures to a situation of widespread adoption of CA systems.

Keywords*: no-till, soil health, machinery, green manure, agroforestry, Guaymango, Quesungual*

1. Introduction

In Central America and Perú, there is severe pressure on the soil due to subsistence agriculture and cash crop agriculture for export, both related to an economy highly dependent on limited economic resources and forced intensive land use. Years of tillage have led to a decrease in yields and soil degradation in many places.

Soil erosion is the most significant ecological restriction to sustainable agricultural production in hilly areas of the region. Unsustainable practices such as conventional inversion tillage, mono-cropping, and heavy use of chemical inputs lead to land and environmental degradation, decreasing soil fertility, rapidly declining production levels, land abandonment, and desertification. The leading cause of these negative consequences is the practice of plough-based or hoe-based agriculture, coupled with poor soil health management and limited crop diversity.

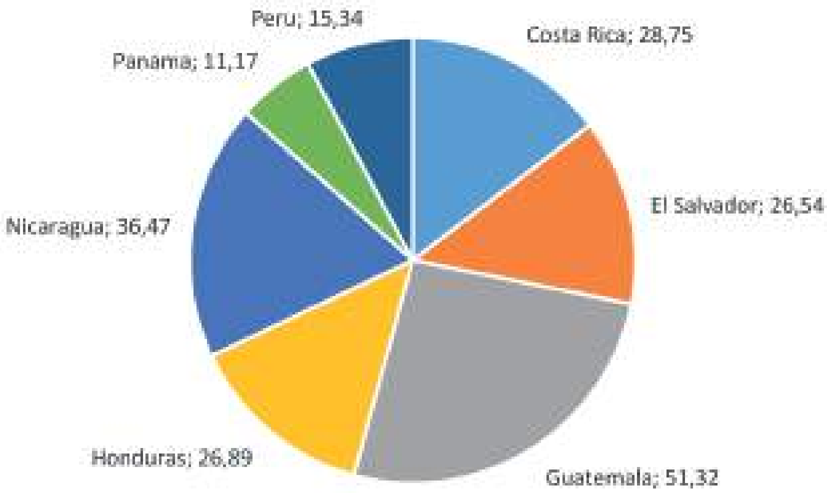

Figure 1. Percentages of the territory of Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and Peru affected by severe land degradation (Bai et al., 2008)

Figure 1 shows severe land degradation[1] affects large proportions of the land areas of the countries: Guatemala (51.32%); Nicaragua (36.47%); Costa Rica (28.75%), Honduras (26.89 %); El Salvador (26.54); Peru (15.34) and Panama (11.17%).

Over the past fifty years in those countries, the traditional approach to controlling soil erosion was based on promoting physical structures, but, sadly, the impacts have been minimal. The physical works achievements of many development programs often considered a success during their life-time, have frequently disappeared a few years after the staff has departed.

Within the last thirty years, some isolated examples have emerged in the region of more successful procedures and technologies such as Conservation Agriculture that have led to acceptable and sustainable agricultural development. Field projects in the region now provide proportionately more emphasis on helping farmers improve land care and soil health and fewer efforts to combat erosion directly through physical structures.

1 Land degradation comprised six classes: water erosion, wind erosion, soil fertility decline, salinization, waterlogging and lowering of the water table

In Central America and Peru, there is a vast agricultural production systems' diversity resulting from a range of topography, soil types, and climates. These systems vary not only in the crops cultivated or the animals raised but also in the plot or farm sizes, types and intensities of management, the arrangement in the landscape, orientation for export or internal markets, agroecological conditions, and their location. The CA principles apply to this diversity and also provide governments opportunities to harmonize specific national objectives - notably better management of natural resources and the development of sustainable agriculture and livelihoods - with the primary purpose of benefiting rural families.

This paper aims to appreciate the actual level of CA adoption in the countries of the Central America region and Peru.

2. Conservation Agriculture in Central America

2.1 Costa Rica

In the 1990s, the Government of Costa Rica, with the technical cooperation of FAO and the financial contribution of the Government of the Netherlands, carried out several projects in the fields of CA systems, agroforestry, comprehensive rural development, and capacity building for the sustainable development of producer organizations. The promotion of new low-cost and easily accessible technical options offered highly relevant experiences; however, there are no significant areas under CA. In addition to the results achieved in various production fields, skilled extensionists served as the basis for the proposal and approval of land management and incentives under 'producing conserving and conserving producing.' In this CA-based approach, soil and water conservation is the key to the sustainability of production systems.

2.2 El Salvador

Experience with CA in El Salvador dates back to 1970, when the Ministry of Agriculture launched a technology improvement program for the maize-sorghum system in the Guaymango municipality, from 1973 to 1983. The Guaymango experience demonstrated that soil and water conservation practices impact producers' socioeconomic systems by improving yields. Table 1 shows that maize yield went from 0.97 t ha^{-1} to 3.25 t ha^{-1} and sorghum from 0.70 t ha^{-1} to 2.1 t ha^{-1} over 15 years.

Between 1994 and 1999, National Center for Agricultural and Forestry Technology "Enrique Álvarez Córdova" (CENTA) implemented the Project "Sustainable agriculture in hillside areas," with technical support from FAO and with funds from the Government of the Kingdom of the Netherlands (CENTA-FAO, 2002). The project's technical proposal followed CA principles, which emphasized soil cover with harvest stubble, pasture management, cover crops such as green manures, and crop diversification to promote land-use changes.

Table 1. Evolution of maize and sorghum yields (t ha-1). CA in the municipality of Guaymango, El Salvador (Osorio et al., 2017).

Year	Maize	Sorghum
1974	0.97	0.70
1978	2.34	1.50
1983	3.25	2.08
1989	3.25	2.10

A first country estimate of the CA areas and crops developed is shown in Table 2. An area under CA is considered one that does not disturb the soil, holds stubble on the surface, and practices associations or rotations with cereals and legumes (beans, Canavalia, or another green manure).

Table 2. Estimated values of areas of CA cropping systems areas. El Salvador.

Cropping systems	Area (ha)	Sources of informatión
Maíze-Beans, Maize-Sorghum	300	PAES (2007)
Maize-Beans, Maize-Sorghum	1,500	Osorio (without date)
Maize-Beans, Maize-Sorghum	600	Casares (2020)
Maize-Beans, Maize-Sorghum	300	Rodriguez (2020)
Maize-Beans, Maize-Sorghum	100	Chicas (2020)
Maize-Beans, Maize-Sorghum	250	Alberto (2020)
Improved pastures	1,000	Alberto (2020); Chicas (2020)
TOTAL	**4,050**	

2.3 Guatemala

The European Union and the FAO decided in November 2010 to carry out a combined technical mission for CA and mechanization in Guatemala. The objective was to demonstrate CA's suitability in the current situation of the hillside terrain for the cultivation of basic grains and vegetables and to establish alternatives of improved management through the application of complementary CA-based Good Agricultural Practices (FAO and EU, 2010).

The program's beneficiary population was more than ten thousand families who depended on agricultural production of maize, beans, coffee, cocoa, achiote, cardamom, peanuts, and chili as a source of food and some income. In some cases, other commercial foods, such as vegetables and dairy products, were also produced.

The project noted that the target areas had unprotected soils due to uncontrolled grazing, inappropriate use of stubble, burning of crop residues and other biological waste, inappropriate use of pesticides, and low subsistence agriculture capacity.

To date, 10,000 hectares of CA-based systems comprising maize and beans have been established in five municipalities in the northern part of the country using CA's three principles. Permanent soil cover consists of a cover crop (*Mucuna sp.)* and crop residues. Crop rotation involves no-till beans, maize, cassava, and sweet potatoes, planted using the "chuzo" or dibble stick. On a further 20 hectares, a diversity of species, mainly coffee, plantains, trees, fruit trees, and pineapple, are managed in CA systems. Also, there are 50 hectares of CA agroforestry systems combining forest tree species planting with the no-till planting of maize in rotation with beans and cassava.

2.4 Honduras

The foundations for CA in Honduras began to be laid in the 1970s and 1980s when World Neighbours promoted improved agricultural practices in the steep lands of the country, introduced minimum soil disturbance or no-tillage in the production of vegetables, and reinitiated the method of direct planting. In the 1990s, a farmer network of teaching and learning centers for sustainable agriculture – CEAS – was formed lead by José Elías Sánchez (Smith, 1994). The Quesungual Slash and Mulch Agroforestry System (QSMAS), which, starting from local agroforestry in Lempira, gradually introduced the three principles of CA: no-tilling; elimination of slash and burn with a permanent soil cover with mulch from crop and pruning biomass, and green cover in fallow periods; diversification of plant species, including maize, pulses, tubers, vegetables, fruit plants and woody tree and shrub species. CA practices are also being used since 2000 with perennial systems involving fruit tree crops, cocoa, coffee, pastures, and industrial crops.

Farmers report yield increases with QSMAS of at least 60% for maize, coupled with year-on-year stability. In addition to maize and sorghum, one hectare of the QSMAS provides a year's supply of firewood and poles to farmers, which adds value CA, together with integrated soil fertility management (ISFM), generates a net income per hectare of maize

Table 3. The estimated area under CA systems in Honduras in 2020

Cropping system	Hectares
Annual crops (Irrigated)	3,000
Annual crops (Dryland)	167,801
Vegetables	200
Fruit trees (bananas, citrus fruits, avocado, vid, etc.)	5,000
Cocoa, coffee, and oil palm plantation	262,895
Pastures	20,000
Agroforestry (includes Quesungual)	79,000
Forestry with cover crop	5,191
Total	**543,087**

Source: Based on the Honduras Forest and Land Use Map (Duarte et al., 2014), Coffee Statistics (IHCAFE 2018).

of up to USD 843 when planted with a legume crop. This income is USD 288 higher than the check plot with standard practices, an equivalent of a one-month minimum wage (CRS, 2018). With increased productivity, farm stabilization, and permanent cropping, QSMAS favors more land to go into long-lasting forest cover, generating forest landscape recovery, watershed management, climate change adaptation, and mitigation.

2.5 Nicaragua

During the years 2000 to 2004, public and private institutions, projects, and NGOs made various efforts to reduce soil degradation processes without achieving significant effects, mainly due to the promotion of practices based on physical structures to control water runoff (Obando and Montalbán, 1994).

As a result, in 2005, the Government requested technical assistance from FAO (FAO, 2005). The project began procuring adequate equipment to do CA such as knife-roller, tractor-mounted no-till seeder, animal traction no-till planters, manual jab-planters known as "matracas," and animal traction boom sprayers. This equipment, which came from Brazil, was essential to carry out the fieldwork in the demonstration areas located in Quezalguaque, Posoltega, and Telica. Other inputs, such as seeds of cover crops and fertilizers, were distributed to the farmers. Preliminary sub-soiling of the areas that suffered from compaction problems received subsidies. Efforts to date, adoption, and areas planted with CA are still very small, as shown in Table 4. However, synergies created between the FAO project and the different institutions involved have led to several initiatives focused on the future expansion of CA[2]

Table 4. The estimated area under CA and the number of adopting farmers managing the CA system in Nicaragua in 2020. Espinoza (2020).

Crop	Area (has)	Number of farmers
Maize	1,375	1,198
Beans	405	357
Sorghum	415	380
Rice	50	1
Sugar cane	300	2
Sesame	150	70
Total	**2,695**	**2,008**

2 The Ministry of Environment and Natural Resources (MARENA); the MST/GEF/OP-15 project; the Nicaraguan Institute of Agricultural Technology (INTA); the National Forest Institute (INAFOR); the Non-Governmental Organization ALFASOL of the Spanish cooperation AECI; the PESA / FAO Project; the Canadian Mennonite Cooperation MEDA Project and the CRS ASA project.

Despite the availability of tools and the intense training of producers, the main barrier that has prevented further expansion of the area under CA in Nicaragua is a weak institutional framework that did not allow the Government to approve policies to support the adoption of CA.

2.6 Panama

In Panama, most maize farmers manage mixed crop-livestock systems, and over 85% of landowners use maize residue to feed their livestock, particularly during the dry season.

Panama has received technical cooperation from FAO projects on issues of soil conservation, land, and water management since the 1980s. These field projects emphasized helping farmers to improve land care and soil health, but there was less emphasis on combating erosion directly. Farmers adopted crop residue retention on the surface but still depended on minimum tillage.

Survey information on land preparation practices of maize farmers in 1994 allowed Pereira de Herrera and Sain (1999) to characterize current tillage methods and to improve the understanding of the process through which farmers adopt zero and minimum soil disturbance practices. The three most common reasons for using no-till were (1) reduced production costs, (2) improved soil conservation, and (3) better weed control (Table 6). The reduction in production costs per hectare with zero tillage compared to conventional tillage varies, depending mainly on the number of passes made with the disk harrow in the conventional system and on the type of desiccant herbicide used in the no-till system.

Table 6. Farmers' reasons for using no-till in maize, in three regions[3] of Azuero, Panama, 1994. (Pereira de Herrera and Sain, 1999).

	Percentage of farmers		
Reason	Region I	Region II	Region III
Reduced costs	46	37	38
Conserves soil	26	32	38
Better weed control	10	5	12
Other	18	26	12

Currently, the most challenging obstacles to increasing CA adoption in Panama are weed infestation and the use of crop biomass or residues for animal feed. Solutions to these problems need participatory research and

3 Region I was formed by the districts of Las Tablas, Pedasí, Pocrí, and Guararé in Los Santos Province and included 28 localities. Region II consisted of the districts of Los Santos and Macaracas in Los Santos Province and included 12 localities. Region III, formed by the districts of Chitré and Parita in Herrera Province, included 10 localities.

increasing awareness of the value of residue for soil cover. Farmers are also beginning to understand the value of residue for soil cover and crop rotation importance.

Experiences on CA and considerations for its implementation show the potential benefits that can be harnessed by farmers with support at the district, provincial, and national levels and highlight the need for longer-term research on the economics of CA systems.

3. Conservation Agriculture in Perú

Since the Pre-Inca era, many Andean communities have used agriculture based on CA systems' principles: direct sowing with a manual "chaquitaclla" seeder with-out-out removing the soil and maintaining a protective plant cover on the ground (Benites and Bot 2014).

Figure 2. Chaquitaclla: before and now (Galvez, F. 2016)

Anyone who has traveled through the three natural regions of Peru recognizes soil management problems viewed with the naked eye. Low crop yields and high production costs marginalize us from the markets and affect the profitability of farmers and the country. CA is one of the ways to reverse this situation. Among the various soil conservation and recovery techniques, the CA fits perfectly and represents the essential option in the conservation of agricultural and livestock soils. Its dissemination and application in the country are imperative, and it is up to all of us to know it well and contribute to its distribution and implementation.

For developing countries, such as Peru, CA would be an alternative protecting the soil, rationing water, saving costs, time, fuel, labor, improving income, and being friendly to the environment. Hence, it is advisable its application, in times of population growth and climate change in the world ".

The first research on the benefits of CA systems in Peru was carried out at the experimental station "San Ramón" Yurimaguas, Loreto, between 1982-1987 and aimed to study alternatives for transition technologies based on CA systems principles to change shifting cultivation into permanent agriculture (Sanchez and Benites 1987).

Peru's territory has three differentiated natural regions: the coast or coastal desert, the Sierra or Andean region, and the Jungle or Amazon region. The coast's agriculture is under irrigation and mechanized, dedicated to annual crop production (corn, soy, sorghum, etc.), fruit, and vegetables. The sierra is mostly dry land (pastures), with small green vegetables and annual crops with supplementary irrigation. The land use in the Amazon region is agroforestry systems of coffee, cocoa, and oil palm.

Potential of CA systems in Peru

Given the importance of CA systems in the humid tropics, they must be supported and promoted by the government's agriculture sector. Low crop yields and high farm production costs currently marginalize many farmers and affect their profitability and the country's rural sector. CA systems are one way to reverse this situation. CA systems protect the soil, ration water use, save costs, time, fuel, labor, improve income, and are friendly to the environment (Benites and Bot 2014). The total area under CA systems in Peru is currently 200,540 ha which represents only 10% of total cultivation. However, this area could be expanded to incorporate about 200,000 ha of the irrigated area on the coast and nearly 2 Mha of alluvial land in the Amazon, and also improve in small/medium farm areas on the Sierra region.

Table 2. The estimated area with Conservation Agriculture in Peru (ha) - the Year 2019

Cropping system	ha
Annual crops (Irrigated)	1,640
Annual crops (Dryland)	1,200
Cocoa and coffee (shade and soil cover)	90,000
Pastures	104,000
Fruit trees (bananas, citrus fruits, apple trees, etc.)	3,650
vegetables	50
Total	**200,540**

Source: Benites, J. 2020. Conservation Agriculture in Peru.

Considering that the total cultivated area is 2 million 216 thousand hectares, we can say that 10% of the cultivation area currently has CA practices. It is possible to incorporate about 200,000 ha of an irrigated area on the coast and nearly 2 million ha of alluvial land in the Amazon suitable for planting annual and fruit crops with CA principles.

Farmers must face a formidable challenge that is to change current agricultural practices with those of Conservation Agriculture. The problem, therefore, requires changes in tools and equipment, together with the new dynamics of soil, weeds, cover crops, and water, for which investment capital and preferential credits are required.

The adoption of CA systems in these areas could mean a real productive revolution and very low cost. However, farmers face a great challenge in making the change to CA systems farming. A mindset change increases the availability of appropriate tools and equipment and an understanding of how to appropriately manage soil, weeds, cover crops, and water under this modified agriculture system. These changes will require capital investment and preferential credits.

Concluding remarks

In the hillside areas in the region, there are traditional systems that follow the principles of CA. These include agroforestry with annual crops, cocoa and coffee plantations, pasture restoration with mixtures of gramineous and legumes plants, and controlled grazing to maintain proper soil cover and fodder supply. There is also increasing adoption of fruit trees with cover crops and establishment of managed forests with various undergrowth strata to increase soil cover and to prevent erosion problems during the establishment phase.

Estimated values in hectares of area under CA as described above were obtained from collaborators of El Salvador (1,950 ha), Guatemala (10,000 ha), Honduras (543,087 ha), Nicaragua (2,695 ha), and Peru (200,540 ha). The total area under different forms of CA reported in the region is 758,272 ha. There is no information on areas under CA in Panama and Costa Rica.

CA also provides governments opportunities to harmonize specific national objectives - notably better management of natural resources and the development of sustainable agriculture and livelihoods - with the primary purpose of benefiting rural families. Lack of 758or insufficient access to machinery for planting, fertilizing, and spraying pesticides limits CA's adoption and spread.

Also, the presence of leaders or champions and farmer organizations is essential for knowledge sharing and capacity building. Besides knowledge, technologies, and supplies, there is still a long way to go in the region, from the old approach of soil conservation in agricultural land based on physical structures to a situation of widespread adoption of CA systems.

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Current status of no-tillage adoption in Brazil

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Brazil is one of the most important agricultural producers and a pioneer on tropical technologies for enhancing environmental conservation. The adoption of no-tillage (NT) in annual crops, since the decade of 1970, has become the most important Conservation Agriculture system to ensure agricultural sustainability, enhancing soil conservation all over the country. The first census of area under NT was conducted in 2006 (2006 Brazilian Census of Agriculture from IBGE). This allowed a deeper understanding on NT distribution in Brazil. With the second census in 2017 (2017 Brazilian Census of Agriculture from IBGE), it became possible, for the first time, to evaluate in detail NT evolution in Brazil. The aim of this study is to characterize the spatial evolution of NT area between 2006 and 2017. The data was obtained from special tabs, elaborated under demand, through the partnership between IAPAR (Agronomic Institute of Paraná) and IBGE (Brazilian Institute of Geography and Statistics). The area under NT has increased in all Brazilian macroregions, with a national average of 84.9%, totalling 33,052,971 hectares in 2017. The highest increment (430.7%) was observed in the North. However, this was a reflex of the small area under no-tillage in 2006 (220,661 hectares), the smallest between all macroregions. The smallest increment was observed in the South (32,1%), the pioneer region in NT adoption, with the second largest area in 2017 (11,912,434 hectares). The Midwest presented the largest area under no-tillage in 2017 (13,726,367 hectares), an increment of 110.4% during the period under study. The Southeast and Northeast regions presented similar trends. They presented an increment of 45.9% and 54.4%, totalling 2,916,464 hectares and 3,326,725 hectares, respectively. The NT has been incorporated in the soybean`s production system in Brazil. Consequently, the expansion of soybean production was highly associated with NT expansion during the studied period, with a linear association of $R^2 = 0.98$. In other words, the soybean expansion was possible, among other factors, due to the use of NT. Despite NT expansion in Brazil, other conservation practices are still incipient. Most soybean production systems are based on less diversified crop rotations, which may limit the beneficial effects of Conservation Agriculture.

Keywords: *Conservation Agriculture, no-till farming, tropical agriculture, crop rotation, soybean*

1. Introduction

Brazil is worldwide one of the most important producers of agriculture-based commodities and services. This success can be explained by a set of factors (e.g., suitable edaphoclimatic conditions for agricultural activities) that warrant a series of advantages. In addition, the constant development of technologies, promoted by the public and private sectors, has resulted in significant productivity gains (Pereira et al., 2012). However, in view of the high rainfall erosivity in the country (Oliveira et al., 2012), managements that foster soil protection are imperative to ensure the long-term sustainability of agriculture.

Official data in Brazil on the cultivated area and number of farms under no-tillage (NT) management, one of the main pillars of Conservation Agriculture (CA), were first collected and disseminated by the Agricultural Census 2006, of the Brazilian Institute of Geography and Statistics - IBGE (Fuentes-Llanillo et al. 2018). This enabled a more detailed understanding of the extension of this system. Later, for the first time, the Agricultural Census 2017 made an accurate assessment of the evolution of NT in Brazil possible, providing relevant information about the progress of sustainable agricultural production. Thus, the objective of this study is to describe the dynamics of the expansion of no-tillage management, in the period from 2006 to 2017, in Brazil.

2. Material and methods

The data used in this study were taken from the Agricultural Censuses 2006 and 2017, both carried out by Brazilian Institute of Geography and Statistics - IBGE. Only the data related to the number and area of agricultural farms with seasonal crops under NT were taken into consideration. The tabulation of the data was requested from the Operational Coordination of the Agricultural Census, based on a technical cooperation agreement. Data of the soybean cultivation area in Brazil were also used (IBGE, 2019a; IBGE, 2019b).

In the enumerator’s manual, the IBGE defined seasonal crops as those with a short or medium cycle duration, i.e., the crop must be replanted after harvest. Sugarcane, cassava and castor bean were also considered seasonal crops. No tillage was defined as the management in which the soil is not plowed or harrowed, and crops are planted in small furrows opened in the soil covered with straw, i.e., the residues of previous crops are maintained on the soil surface.

Moreover, the NT area under seasonal crops and its proportion in relation to the total area of seasonal crops were calculated, as well as the variation rates between 2006 and 2017. In this study, only agricultural farms that used exclusively NT were taken into account. To analyze the relation between the extent of the area of NT and of soybean cultivation, within states, a simple linear relationship between the variation in the NT area (2006 – 2017) and the variation in the soybean area (2006 – 2017) was used. Maps were drawn using software ArcGIS 10.3.1.

3. Results

Between 2006 and 2017, an increase of 84.9% in the area of seasonal NT crops was recorded in Brazil, rising from 17.9 to 33.0 million ha (Table 1). This increase in NT cultivation area was observed in all five major regions of the country (South, Southeast, Midwest, North and Northeast). The number of producers using NT also rose from 507 thousand to more than 553 thousand, i.e., an increase of 9.2% (Table 1). In all macro-regions except the Northeast, the same national trend could be observed. When relating the variation in area with the number of producers (mean farm area), the conclusion can be drawn that predominantly large farms implemented the system. This pattern was observed in all macro-regions, most clearly for the Northeast and least evident in the Southeast region.

In the South, the region in which the system was first implemented in Brazil, a remarkable area expansion (39.3%) of NT cultivation was recorded, i.e., an increase from 8.6 to 11.9 million ha. The system spread mainly into areas with less agricultural suitability, where it was implemented on over 3.4 million ha, particularly in Rio Grande do Sul. To date, the South is the region with the highest number of producers using NT management in Brazil (Table 1), in particular in Santa Catarina, where an increase in number of farms of 11.8% was recorded. In this region with mostly small producers, the mean farm area under NT management rose from 24 to 32 ha in the period, which is the lowest mean area in the country.

The greatest expansion of NT cultivation in Brazil occurred in the Midwest region, from 6.5 to 13.7 million ha, i.e., an increase of 110.4%. This amplification occurred mainly in Mato Grosso, the state with the largest mean farm area and first in the national ranking of NT area in the study period, surpassing the South region. In the state of Goiás, the mean farm area shrank regardless of the expansion of the area, suggesting the incorporation of smaller areas into the system.
In the Southeast, the percentage growth in the states of Rio de Janeiro and Espírito Santo was very high. The high percentage increase was mainly due to the small size of areas under NT in these states in 2006 (Table 1). The reduction in mean farm area indicates that this growth was due to the incorporation of small producers into the system.

Table 1. Total area and number of farms under no-tillage management of macro-regions in Brazil, in 2006 and 2017.

	2006			2017			Variation (2006/2017)		
	Area	Farms	Mean farm area	Area	Farms	Mean area	Area	Farms	Mean farm area
	(ha)		(ha)	(ha)		(ha)	(%)	(%)	(%)
Brazil	17,871,773	506,667	35.3	33,052,971	553,382	59.7	84.9	9.2	69.1
North	220,661	20,355	10.8	1,170,981	28,964	40.4	430.7	42.3	274.1
Northeast	1,170,724	81,930	14.3	3,326,725	61,163	54.4	184.2	-25.3	280.4
Southeast	1,406,496	32,753	42.9	2,916,464	63,479	45.9	107.4	93.8	7.0
South	8,550,269	355,445	24.1	11,912,434	370,953	32.1	39.3	4.4	33.2
Midwest	6,523,624	16,184	403.1	13,726,367	28,823	476.2	110.4	78.1	18.1

Source: Data from special tabulations of the Agricultural Census 2006 and 2017, of the Brazilian Institute of Geography and Statistics (IBGE).

The NT area in the Northeast region rose from 1.2 to 3.3 million ha, corresponding to a 184.2% increase. However, in this region, this increase was the result of different phenomena. On the one hand, a marked increase in NT area was recorded in the states of Bahia, Maranhão and Piauí, which belong to the new expansion area of the Cerrado called MATOPIBA, an acronym that also includes the state of Tocantins of the North region. In Piauí and Bahia, the number of farms using NT decreased, whereas the mean farm area increased. This indicates that small producers reduced their use of the system and the remarkable expansion in these two states was the result of the inclusion of large properties. In Maranhão, the number of farms using NT and mean farm area increased, with a similar trend as observed in Piauí and Bahia. On the other hand, the states with the largest areas of Caatinga were most affected by drought in the last 30 years, with a severity peak in 2017. As a result, there was generally a reduction in the number of farms or in the NT area. This indicates that the prolonged drought may have affected the use of NT, in view of the difficulties of managing seasonal crops on small properties in a semiarid climate. In contrast, the NT area in Sergipe and Rio Grande do Norte tended to increase.

In the North, the NT area increased from 0.2 to 1.2 million ha, i.e., an augmentation of 431%. The states of Tocantins, Pará and Rondônia, which together account for 93% of the NT area in the region, were the most notable. In Tocantins, large properties switched from the conventional to NT management, which is a typical phenomenon in the Cerrado areas of MATOPIBA. The situation in Rondônia is different; the NT area increased between 2006 and 2017, while the number of farms decreased, extending the mean farm area under NT in the state from 12.6 to 93.3 ha. This indicates the exit of small properties in the north of the state and the inclusion of large properties on the border with Mato Grosso.

Another type of expansion was observed in Pará, where the NT area as well as the number of farms increased significantly. This increase is relevant since the entire area belongs to the Amazon, where a more sustainable agriculture with an adequate crop management is particularly desirable, in view of the natural fragility of the soils. In the other states (Roraima, Amazonas, Acre and Amapá), the expansion of NT management was inconspicuous, since seasonal crops are not frequent in this biome. In Roraima, the mean NT area per farm increased from 16.4 to 24.3 ha, an impressive expansion, in view of the predominantly small production units. In the state of Amazonas, the number of farms increased considerably, while the NT area remained almost stable, and in Acre the number of farms decreased 23.5% and the NT farm area increased 31.8%. In the two states, most NT farms were small, with mean farm areas of 2.1 and 3.7 ha, respectively, in 2017.

4. Discussion

The expansion of NT in Brazil was intensive between 2006 and 2017, due to the agricultural, environmental and economic benefits resulting from its use. As is well-known, the inclusion of NT in the soybean production system in Brazil was one of the factors that allowed the expansion into areas previously considered unfit for this crop.

Historically, NT was incorporated into the grain production system in Brazil as a reference practice of soil and water conservation. It is considered fundamental in tropical and subtropical regions, where the levels of rainfall erosivity are high (Oliveira et al., 2012), and an year-round soil cover helps to mitigate the impact of rain drops on the soil surface, reducing the transport of particles by runoff and, consequently, the erosion process (Didoné et al., 2019). By not tilling the soil, apart from minimizing erosion losses, the NT also benefits the soil quality directly. These changes are associated with the greater connectivity and total volume of the soil pores (Galdos et al., 2019), higher water retention and infiltration (Kassam et al., 2014), higher nutrient availability in the surface layer (Tiecher et al., 2017) and higher microbial activity (Babujia et al., 2014). Moreover, a reduction in greenhouse gas emission was reported (Abdalla et al., 2013).

In addition, the NT system is one of the pillars of Conservation Agriculture, which has been increasingly used around the world (Kassam et al., 2019), since it enables gains in crop yields (Camargo et al., 2017) and, consequently, improves the profitability of the agricultural activity (Fuentes-Llanillo et al., 2018). It is based on, as the name says, the absence of or minimal soil tillage; on a permanent soil cover, formed by crop residues left on the soil surface; and on crop rotation, with a particular emphasis on species diversification (Vanlauwe et al., 2014; Kassam et al., 2019).

The NT was one of the contributing factors to the expansion and productivity gains in Brazilian agriculture, driven mainly by investments in public research (Gasques, 2017). Since the NT, other techniques have also been developed, such as the planting of two annual crops: a first crop (grown in the summer) and a second one (grown in autumn), also called "safrinha", in some regions of Brazil, characterized by the sequences of soybean/maize and soybean/wheat. This became possible owing to the favorable environmental conditions and to research efforts in breeding of specific plant material for the different regions of the country, with the characteristic of a shorter development cycle of the main crops.

Thus, the expansion of the NT area in Brazil was strongly associated with the expansion of soybean cultivation ($R^2 = 0.98$), which increased from 17,883,318 ha in 2006 to 30,722,657 ha in 2017, i.e., an increase of almost 72%. This was, above all, due to economic aspects linked to production (Telles et al., 2018). A price reduction of herbicides such as 2,4-D, atrazine, paraquat and glyphosate lowered the costs of weed control (Huggins and Reganold, 2008; Perry et al., 2016), making herbicides an alternative to mechanical weeding and eliminating the need for soil tillage. In addition, the costs for agricultural operations are reduced, since soil tillage operations such as plowing, harrowing and chiseling become superfluous. This reduces the cost of fuel, labor and maintenance of the machinery or expenses with outsourced operations.

The phenomenon of NT expansion, due to the association with the expansion of soybean, was most evident in MATOPIBA, the current agricultural frontier of the country, and in Mato Grosso, the state with the greatest growth in NT. In MATOPIBA, the system augmented most in the main soybean-producing counties (Araújo et al., 2019). However, a significant portion of the expansion of soybean occurred at the cost of areas with native vegetation (Gibbs et al., 2015) In Mato Grosso, the increase in the NT area in the state occurred mainly at the expense of pastures replaced by crops, in particular by soybean (Cohn et al., 2016).

In southern Brazil, in the regions where NT management has become a tradition, e.g., in the states of Paraná, Santa Catarina and Rio Grande do Sul, the success of this system was confirmed. In Rio Grande do Sul, a large NT area of cultivation expanded into the Pampas region, also driven by the expansion of the soybean area. The same phenomenon was observed in regions of Paraná and Santa Catarina. In these states, where soybean is the main summer crop, the predominance of soils derived from volcanic rocks allows intensive grain cultivation.

However, despite the expansion of the cultivation area of seasonal crops in NT systems in Brazil, some questions about the benefits of the isolated use of this practice are still unanswered. In other words, the implementation of NT systems alone is not enough to warrant soil and water conservation or the sustainability of agriculture (Pittelkow et al., 2015). In this sense, efforts should be made in the country to encourage the implementation not only of a NT management, but of all pillar practices of CA. Furthermore, for the edaphoclimatic conditions of most of Brazil, for a truly conservation-based agriculture, mechanical practices of soil and water conservation, e.g., level planting and the use of agricultural terraces, must also be included.

5. Conclusions

The impact of research, development and technology transfer are seen as fundamental factors for the widespread implementation of no-tillage in Brazil. The area of seasonal crops under no-tillage increased considerably between 2006 and 2017. This amplification was mainly attributed to the integration of the no-tillage system in soybean production and was one of the factors that contributed to the expansion of the crop in Brazil.

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Long-term no-fire Conservation Agriculture diversifies production on a sandy acrisol in Acre State, Southwestern Brazilian Amazon

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Slash-and-burn agriculture (SBA) is still common in the Brazilian Amazon. Family farming in Juruá, Acre State, is also SBA-based with an aggravating prevalence of sandy soils in the region. In the search for a technological solution to the problem, no-fire Conservation Agriculture models (no-fire CA) were evaluated adopting soil tillage with a plow harrow (CT) and no-tillage (NT), the application of lime, phosphorus and potassium and the cultivation of plants of intercropping and/or rotation with cassava or maize crops. The SBA and no-fire CA systems were compared for 13 years on a sandy Acrisol in the rural area of Mâncio Lima municipality. The agroeconomic and environmental results of no-fire CA were positive compared to SBA. The total cost, with no-fire CA being 50% greater than SBA, was offset by increases in total income from the activity (327% NT / 204% CT), in the remuneration of labor (347% NT / 202% CT); in the daily rate paid to the small farmer (430% NT / 217% CT) and in the total productivity of the factors of production (181% NT / 100% CT). The net income was positive only in the NT, demonstrating its economic viability. The associated average productivity (cassava + maize from 2006 to 2019) at SBA was 7.6 t*ha^{-1}, while for no-fire CA it was 21 t*ha^{-1} (NT) and 20 t*ha^{-1} (CT), as a result of increasing technology input of 178% (NT) and 165% (CT). In addition, the NT avoided the emission of 1,536 t*ha^{-1} of carbon dioxide equivalent in 13 years due to the absence of fire and soil preparation. No-fire CA is a suite of technologies with proven agroeconomic feasibility and low carbon emission. From easy learning, technology can be transferred to farmers, technical assistance and rural extension professionals and students. The results hereby generated can support public policies to strengthen family farming. Family farmers from Juruá, especially residents of areas with sandy soils, are the target for technological solution. Nevertheless, this technology is also applicable to other scales of production in Acre and other states in the Brazilian Amazon.

Keywords: *Slash-and-burn agriculture, Cassava, Maize, Low carbon emission agriculture*

1. Introduction

Conservation Agriculture (CA) (FAO, 2020) is spreading worldwide (Kassam, A. et al., 2018) as a part of the answers to the demands of present day to change the technological pattern since 1930 in USA and since 1970 in Brazil. While CA area worldwide is estimated in 12.5%, in Brazil the nowadays area of CA is almost 50% of the total cultivated area (Febrapdp, 2021). However, the real CA area worldwide and in Brazil, with focus in Brazilian Amazon, is uncertain due to adoption only part of the total suite of CA, i.e., only no-till or only permanent soil mulch cover or only crop diversification or combinations among three practices through schemes of successions, rotations and/or consortia.

The three principles of CA need to be summed to no-fire cultivation in the Brazilian Amazon, here called "no-fire CA". Slashand-burn agriculture (SBA) is still common in the Brazilian Amazon. Beyond soil tillage, fallow, monoculture, and no soil fertilization after slash of native or secondary forests, burning forests and crop debris increase nutrients losses, soil organic matter (SOM) reductions and greenhouse gases emissions. Soil tillage at scale of small-holders do not is actually a common practice nowadays. But this scenario is changing insofar largest areas are being introduced in the regional agribusiness (FuentesLlanillo, R. et al., 2021).

In the Juruá region of Acre State, where this study was carried out, predominate sandy soils in general Argissolos (Santos et al., 2018) or Ultisols (Soil Taxonomy, USDA, 1999; 2010) or Acrisols (FAO, WRB, 2006). The regional mean annual temperature is 25 °C and total annual precipitation is > 2.000 mm (Inmet, 2021). These soil and climate conditions and SBA increase SOM degradation processes and also of crop residues left above soils after cultivations.

Cassava (*Manihot esculeta*, Crantz) is the main crop and almost monoculture in Juruá especially in family farming or smallholder farming with an aggravating that sandy soils are predominant in the region. But cultivation of cassava is SBAbased, i.e., a low technological system. There is no use of fertilizers and limestone. Soil tillage associated to soil sandy features and total annual precipitation in Juruá can increase erosion because cassava cultivation begin is coincident to begin of rainfall regional station, when the soil is not yet protected by cassava plants.

The corolarium above indicate to a decreasing productivity of cassava and likewise to others agricultural crops. The hypothesis of this study is that no-fire CA to family farming is part of the solution of above scenario, considering that family farming is poor, without tradition to use technology and bank credits, but with potential to adopt them without expand cultivated area, highlighting diversity of agricultural cash crops and soil cover species. To test this hypothesis no-fire CA models were evaluated in comparison to SBA. Results of economic and environmental aspects are presented.

2. Material and methods

This study was carried out in a ongoing 15-year long-term experiment located at the rural area of Mâncio Lima municipality (7°28′ S, 72°56′ W, 190 m asl), Acre State, Brazilian Amazon. The history of the experiment from 2006 to 2014 was published in Costa, F.S. et al. (2014). In this study are presented additional results from 2015 to 2019.

In brief, the experiment was stablished in a small-holder farming partnership featuring a participative field research on a Acrisol (Argissolo Amarelo distrófico, Santos, H.G. et al., 2018), with 134, 77 and 786 g kg^{-1} of clay, silt and sand respectively in the 0–20 cm layer. The soil chemical attributes in 2006: pH (H_2O) 4.0, Al 2.1 $cmol_c\ dm^{-3}$, sum of the bases 0.8 $cmol_c\ dm^{-3}$, and Al saturation 72%. The regional climate is Af without dry station according to Köppen classification (Alvares. C.A. et al., 2014) with 2005-2019 mean annual precipitation of 2,151 (±342) mm and mean annual temperature of 25.6°C (±0.22) (Inmet, 2021).

The experiment is a split-plot design in a randomized complete blocks with three repetitions for no-till (NT) and conventional tillage (CT – plow harrow) (main plots), employing cassava/green manure/maize/cowpea. For CT and NT, five treatments (subplots) were established: (1) Control or local usual system: slash-and-burn; (2) green manures (*Mucuna aterrima, Canavalia ensiformes, Sorghum bicolor, Cajanus cajan, Pennisetum glaucum*) as cover crops; (3) cover crops with P-fertilizer; (4) cover crops with liming and (5) cover crops with P-fertilizer and liming. CT and NT in combination with subplots from 2 to 5 are considerate in this order technological evolutions of no-fire CA systems. This study is concern to comparisons among CT-slash-and-burn agriculture and CT5 and NT5, named SBA, CT and NT, respectively.

In brief, to search for a technological solution to the SBA, no-fire Conservation Agriculture models (no-fire CA) were evaluated adopting soil tillage with a plow harrow (CT) and notillage (NT), the application of lime, phosphorus and potassium and the intercropping and/or rotation soil cover crops with cassava or maize or cowpea crops. Except in SBA, in the soil under CT and NT was applied potassium according to soil analyses.

The economic analysis integrated cassava and maize crops in the time considered from 2015 to 2019, taking into account the premise that agricultural production on a family scale must be diverse in space and time, contemplating opportunities to obtain regular income from according to the supply and market demand of the cultivated products. Costs and economic indicators were calculated according to Guiducci, R. do C.N. et al. (2012).

The CO_2e costs of agricultural operation and biomass burning in each considered treatment were calculated according to IPCC (1996) and Lal (2004) with NT-SBA meaning avoided emissions of plow harrow operation and biomass burning and NT-CT meaning avoided emissions of plow harrow operation.

3. Results and discussion

The economic and environmental results of no-fire CA were positive compared to SBA. The total cost, with no-fire CA being ~50% in average NT-CT greater than SBA, was offset by increases in no-fire CA in NT and CT compared with SBA also in NT and CT in total income from the activity (327% NT and 204% CT), in the remuneration of labor (347% NT and 202% CT), in the daily rate paid to the small farmer (430% NT and 217% CT) and in the total productivity of the factors of production (181% NT and 100% CT) (Table 1). The net income was positive only in the no-fire CA in NT (R$31.36) *versus* SBA (R$1,434.60), demonstrating its economic viability. The associated average productivity (cassava + maize from 2006 to 2019) at SBA was 7.6 t ha^{-1}, while for no-fire CA it was 21 t ha^{-1} (NT) and 20 t ha^{-1} (CT), as a result of increasing technology input of 178% (NT) and 165% (CT).

Table 1. Economic analyses of the slash-and-burn agriculture (SBA) and no-fire Conservation Agriculture (nofire CA) models in conventional tillage (CT) and no-tillage (NT). Mâncio Lima municipality, Acre State, Brazilian Amazon. Results are in Brazilian Real (R$1.00).

	-------SBA-------		-----no-fire CA-----	
Economic parameter	**CT**	**NT**	**CT**	**NT**
Total cost	2,377.77	2,242.00	3,584.41	3,412.73
Total income	1,083.60	807.38	3,296.60	3,444.10
Remuneration of labor	530.77	392.23	1,602.60	1,753.82
Daily rate paid to the small farmer	21.01	14.68	66.60	77,75
Total productivity of the factors (dimensionless)	0.46	0.36	0.92	1.01

In relation to environmental issues NT avoided the emission of 1,536 t ha^{-1} of CO_2e in 13 years due to the absence of fire and soil preparation in comparison to SBA-CT. The avoided emission of NT in comparison to CT due only soil tillage was 1,470 t ha^{-1} of CO_2e in 13 years.

The agronomic, environmental and economic results, except to net income for the no-fire CA in CT, demonstrated that SBA in NT or CT is a no friendly agricultural system to small-holders in Juruá. No-fire Conservation Agriculture in NT or CT can be alternatives to SBA but the choice of NT or CT must be taking in to account all the conditions of the small-holder, e.g., culture-traditions, human and financial capital, size of the family, close markets to sell agricultural products and in focus the status of soil degradation at the moment of the adoption. Beyond soil texture, rainfall regime also must be considered across Acre State and Brazilian Amazon with respect to adoption elsewhere.

4. Conclusions

No-fire CA is a suite of technologies with proven agronomic and economic feasibility and low carbon emission. From easy learning, no-fire CA in NT technology can be transferred to farmers, technical assistance and rural extension professionals and students. The results hereby generated can support public policies to strengthen family farming. Family farmers from Juruá, especially residents of areas with sandy soils, are the target for this technological solution. Nevertheless, this technology is also applicable to other scales of production in Acre and other states in the Brazilian Amazon. Insofar practices of the Conservation Agriculture (no-till, permanent soil cover and crops diversity in schemes of successions, rotations or consortia) are full adopted in the fields, the small-holder agribusiness can be a profitable agriculture and food security, i.e. a win-win strategy.

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An operational definition of Conservation Agriculture to categorize the diversity of models in a given territory

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Conservation Agriculture (CA) is not a uniform agrarian system, but rather contains multiple models to fit the constraints and needs of farmers. Although the presence of a diversity of models in Wallonia has already been relayed several times, the models are not yet known and identified. Knowledge of these models is necessary to assess their economic, social and environmental potential.

To categorize the models present in a given territory, a typology based on the definition of CA must be constructed. But which definition of CA should be used as a reference? Three pillars are commonly accepted within the scientific community as the foundations of CA. Nevertheless, there is a lack of clear indications regarding the practical implementation of the pillars to enable the definition to be operational on the field. Moreover, the definitions diverge and contradict each other within the various scientific papers.

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A literature review of the convergences and divergences is conducted among fourteen sources to construct a working definition of CA that can be used to establish a typology. The analysis of these sources revealed a definition of CA comprising the three fundamental pillars, combined with additional practices. While pillars distinguish CA from other farming systems, additional practices facilitate the adoption and the sustainability of a CA model.

This definition provides a comprehensive conceptual framework that is applicable and modifiable to all regions where CA is practiced. It has been adapted to respond to the local context. Typologies can be constructed from this operational definition of CA to study the diversity of CA practices.

Keywords: *Operational definition, Literature review, Pillars, Additional practices*

1. Introduction

Three pillars (or principles) define Conservation Agriculture (CA): (i) minimum tillage, (ii) soil cover and (iii) crop diversification. There is no ready-made recipe for implementing these pillars on a farm (Coughenour 2003; Stroud 2020). The diversity of practices originates from the flexibility of applying CA pillars to design cropping systems (Scopel et al. 2013 quoted by Hauswirth et al. 2015). The pillars of CA must take into account local constraints and the specific needs of farmers (Giller et al. 2009; Scopel et al. 2013; Vankeerberghen and Stassart 2014; Hauswirth et al. 2015; Derrouch et al. 2020). CA consists of a transnational agrarian system that takes many forms (Vankeerberghen and Stassart 2014) which we call Conservation Agriculture Models (CAM).

The potential of CAM to provide the various benefits attributed to CA (reduced labor time, improvement of soil structural stability, etc.) depends on the developed CAM (Giller et al. 2009).

In this review, we argue that CA currently lacks a clear and robust definition, preventing the construction of a typology to assess the CAM diversity and to support the expansion of the most sustainable models. We propose a consolidated definition of CA based on an examination of the convergences and divergences among the definitions.

2.Materials and methods

On the one hand, the FAO (Food and Agriculture Organization) is the main place where agriculture and food security are discussed (Loconto and Fouilleux 2019). On the other hand, the vast majority of scientific articles refer to the FAO's definitions of CA. This is why FAO is the chosen entry point for the study of CA definition. Five sources from FAO were selected. Some discrepancies are pointed between the FAO sources, leading to a definition of CA that is difficult to transpose to the field. The combined analysis of FAO documents and nine reference articles on CA provides a clear and operational definition.

To select reference articles (Fig. 1 Illustration of the research methodology to select the reference articles, in which 'n' represents the number of search records.1), we

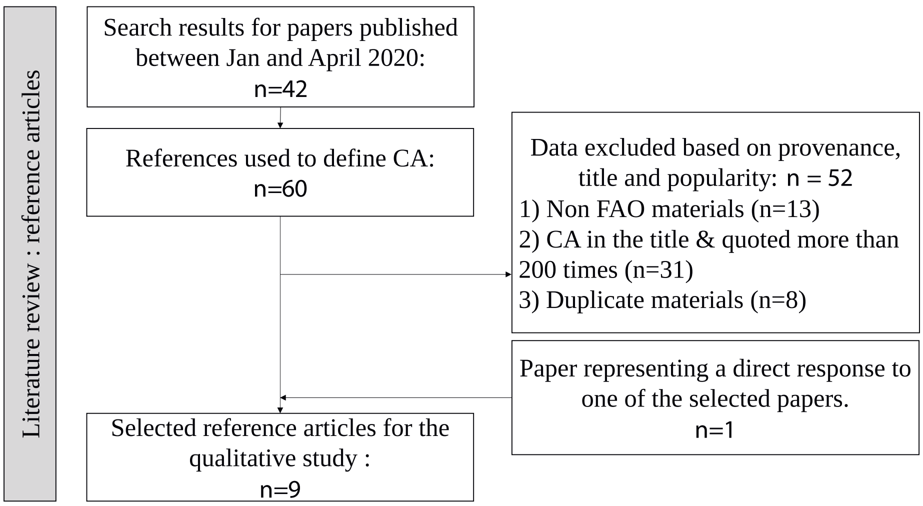

Fig. 1 Illustration of the research methodology to select the reference articles, in which 'n' represents the number of search records.

identified all papers published between January and April 2020 that contained the word "Conservation Agriculture" in their title. The Google Scholar search engine presented 42 articles. In these 42 articles, we extracted the references used to define CA. A selection was then made on the provenance of the articles (non-FAO) as well as on their title and popularity. The Sommer et al. (2014) article was added because it represents a direct response to one of the eight selected articles, the one by Vanlauwe et al. (2014).

These nine reference articles are analyzed alongside the five FAO sources (Table 1. Presentation of the FAO sources and reference articles.1).

Table 1. Presentation of the FAO sources and reference articles.

First author	Year	Type of document	Title
FAO sources:			
FAO	2014	Web page	Conservation agriculture: The 3 principles
FAO	2017	Leaflet	Conservation Agriculture
Corsi	2019	Book	Conservation Agriculture: Training guide for extension agents and farmers in Eastern Europe and Central Asia
FAO	2020a	Web page	Conservation Agriculture
FAO	2020b	Web page	Agriculture de conservation
Reference articles:			
Hobbs	2007	Paper	Conservation agriculture: what is it and why is it important for future sustainable food production?
Hobbs	2008	Paper	The role of conservation agriculture in sustainable agriculture
Kassam	2009	Paper	The spread of Conservation Agriculture: justification, sustainability and uptake
Giller	2009	Paper	Conservation agriculture and smallholder farming in Africa: The heretics' view
Thierfelder	2009	Paper	Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe
Friedrich	2012	Paper	Overview of the global spread of conservation agriculture
Vanlauwe	2014	Paper	A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity
Sommer	2014	Paper	Fertilizer use should not be a fourth principle to define conservation agriculture: Response to the opinion paper of Vanlauwe et al. (2014)
Pittelkow	2015	Paper	Productivity limits and potentials of the principles of conservation agriculture

3. Results and analysis

3.1. Questions to solve to construct the definition of CA

The aim of this literature review was to consolidate the definition of CA and to address uncertainties about accepted practices for each pillar. The discrepancies between the sources raise two fundamental questions that need to be answered to construct the definition of CA.

Should the pillars be ranked?

Several authors (Hobbs 2007; Kassam et al. 2009; Friedrich, Derpsch, and Kassam 2012; FAO 2014; 2020a) pay less attention to the third pillar of CA (crop diversification), compared to the other two. This omission can result in an acceptance of monoculture (Kassam et al. 2009; Friedrich, Derpsch, and Kassam 2012; FAO 2020a) or an absence of reference to crop diversity in the definition of CA (FAO 2014). When Hobbs (2007) uses Derpsch's (2005) data to give an idea of the spatial distribution of CA he does not give any information about the third pillar, unlike the other two. Other authors emphasize the central role of rotations in CA (Giller et al. 2009; Pittelkow et al. 2015). As no reference article mentions or justifies a hierarchy of pillars, we decided to give equal weight to each pillar for further work.

How is a pillar different from an additional practice?

A series of practices that do not fall under the definition of CA (built on the three pillars) have been identified in the papers. We call them "additional practices". The question of whether some of these additional practices deserve to be part of the CA pillars has already been raised (e.g. Vanlauwe et al. 2014; Sommer et al. 2014). Knowing what differentiates a pillar from an additional practice is essential to defining CA.

There are two competing definitions of pillars. According to Vanlauwe et al. (2014), pillars are practices that are essential to the proper functioning of CA and thus to the success of the farming system. Sommer et al. (2014) define pillars as practices that distinguish CA from other farming systems.

We decided to follow the definition of Sommer et al. (2014). A pillar should define an agrarian system and thus differentiate it from another. Additional practices may increase the sustainability (FAO 2020a; 2020b) and/or facilitate the adoption of a CAM (Sommer et al. 2014).

3.2. A comprehensive and operational definition of CA

Alongside the three core pillars that define CA, we have highlighted eight additional practices, detailed below (Table 2).

Minimum tillage

"Minimum tillage" define the first pillar (FAO 2014; 2017; Corsi and Muminjanov 2019; FAO 2020a; 2020b). The aim is to minimize soil disturbance by reducing tillage and excessive mixing of horizons (Corsi and Muminjanov 2019).

In CA, the disturbed area must be less than 15 cm deep or less than 25% of the cultivated area (whichever is less) (Kassam et al. 2009; Friedrich, Derpsch, and Kassam 2012; FAO 2020a). Direct seeding is the ultimate goal (Hobbs, Sayre, et Gupta 2008; Kassam et al. 2009; Friedrich, Derpsch, et Kassam 2012).

Agricultural machinery traffic is minimized to limit soil compaction (Kassam et al. 2009). Finally, tools such as plows, disc harrows, and rotary cultivators are avoided to limit soil degradation (Kassam et al. 2009).

Permanent or semi-permanent soil cover

The aim of covering the soil is to reduce weed pressure, protect the soil from extreme weather events, preserve soil moisture and avoid compaction (FAO 2017). While most authors insist on the permanent character of the soil cover, Hobbs (2007; 2008) proposes a more flexible definition of the second pillar: a "permanent or semi-permanent soil cover". We have followed the definition of the latter. If it is allowed to till the soil up to 15cm or 25% of the surface (see), it seems coherent to us to accept that the plot can be uncovered at certain times in CA. Permanent coverage is the ultimate goal.

Farmers can use dead (e.g. crop residues, decaying leaves, bark, compost) (FAO 2014) or living (e.g. crops and intercrops) mulches to cover the soil (FAO 2014; 2017; Corsi and Muminjanov 2019; FAO 2020a; 2020b).

At least 30% of the plot should be covered by mulch (FAO 2017; 2020a; 2020b) to reduce soil erosion by 80%. The relationship being exponential, the more the cover is developed, the more the erosion risk is reduced (Allmaras et Dowdy 1985; Erenstein 2002 quoted by Giller et al. 2009 et Vanlauwe et al. 2014). It also seems coherent to us to make the importance of exceeding the critical threshold of 30% soil cover coincide with the risk of soil erosion, which can vary over time.

To achieve 30% coverage, the reference articles only mention crop residues (Hobbs 2007; Hobbs, Sayre, and Gupta 2008; Giller et al. 2009; Kassam et al. 2009; Vanlauwe et al. 2014). We argue that this objective should be valid for all types of mulch.

Crop diversification

Crop diversification defines the third pillar. This enables a combination of the advantages of each species (Corsi and Muminjanov 2019) which improve water use, reduce pests and diseases and increase fertility and productivity (FAO 2014). Rotations, crop associations, intercrops or varietal mixtures allow diversification of a cropping system (Corsi and Muminjanov 2019; FAO 2020a; 2020b).

Although some sources accept monoculture (Kassam et al. 2009; Friedrich, Derpsch, and Kassam 2012; FAO 2020a) fort others (and sometimes the same) three different crops must be involved in the cropping system (Kassam et al. 2009; Friedrich, Derpsch, and Kassam 2012; FAO 2017; 2020a; 2020b).

Additional practices

A list of eight additional practices was developed from three FAO sources (Corsi and Muminjanov 2019; FAO 2020a; 2020b).

The first additional practice relates to the use of quality seeds and adapted varieties (Corsi and Muminjanov 2019; FAO 2020a; 2020b). The availability of seeds and the certainty of selling the products must be taken into account when choosing the crop (Corsi and Muminjanov 2019).

Four types of integrated management are presented: pests and diseases, external inputs, weeds and water (Corsi and Muminjanov 2019; FAO 2020a; 2020b). Pest and disease management needs to be reviewed in the transition to a CAM. Plant protection products and fertilizers must be applied optimally and on time (FAO 2020a; 2020b). Plot observation, rotation and choice of species are strategies to reduce the use of plant protection products and related production costs (Corsi and Muminjanov 2019; FAO 2020a; 2020b). Controlling the products and their use enables to reduce the doses (Corsi and Muminjanov 2019; FAO 2020a; 2020b).

Herbicides are used instead of intensive tillage to manage weeds, residues or intercrops (FAO 2020a; 2020b). It may be important to have pesticides and mechanical spraying available (Corsi and Muminjanov 2019).

Synthetic fertilizers can be used to correct possible nutrient deficiencies and organic nitrogen immobilization during the first years of transition (Corsi and Muminjanov 2019; FAO 2020a; 2020b).

The mastery of knowledge, experience and tools allows to integrate all the principles of CA and to maximize its benefits (Corsi and Muminjanov 2019; FAO 2020a; 2020b). Although a learning phase is essential, sharing knowledge with other more experienced farmers helps to reduce mistakes (FAO 2020a; 2020b). Having the right tools at disposal at an affordable cost facilitates the adoption of CA (Corsi and Muminjanov 2019).

CA also increases the possibilities for integration of production sectors, such as crop-livestock integration, integration of trees and pastures into the agricultural landscape (FAO 2020a; 2020b).

Several anti-erosion methods can be implemented to further reduce plot erosion. Examples are the planting of crops along contour lines, the establishment of windbreaks and controlled grazing (Corsi and Muminjanov 2019).

Finally, flotation tires on tractors and controlled traffic (i.e. using permanent tracks on plots) can reduced compaction (Corsi and Muminjanov 2019).

Table 2. General definition of Conservation Agriculture.

PILLARS	INDICATORS, BENCHMARKS AND COMMENTS
Minimum tillage	Disturbance less than 15 cm deep or less than 25% of the cultivated area. Direct seeding is the ideal. Traffic of agricultural machinery is minimized. Tools such as plows, disc harrows and rotary cultivators are avoided.
Permanent or semi-permanent soil cover	Soil cover through dead (e.g. crop residues) or live mulches (e.g. intercrops). At least 30% of the plot covered by mulch, depending to the erosive risk. A developed and permanent cover is the ideal.
Crop diversification	Diversification through rotations, associations, intercropping or varietal mixes. At least three different crops.
ADDITIONAL PRACTICES	
Use of quality seeds and adapted varieties	Choice to be made according to the availability of seeds, crops adapted to the region and the market to ensure the sale of the products.
Integrated management of pests, external inputs, weeds and water	To reduce doses there are strategies such as plot observation, rotation, choice of species and the application.
Herbicides	Pesticides and mechanical spraying must be available.
Synthetic fertilizers	Fertilizers must be available.
Knowledge, experience and tools	Essential components to maximize the benefits of CA.
Integration of production sectors	Such as crop-livestock, agroforestry, pastures.
Anti-erosion methods	Such as contour lines, establishment of windbreaks, controlled grazing.
Anti-compaction methods	Such as flotation tires and controlled traffic.

4. General discussion

CA-related studies generally spend little time defining the CA model they analyze. CA is sometimes limited to one pillar, and sometimes two or three. The divergence in definitions of CA makes it difficult to compare the results of these studies.

This study is the first to analyze the divergences and convergences of current CA definitions to construct a uniform, robust and operational definition. CA is built on three pillars (or principles), which can be combined with additional practices depending on the context. Eight additional practices emerged from the literature review. We have defined the difference between a pillar and an additional practice and have defined indicators and benchmarks to delineate which practices belong to CA or can increase the sustainability of CA.

The definition of CA takes into account the diversity of practices in the field and is generally more flexible than the usual definitions. This definition can thus be used for all CAM in the world. Depending on the context, it may be necessary to adjust the pillar indicators or to remove/add additional practices.

5. Conclusion

This literature review has led to a consolidated definition of CA. We have defined CA by its three pillars combined with eight additional practices. On the basis of this definition, typologies can be constructed to study the diversity of CAM in a given territory. Knowing this diversity makes it possible to represent and choose the agricultural trajectories of tomorrow.

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Graphical representation and monitoring of the agricultural sustainability on olive orchards and vineyards; the suitability of CA

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Agricultural sustainability is a crucial aspect for the protection of the capital natural and its future use. Hence, sustainability assessment of the farms and the identification of their potential improvements is crucial. The objective of this study was to evaluate agricultural sustainability through graphical-polygonal representations and alphanumeric data, on a permanent cropped land in Southern Spain. A mixed farm of vineyard and olive trees was selected as model farm for sustainability assessment based on the farming practices (BMPs), mainly centred on Conservation Agriculture (CA), that have been applied.

The monitoring assessment has been performed throughout 5 agricultural seasons on the farm by the INSPIA methodology. INSPIA methodology is based on the application of a set of 15 BMPs which are determined through 31 basic sustainability indicators, providing in the end, a final composite index of sustainability. Basic values of the indicators are in consequence of what farmers do in practice to farm their land. The greater the composite index, the greater the implementation of sustainable farming practices is reached, such as the ones flagged by CA: enhanced soil, water and air quality, improvement of the farmed environment for biodiversity, and thus, enhanced ecosystem services on which agricultural productivity relies.

Results on sustainability (alphanumeric and graphical findings, and indexes), are shown during that period, depicting the correspondent relationship among the implemented Conservation Agriculture practices and the indicators. The highest result of the composite index was reached when the groundcover was established, and the soil disturbance was minimized.

This research confirms the importance of CA practices, such as the groundcover establishment and the minimum or no-till management to upgrade agricultural sustainability on the permanent cropped lands in Southern Spain. While soil-tillage reductions of nearly 42% are measured, economic, social or environmental benefits emerge, such as increases in both organic matter content and in energy productivity of 66.6% and 3.7% respectively, among others.

Keywords: *Best Management Practices, sustainability indicators, groundcovers, indexes, sustainability graphical representation*

INTRODUCTION

Agricultural sustainability could be monitored through the assessment implementation of a set of Best Management Practices (BMPs) that are economically viable, environmentally safe, and socially acceptable. There is some difficulty to represent graphically sustainability assessment results (Almeida C.M.V.B. et al., 2007). However, the assessment of environmental, social and economic factors requires an understanding of all the relationships among their multiple dependent and independent variables.

In the literature, there are some successful schemes or methodologies to monitor specific issues in agricultural systems, that try to show in a graphical way the sustainability index (Triviño-Tarradas, P., et al., 2019). However, there are not many holistic approaches, among stakeholders, that consider a multi-disciplinary aspect for agricultural sustainability assessment (Abbona, E.A., et al., 2007; Lichtfouse, E., et al., 2009). Despite the difficulties in representing the assessment of agricultural sustainability at the farm level, several attempts to measure agricultural sustainability have been raised and developed on a different scale, e.g. the Indicateurs de Durabilité des Exploitations Agricoles-IDEA method (Zahm, F., et al., 2008), the SOSTARE model (Paracchini, M.L., et al., 2015) or the Initiative for Sustainable Productive Agriculture-INSPIA model (Triviño-Tarradas, P., et al., 2019) measuring and representing sustainability from a holistic perspective. Some of these initiatives symbolize the sustainability index through a radial or spider graphic, where the three main dimensions of sustainability: economic, social and environmental, are shown. For instance: SAFE, Multicriteria Assessment of the Sustainability of Cropping Systems-MASC 2.0. (Craheix, D., et al., 2012), Sustainable Agri-Food Evaluation methodology-SAEMETH (Peano, C., et al., 2015), IDEA, Monitoring Tool for Integrated Farm Sustainability-MOTIFS (Meul, M., et al., 2008), whereas others, pay attention to just one or two of the aforementioned aspects, e.g., INDIGO method (Bockstaller, C., et al., 1997), which is only based on the environmental dimension, or the SOSTARE models which are lacking in their social dimension.

These tools help farmers monitor their farm sustainability, year by year, helping them with their decision-making, and allowing them to improve their performance in the field, through the implementation of a set of BMPs that improve the farmed environment for biodiversity and protect and enhance the natural capital on which productivity relies (Triviño-Tarradas, P., et al., 2019).

Any farmland should be committed to sustainability nowadays (FAO, 2017). It is therefore important, to conduct the work research over different types of farms and be aware of the level of sustainability of the farm. In this context, the aim of this paper is to evaluate agricultural sustainability through graphical-polygonal representation and alphanumeric data, on the permanent cropped land in Southern Spain.

GRAPHICAL MONITORING ASSESSMENT

Graphical layouts to represent agricultural Sustainability Index

The analysis of most systems needs an understanding of the relationship built among the different variables represented via indicators. In the literature, there are some methods to represent agriculture sustainability at the farm level. However, there are not so many holistic approaches monitoring it, that take into account the multifactor level of sustainability: economic, social and environmental.

Needless to say, that the utilization of a graphical layout representation is a powerful tool in gaining understanding in any field, because it allows the visualization of the relationships among the different monitored variables. In this context, some authors use ternary diagrams (Pelzer, E., et al., 2012), whereas others prefer polygonal or radar ones (Meul, M., et al., 2008; Zahm, F., et al., 2008). But both of them assist farmers and technicians with a useful graphic tool for decision-making at the farm level. In addition, providing with a numbered sustainability index, as some sustainability assessment methodology, such as INSPIA does, makes having a better understanding of le level of sustainability.

MATERIALS AND METHODS

Study farm

A mixed farm of vineyard and olive-groves was chosen as average-role-model farm for sustainability assessment (from 2013/2014 to 2017/2018) based on the agricultural practices (BMPs). The farm is located in Montilla, in the province of Cordoba in Southern Spain: 37º32'29.09" N, 04º33'24.59" W according to the WG84 geodesic system (Figure 1a). Within the farm, there are 18.01 ha. of rainfed vineyard on trellises system with a 2.90 x 1.20 m. of plantation frame and 2.11 ha of irrigated olive trees, with a plantation frame of 8 x 8 m (Figure 1b).

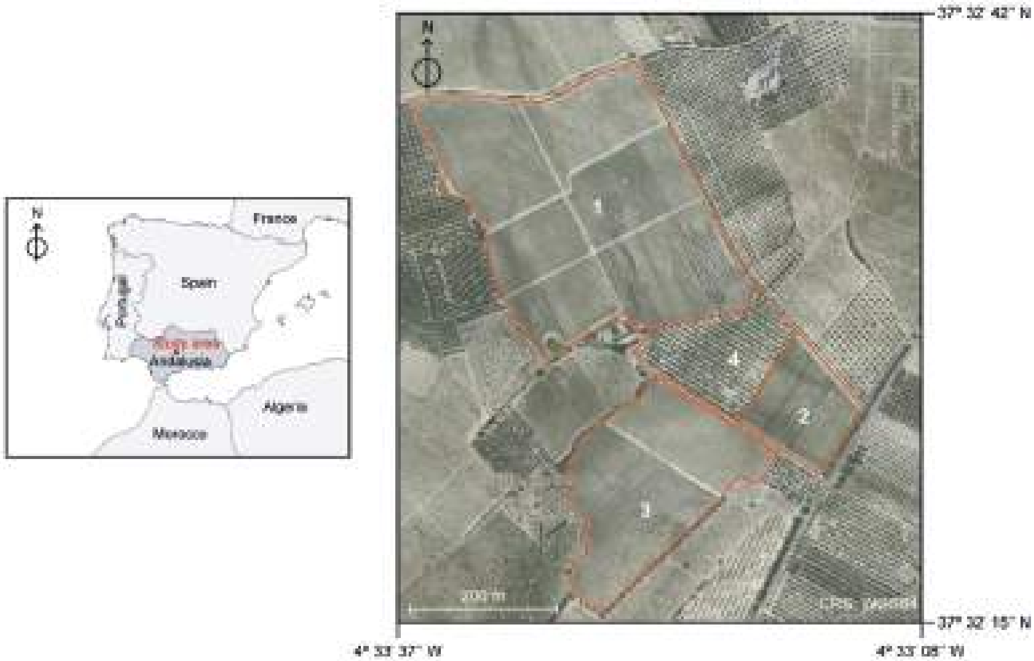

Fig 1. Location of the study farm (a). Location of the vineyard plots and olive trees plot of the farm. Plots number 1, 2 and 3 (rainfed vineyards) and plot number 4 (irrigated olive orchard) (b).

Graphical layout of Sustainability Assessment

The most commonly used graphic is 2-D plotting of data (Almeida, C.M.V.B, et al., 2007), however, this layout lacks of a holistic view, since it only permits the visualization of the relationship of two variables. The selected sustainability assessment for this research was the INSPIA model (Triviño-Tarradas P., et al., 2019), since it provides with different type of diagrams: bar diagram and radar diagram. The bar diagram presents the information on the evolution of each basic sustainability indicator to calculate (Figure 2), whereas the radar or pie graph compiles the information of the three aggregated indicators (Figure 3); economic, social and environmental ones.

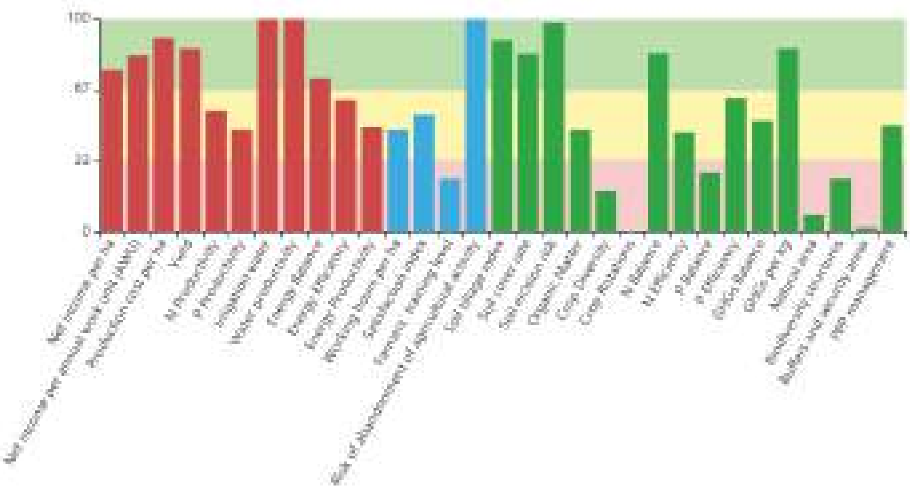

Fig 2. Graphical and numerical outcomes on basic sustainability indicators. Agricultural season 2014/2015.

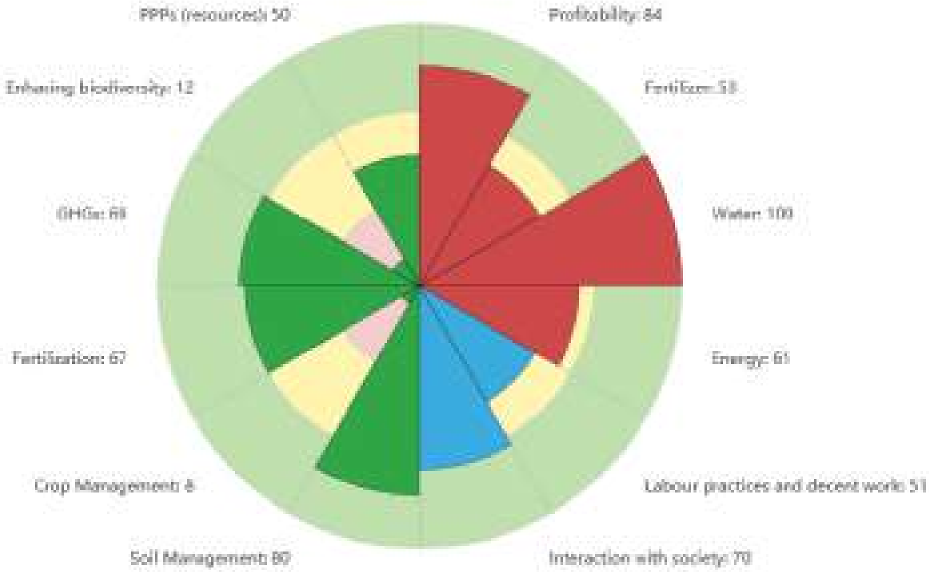

Fig 3. Graphical and numerical outcomes on aggregated indicators. Agricultural season 2014/2015.

Indicators’ assessment and their linkage with the Best Management Practices (BMPs) implementation

The sustainable performance of the farm is influenced by the number of BMPs implemented. The INSPIA index result and its basic indicators’ value, are also related to the number of BMPs followed by a farmer, as it will be shown on the results.

RESULTS

Indicators’ value come from what farmers do in practice to farm the land. Hence, INSPIA promotes a set of farming practices that have been demonstrated to improve the farmed environment for biodiversity, as well as other ecosystem services. The indicators’ values are actively influenced by farmers. The optimal sustainability index value is often related to a set of uniformly high aggregated indicators. This can be easily shown by Figure 5 and 6, corresponding each of them to the worse (Figure 5) and the best (Figure 6) monitored agricultural season respectively, according to the implementation of the BMPs and their calculated indicators.

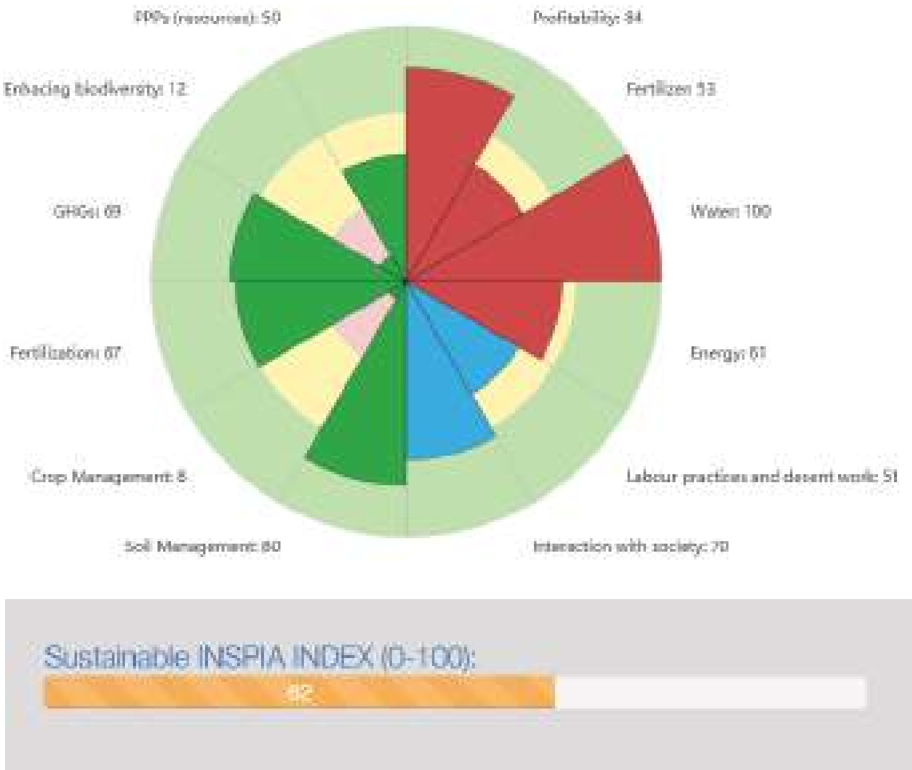

Fig 5. Aggregated indicators and global Sustainability Index calculated in agricultural season 2014/2015.

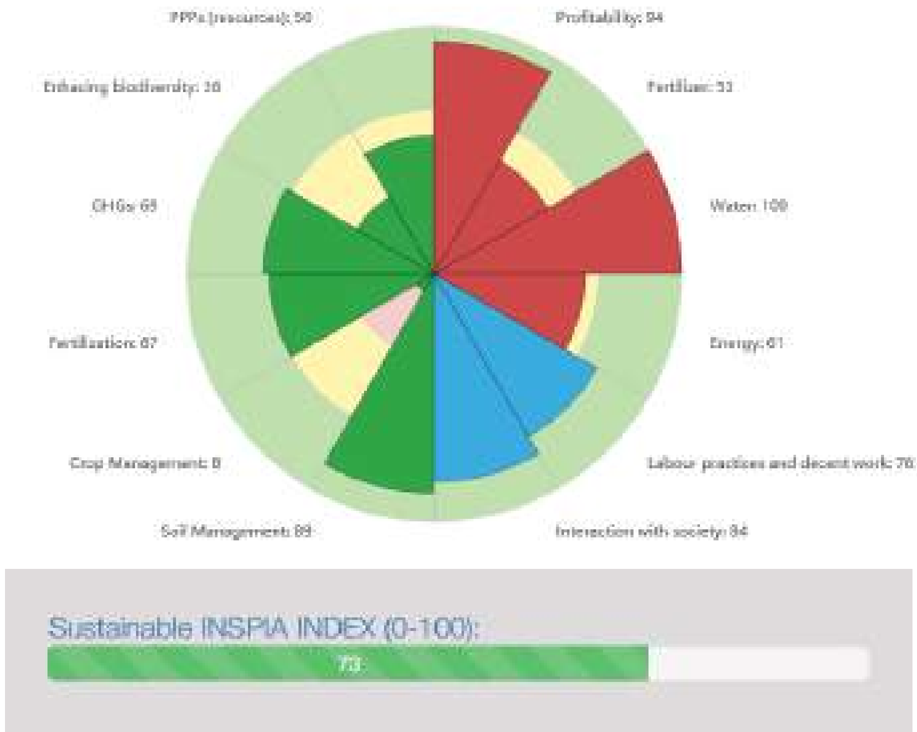

Fig 6. Aggregated indicators and global Sustainability Index calculated in agricultural season 2016/2017.

A high average score including low values on some basic indicators is suboptimal and not sustainable, as shown in Figure 5. Despite the two basic indicators water-related are optimal, and in the right direction, and its aggregated indicator as well, the global index is not.

CONCLUSIONS

Providing farmers and stakeholders not only with a numbered sustainability index but with a global graph which compile information on all aggregated indicators is optimal. Having a better understanding of the sustainability graphical representation serves farmers as a guide to contribute towards global sustainability challenges.

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Successful scaling approaches leading to autonomous adoption of Conservation Agriculture in West Bengal

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In West Bengal, India, the agricultural sector needs options that can address labour scarcity, reduce production costs and improve productivity. Conservation Agriculture-based technologies offer potential solutions for these issues. Since 2012, a network of actors comprised of research (local university, international research organisations), extension (Department of Agriculture) and farmers groups have been working together through participatory field trials, capacity development, supply chain and policy interactions to undertake research and development activities with the unified aim to take CA to scale across the state of West Bengal.

As a result of this, more than 70,000 farmers in the state are now using CA practices, with several important factors identified that have contributed to the scaling CA. First, the opportunity to strengthen links and build networks in the agricultural system that were limited before. For example, agricultural universities worked very closely with the state extension department, which was integral to fostering trust in academic results. An important part of this network was the farmers' groups (i.e., state sanctioned Farmers Groups, Farmer Producer Organisations and Self-Help Groups). These groups have played a crucial role in machinery provision and as an information channel for farmers. As emerging entrepreneurs, they have been linked to partner networks, and had access to technical expertise that has reduced risk and allowed them to capitalise on an opportunity to use more profitable and inclusive enterprises. Engagement of women and rural youth through farmers groups and alternative income generating activities makes the new system attractive to communities and government alike. These strong networks helped develop trust with communities, and coupled with over 200 participatory trials and ongoing technical backing from international research organisations, resulted in greater buy-in from multiple actors in the system and gave confidence to partners to channel demand to higher levels. A combination of proof of concept and increasing demand from farmers meant policy makers had something to see in the field that was also supported by locally produced, international standard science. Having dedicated, focal staff at every level from local (block and subdivision) and higher allowed for coordinated lobbying from different levels within the government system.

Convergence with government schemes was the ultimate aim for scaling and sustainability of CA use in West Bengal, and these outcomes are demonstrated in several ways. Now, it is compulsory that all new Custom Hiring Centres (CHC) include at least two CA machineries in their portfolio of five machines (minimum), in an attempt to promote CA technologies and avoid environmental hazards associated with straw and stubble management. At the local (block) level, extension staff are able to commit resources from state extension schemes to activities of their choosing, allowing these schemes to promote CA. This promotion of CA is supported by government research and extension staff assigned at district levels who have a commitment of both time and funds for technical backstopping, troubleshooting and adaptation as adoption spreads in both time and space. The approaches used here will continue to contribute to scaling and long-term sustainability of CA use in West Bengal, and provide key learnings more broadly for successful scaling.

Keywords: *Conservation Agriculture, West Bengal, policy convergence, agricultural transformation, policy*

Introduction

In West Bengal, India, the agricultural sector needs options that can address labour scarcity, reduce production costs and improve productivity. Conservation Agriculture based sustainable intensification (CASI) technologies offer potential solutions for these issues, and have been tested in the north of the state since 2012, with promising results. Through a research for development project, a network of actors comprised of research (local university, international research organisations), extension (Department of Agriculture) and farmers groups have been working together through participatory field trials, capacity development, supply chain and policy interactions to undertake research and development activities with the unified aim to take Conservation Agriculture (CA) to scale across the state of West Bengal. As a result of this, more than 100,000 farmers in the state are now using CASI practices, while opening a new window of opportunity to engage youth in agriculture, with several important factors identified that have contributed to the scaling success.

Approach to scaling

Proof of concept

A coordinated set of over 200 participatory, on-farm field trials in five nodes over several seasons provided proof of concept of the benefits of CASI systems. The results showed that CASI systems improve profitability, maintain productivity, and reduce the emissions footprint, water and energy inputs, and labour requirements of food production systems (Dutta et al., 2020; Gathala et al., 2021; Gathala et al., 2020; Gathala et al., 2020; Islam et al., 2019). These more productive and sustainable farming techniques offer the potential for significant impact if widely adopted.

Strengthened networks

A network of key actors in the agricultural system were engaged in the project, including research (local university Uttar Banga Krishi Viswavidyalya (UBKV), international and Australian research organisations), extension (Department of Agriculture West Bengal (DoA-WB)) and farmers' groups. The opportunity to strengthen links and build networks that were limited before was a key element of the project and scaling success. For example, agricultural universities worked very closely with the state extension department, which was integral to fostering trust in academic results. These strong networks helped develop trust with communities, and coupled with the participatory trials and ongoing technical backing from international research organisations, resulted in greater buy-in from multiple actors in the system and gave confidence to partners to channel demand to higher levels.

Farmers' Groups

An important part of this network was the farmers' groups (i.e., state sanctioned Farmers Clubs/ Farmers Groups and Farmer Producer Organisations). These groups played a crucial role in machinery provision, access to quality inputs and as an information channel for farmers. As emerging entrepreneurs, they have been linked to partner networks, and had access to technical expertise and act as a single window service mechanism that has reduced risk and allowed them to capitalise on an opportunity to use more profitable and inclusive enterprises. The CASI system has been demonstrated to be inclusive, reducing labour requirements and providing new business opportunities to women led farmers' groups like production of rice seedlings for the mechanical transplanter.

A commercially viable agri-service delivery model offered young agricultural career professionals the opportunity to develop their entrepreneurial skills through providing locally focused information and on-farm technical services. They could provide farmers with access to high quality technical and information services utilising effective Information and Communication Technologies (ICTs) and innovative e-based training and capacity building. Building trust and lasting partnerships, linking farmers to markets and creating innovation platforms along the agricultural value chain were also the other key opportunities available.

As an example, the Satmile Satish Club O' Pathagar (SSCOP) in Coochbehar, West Bengal has demonstrated exemplary success in providing CASI services, identifying suitable farmers for key activities such as participatory adaptive on-farm trials, and facilitating training and demonstrations. They have been nominated by the Indian National Bank for Agriculture and Rural Development (NABARD) as a Producer Organization Promoting Institution which trains other farmer organisations developing as commercial organisations. They have acquired dealership of agricultural machineries (Zero-till multi-crop planters, mechanical rice transplanters, mini combine harvesters, threshers etc.) from the producer companies (National Agro Industries, Mahindra and Mahindra, Yanmar and more).

About 60 such farmers' organisations in North Bengal of different sizes have filled a critical gap in both knowledge transfer and making the CASI machinery and servicing and repair available to a large number of farmers in the northern part of the state. Their current portfolio includes paid trainings; agri-advisory services; input sales (linked to agribusiness company Mahindra Samriddhi); farm equipment rental and sales (with Yanmar Coromandel, Mahindra, Vijay Villiers, National Agro); market linkage and product aggregation and processing for providing better prices to farmers; soil testing; financial services (with strong linkages with financial institutions such as NABARD. SSCOP is also supporting the DoA-WB to promote CASI technologies in other districts of the state. Government agencies have sent their lead farmers for CASI training to SSCOP, which receives visitors from across India, but also from Nepal and Bangladesh.

The private sector

The private sector is a key part of CASI systems in South Asia, both through direct provision of machinery, supporting mechanisation service provision, and input and output markets. Large private players like National Agro and Yanmar provided dealership and services on soft terms, after continuous negotiation with research partners, which saw several farmers' associations even in the poorest settings become dealers of CASI machinery with the support of these companies. Farmers' Cooperatives who had previously focused on agro-input business added CASI service provision to their portfolio of services, expanding the number of people who could access the services. Other agro-input dealers made new generation herbicides available, which was a key factor for agronomic success of CASI in some areas. Corporate Social Responsibility funds from companies like Godrej and Mahindra were used to train more people in the region in best practice implementation of CASI.

CASI systems have resulted in business opportunities in rural communities, including for individual service providers. Service Providers are a critical part of the wider CASI system in a region where farms are small and fragmented, access to finance is low, and the opportunity for individual farmers to own machines and tractors is limited. Service Providers fill the gap by taking on the mechanisation services as a business, and selling their services for crop establishment, harvest and post-harvest processes to farmers. CASI mechanisation adds an additional income stream in a portfolio of services. Timely and quality service provision is a key enabler in successful CASI systems.

Enagement of women and rural youth makes the new system attractive to communities and government alike. Time saved and removed drudgery during crop establishment has been demonstrated to equitably allow the pursuit of alternative income generating activities.

Engaging at all levels

A combination of proof of concept and increasing demand from farmers meant policy makers had something to see in the field, that was also supported by locally produced, international standard science. Engagement with government officials and policy makers on issues of CASI, agriculture mechanization and sustainable irrigation were delivered through multiple channels such as workshops, policy dialogues and high-level meetings. To promote scaling in West Bengal, the project team conducted policy and orientation meetings for DoA-WB extension officials at all levels. Having dedicated, focal staff at every level from local (block and subdivision) and higher allowed for coordinated lobbying from different levels within the government system. Engaging high-level officials including the Minister for Agriculture, Chief Secretary of Agriculture and the Adviser on Agriculture to the Chief Minister has given credence to research results and project aims.

Demonstrating convergence

Convergence with government schemes was the ultimate aim for scaling and sustainability of CASI use in West Bengal, and these outcomes are demonstrated in several ways.

Government of West Bengal, Department of Agriculture agreed and endorsed the CASI evidenced based recommendations from the project, and is using the protocols developed.

The state government has made CASI machineries a compulsory part of new Custom Hiring Centres (CHC) that receive government subsidies, which means that every new CHC must have at least two CASI machineries in their portfolio of five machines (minimum), in an attempt to promote CASI technologies and avoid environmental hazards associated with straw and stubble management.

To support this mandate, a Centre of Excellence for Conservation Agriculture (CECA) has been approved by the GoWB to be located at UBKV. Given the rate of adoption within the state, and aligned with government subsidies for machinery purchase, it is necessary to ensure that there are enough people trained in Conservation Agriculture (CA) principles and practical elements, to ensure good quality operations for farmers. The CECA will increase the number of people professionally trained in CASI across the state and improve the quality of information available to farmers and service providers. This centre will establish the infrastructure to further promote CASI beyond the life of the project, a great development for CA training infrastructure for long term capacity impact. The GoWB is also providing the operating funds for this center to ensure sustainability outside of the project.

At the local (block) level, extension staff are able to commit resources from state extension schemes to activities of their choosing (e.g., ATMA, NFSM), allowing these schemes to promote CASI. This promotion of CASI is supported by government research and extension staff assigned at district levels who have a commitment of both time and funds for technical backstopping, troubleshooting and adaptation as adoption spreads in both time and space.

Conclusion

The approaches used here have contributed to scaling and long-term sustainability of CASI use in West Bengal, and provide key learnings more broadly for successful scaling approaches that can be used elsewhere. Experience highlights the need for proof of concept that incorporates equitable and multi-dimensional assessment of CASI approaches; this generates interest at multiple levels, and needs to be coupled with technical backstopping. A strong network of actors that includes farmers, research and extension, and the private sector is critical to promote local ownership and fill gaps that can otherwise inhibit scaling.

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Effect of fertilizer rate and tillage method on productivity of winter wheat in the Aral Sea Basin of Uzbekistan

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Conservation Agriculture (CA) proposes options for such changes through addressing a very broad variety of issues related to soil management concepts, water resources management and erosion control, mechanization and tillage, mulching, etc. Five nitrogen rates were evaluated in under two different tillage methods.

The rate of nitrogen had no significant effect on the yields in either of the two tillage systems. The increased fertilizer rates produced the greatest yield response. Most of the grain yield response was due to treatment no-till+nitrogen 120 kg/ha which produced an additional yield increase that was statistically significant across the four years. The highest yield was recorded (5003 kg ha^{-1}) in the treatment where nitrogen rate was 120 kg/ha in 2015 under no-till while the lowest yield was recorded (3733 kg ha^{-1}) in the treatment where nitrogen rate was 80 kg/ha in 2014 under no-till method.

Overall, no-till winter wheat had higher yield compared to conventional tillage method. On the basis of primary findings of this research it can be concluded that the year and fertilizer rate are one of the factors that has been implicated as critical in determining winter wheat productivity in the region under no-till. It should also be concluded that fertilizer use efficiency will be increased while fertilizer rate will be decreased in the no-till. Further investigations of the effect of fertilizer rate are needed to assess its effects in the longer term

Keywords: *no-till, fertilizer rate, winter wheat, yield*

INTRODUCTION

Conservation Agriculture (CA) proposes options for such changes through addressing a very broad variety of issues related to soil management concepts, water resources management and erosion control, mechanization and tillage, mulching, etc. CA practices can increase crop productivity and can improve environmental quality including financial gains (Nurbekov, 2018). Derpsch, (2008) reported that over a period a 17-year period where CA was practiced, fertilizer and herbicide inputs dropped by an average of 30-50 per cent in the CA systems in Brazil. The same author found that over a 17-year period, maize and soybean yields increased by 86 and 56 per cent respectively, while fertilizer inputs for these crops fell by 30 and 50 per cent respectively. No-till controls soil erosion because the plant material protects the soil surface from high winds and rainfall and prevents loosening and carrying away of soil elements. Thus, plant nutrients and soil organic matter remain in the field where they are very useful for crop production. More recent findings from Uzbekistan have shown that during the transition period the need for N for irrigated crops did not differ between conventional and CA practices (Devkota 2011). The objective of this experiment was to see effect of fertilizer rate on productivity of winter wheat growth and development in the region of Aral Sea Basin of Uzbekistan.

MATERIALS AND METHODS

The soil of experimental site is rather dense with the bulk density fluctuating between 1.4 and 1.6 g/cm^3. The highest bulk density was noted in the depth of 20-40 cm. The experiments were initiated in the autumn of 2014 and winter wheat was planted in the beginning of October across all four years. Five treatments were setup under conventional tillage (CT) and no-till (NT): 1. CT N 120; 2. NT N 100; 3. NT N 120; 4. NT N 140; 5. NT N 160. Nitrogen application was managed for intensive production with 1/3 of the N applied at tillering stage and the remainder at jointing stage. Each treatment was arranged in a randomized complete block design with four replicates. Plot size was 200 m2 (25x8 m). All statistical analyses were performed with GenStat 18th edition. Newly released winter wheat variety Turkiston using no-till planter in the experimental station of Nukus branch of Tashkent State Agrarian University.

Monitoring over the crop growth and development was conducted from the time of the starting (10%) and full completion (75%) of the different stages during crop season (SVTCAC, 1989). Field observations on length, thousand kernel weight, plant height and grain yield.

Phosphorus 90 kg ha^{-1} and potassium 60 kg ha^{-1} fertilizers were applied before planting. Field observations were recorded on seed germination, tillering, days to heading, days to maturity. Yield components were analyzed using method of SVTCAC (1989). The yields were recorded before harvest at one square meter from each plot.

RESULTS

No-till practices are new direction in the crop management in Uzbekistan. A lot research is needed to study the effect no-till on agronomic traits of winter wheat in the irrigated conditions of Uzbekistan (Nurbekov, 2018). In this study yield elements such as spike length, spike weight, plant height and TKW assessed under different tillage methods and nitrogen fertilizer rates.

There was no significant effect between agronomic traits and nitrogen rates and also the differences between tillage methods and fertilizers were not significant. Plant height, spike length, spike weight and TKW in treatments NT N 140 and NT N 120 were higher than those in control and NT N 100 treatments (Fig. 1~4). Significant difference in number of spike weight and length occurred among each of the treatments and the maximum number was achieved in NT N 140 followed by NT N 120, NT N 160, NT N 100 and control.

The increased fertilizer rates produced the greatest yield response. Most of the grain yield response was due to treatment NT N 120 kg ha^{-1} which produced an additional yield increase that was statistically significant across the four years. The highest yield was recorded (5003 kg ha^{-1}) in the treatment where nitrogen rate was 120 kg ha^{-1} in 2015 under no-till while the lowest yield was recorded (3733 kg ha^{-1}) in the treatment where nitrogen rate was 80 kg/ha in 2014 under no-till method (Fig. 5).

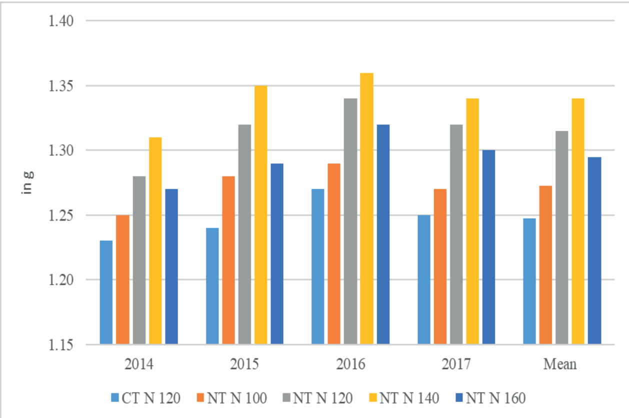

Fig.1. Spike weight as effected by tillage and nitrogen rates (2015-2017)

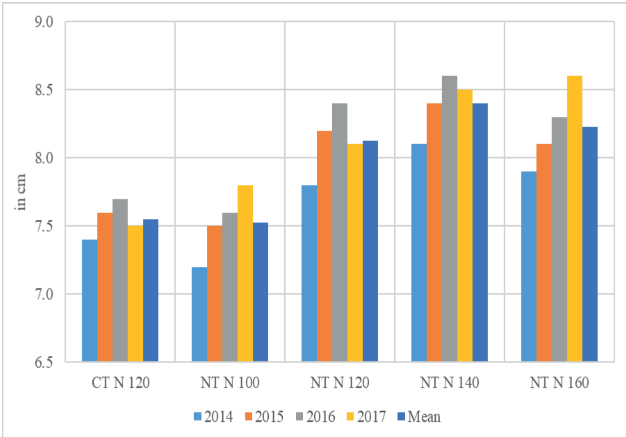

Fig.2. Spike length as effected by tillage and nitrogen rates (2015-2017)

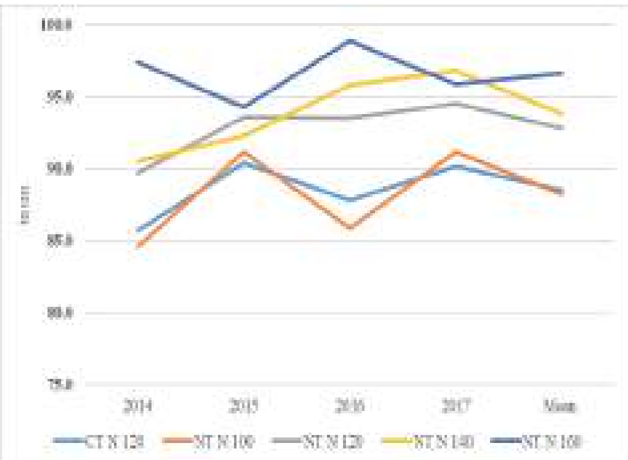

Fig.3. Plant height as effected by tillage and nitrogen rates (2015-2017)

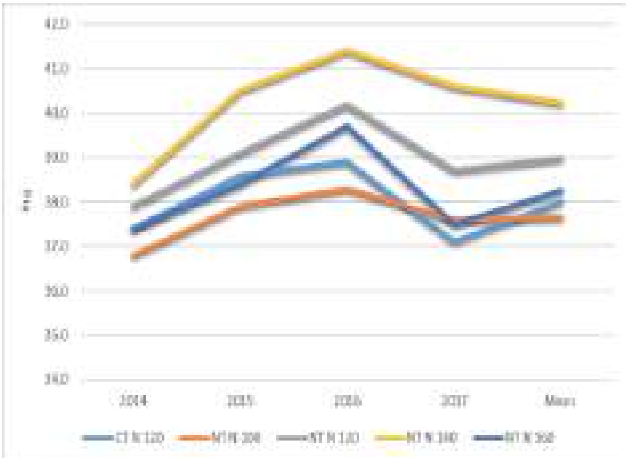

Fig.4. TKW as effected by tillage and nitrogen rates (2015-2017)

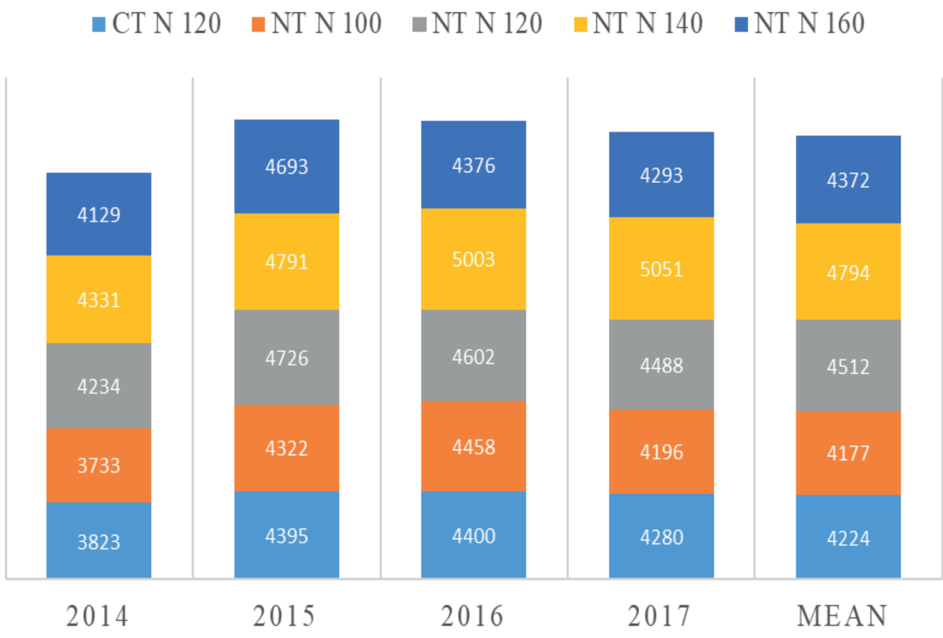

Fig.5. Grain yield as effected by tillage and nitrogen rates (2015-2017)

Overall, no-till winter wheat had higher yield compared to conventional tillage method. On the basis of primary findings of this research it can be concluded that the year and fertilizer rate are one of the factors that has been implicated as critical in determining winter wheat productivity in the region under no-till. It should also be concluded that fertilizer use efficiency will be increased while fertilizer rate will be decreased in the no-till. Further investigations of the effect of fertilizer rate are needed to assess its effects in the longer term.

CONCLUSIONS

On the basis of primary findings of this research it can be concluded that the year and fertilizer rate are one of the factors that has been implicated as critical in determining winter wheat yield components such as spike length, spike weight, plant height, TKW and grain yield. It should also be concluded that fertilizer use efficiency will be increased while fertilizer rate will be decreased in the no-till. Further investigations of the effect of fertilizer rate are needed to assess its effects in the longer term, specifically to monitor long-term effect of CA.

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SUBTHEME 2

FARM AND ECOSYSTEM LEVEL BENEFITS OF CA SYSTEMS TO FARMERS, SOCIETY AND ENVIRONMENT

8th World Congress on Conservation Agriculture

The future of farming
Profitable and Sustainable Farming
with Conservation Agriculture

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8th World Congress on
Conservation
Agriculture

Farm and ecosystem level benefits of CA systems to farmers, society and environment

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The expanding global population, expected to reach 9.5 billion people by 2050, is exerting mounting pressure on the finite land area and resources for growing food. Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure. The objective of this review is to discuss the important role of carbon (C) and all of its attributes that make resource management critical for food security. The many attributes of C are critically important in transforming Conservation Agriculture (CA) systems into regenerative agricultural systems through the C cycle. Conservation Agriculture, C-based and C-focused, integrates system concepts based on three key principles: 1) continuous crop residue cover on the soil surface; 2) continuous minimum soil disturbance (no-tillage); and 3) diverse crop rotations and cover crop mixes with location-specific complementary practices, all important elements of CA. Enhanced C management enables interactive synergies between the biological, physical, and chemical properties and processes with multiple economic and environmental benefits. At the core of CA is the transformation toward soil health and systems management innovation with emphasis on regenerative C management. The important role of new diverse crop rotations and cover crop mixes providing opportunities for C input will make food production systems more resilient and increase water use efficiency. Benefits of soil C management for agricultural ecosystems are discussed starting with C capture in photosynthesis and following C flow through the system eventually back to the atmosphere. The long list of benefits provided by cover crop mixes, including different species and innovative cover crop management provides options for many soil types and geographic locations. The goal is to achieve "continuous living cover" and C input as much as biologically possible.

Keywords: *resilience, hydrology, biodiversity, soil carbon, soil structure*

INTRODUCTION

Global climate change is dramatically increasing the variability of weather conditions worldwide and soil is a critical buffer medium for hydrologic and biogeochemical processes to help mitigate the effects of extreme weather conditions and uncertainty in the availability of water resources. Future resilience building to feed humanity in a world characterized by climate extremes and increasing population will require improved water management. This involves productivity improvements across the full range of agricultural water management options, from purely rainfed agriculture, to supplementary irrigation with water harvesting. In view of the pending concerns and challenges with respect to C management and global food security, the objective of this review is to address the role of soil organic carbon (SOC) centered Conservation Agriculture Systems (CAS) and enhanced carbon (C) storage management providing food security with enhanced ecosystem services (ESs).

THE “LIVING SOIL”

Any agricultural practice altering the soil physical structure or affecting the micro resources and the environmental conditions can modify the mineralization rate of SOC. Human society is literally built on soil. It feeds the world and produces vital fuel and fiber. Soil is one of the most important natural resources on Earth, being required both directly and indirectly for food production, manufacturing of industrial raw materials, and for generation of energy sources. Soil is essential for the function of ecosystems providing nutrients, oxygen, water, and energy. As humanity evolved, we learned to use our human intellect as a major resource for maintaining global food security while not degrading the environment. An additional resource readily evident in natural systems that has recently evolved as vital in agricultural production systems is biodiversity. A few generations of conventional intensive tillage agriculture and monoculture practices are not providing the necessary ecosystem services. Soils themselves as a whole are “dynamic living systems” because the tremendous numbers and varieties of organisms live within soils and the enormous fluxes of energy and matter continuously move in and out of soils that create life-sustaining environments. The “living soil” is full of bacteria, fungi, algae, protozoa, nematodes and many other fragile creatures affected by intensive tillage reflects a need for a fundamental shift in care for our soils. The soil has long been perceived to harbor the greatest microbial diversity among all ecosystems.

Soil is the most complicated biomaterial on the planet. The new understanding of a “living soil system” and “biological laws” require new views on the development of soil structure for agro-ecosystem services. We must develop a “microscopic mentality/perspective” at the level of the organisms living in the soil. Chenu, C. et al. (2019) suggest the vision showing the prominent role of soil microorganisms in the stabilization of SOM emerging from the literature, draw the attention to more exploratory changes in microbial physiology or soil biodiversity induced by agricultural practices that require more in-depth research. Continual pioneering efforts linking biological microbial activity to soil structural development advanced the importance of interaction between biotic and abiotic phenomena in the process of generating soil structural complexity and its role in carbon storage (Rabot, E. et al. 2018; Banwart, S. et al. 2019; Chenu, C. et al. 2019). The clarity in the science is slowly evolving in this complex soil system, and offers hope of finding new ways to store and protect C in our fragile soils.

CONSERVATION AGRICULTURE SYSTEMS

Consensus is mounting for a universally accepted definition for food grown using soil health attributes in a regenerative manner that restores and maintains natural systems, like water and carbon cycles, to enable land to continue to produce food in a manner that is healthier for people and the long-term health of the planet and its climate. Conservation Agriculture (CA) is a relatively new definition for agriculture that's better for profitability, people, ecosystems, and the planet that leads to reduced inputs and increased profits through farmer driven, farmer-led, conservation and education through networking. Conservation Agriculture emphasizes ecological perspective that the soil is a "living system", essential to sustain quality of life on the planet. While principles of CA are universally validated, they still must be innovatively adopted locally to meet site-specific conditions. Conservation Agriculture Systems (CAS) are based on three foundational interlinked principles: 1) permanent minimum mechanical soil disturbance; 2) continuous crop biomass mulch on the soil surface; and 3) biodiversification through diverse crop rotations and associations including cover crop mixes, along with location specific complementary agronomic practices, have slowly evolved as a sustainable/regenerative production system that can lead to enhanced ecosystem services improving food security and environmental benefits. Conservation Agriculture (CA) is a C-focused system requiring simultaneous integration of all 3 principals to enhance C in the system where biogenic C inputs must be maintained as illustrated in the schematic in Fig. 1. The objective optimizing C management is obtained through minimum soil disturbance minimizing the tillage-induced C loss and to maximum C input with diverse rotations and cover crop mixes. Zero tillage/no-tillage is a "cornerstone" of CA, that can be practiced in both large and small farming systems that enhances ESs. Other recent reviews of CA systems have been provided by (Palm, C. et al. 2014; Robertson, P.G. et al. 2014; Banwart, S. et al. 2019; Reicosky, D.C. and Janzen, H.H. 2019; Reicosky, D.C. 2020; and Kassam, A. 2020a,b).

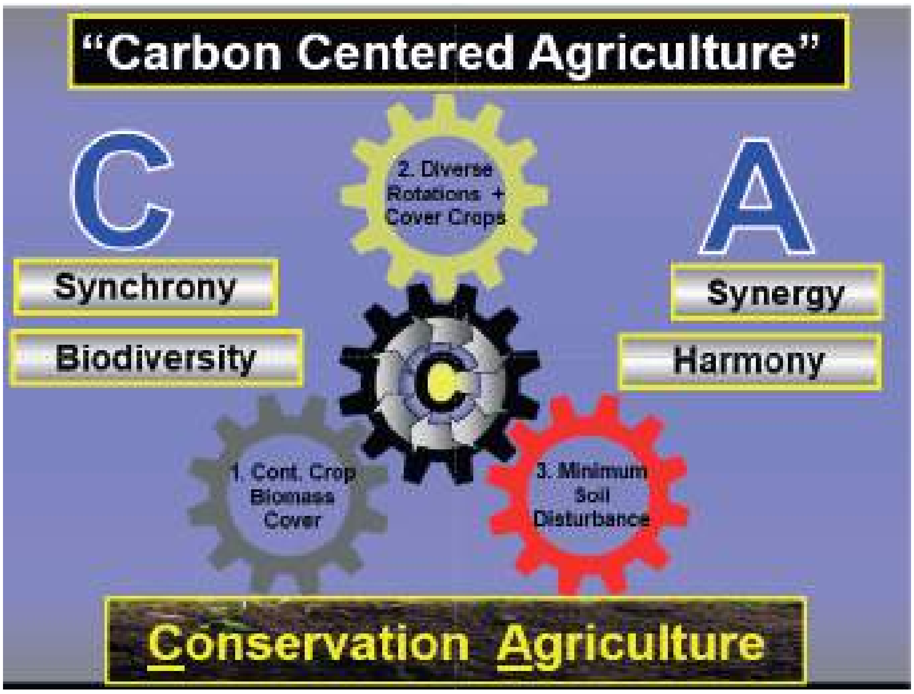

Fig. 1. Schematic representation of the synergy and synchrony in Conservation Agriculture organized around C cycling.

Conservation Agriculture Systems (CAS) restores ESs by minimizing soil disturbance which leaves organic crop residues on the soil surface reducing soil erosion, increasing C in the topsoil, improving soil fertility, structure, nutrient cycling, and improves water use efficiency (WUE) through enhanced infiltration, percolation, plant available water storage, groundwater recharge, and stream baseflow and decreases in peak stream flows and downstream flooding. CA systems provide food, clean air and water, biodiversity, genetic resources, pollinator and wildlife habitat, pest control, natural medicinal products, recreational benefits, anesthetic benefits and other ESs.

ECOSYSTEM SERVICES (ESs)

Ecosystem services are the many and varied benefits to humans provided by the natural resources and the environment in the form of healthy ecosystems. Ecosystem services can be considered nature's contributions to Humanity. Agricultural practices can have significant impacts on environmental quality, and substantial effort has been dedicated to identifying what influences farmers' decisions and incorporating that knowledge into projects, programs, and policies. Ecosystem services are functions provided by the environment that benefit humans and they can be broadly classified as provisioning, regulating, supporting, or cultural services (MEA - Millennium Ecosystem Assessment, 2005), into 4 groups shown in Fig. 2. Agriculture, which is practiced on 40% of the Earth's land surface, both provides and depends on ecosystem services (Lal, 2013a, b). For example, crop production, a provisioning ecosystem service, depends on supporting services, such as C, nutrient and water cycling, pest regulation, and maintenance of soil quality and biodiversity (Power, A.G. 2010). In addition, production practices influence regulating services that provide benefits external to the farm, including regulating water and air quality, storing SOC, and supporting biodiversity (Power, A.G. 2010).

Fig. 2. Broad groupings of ecosystem services in agricultural landscapes (after MEA, 2005).

Nature's warehouse of ecosystem services operates as a community of living organisms, including humans, interact as a system with nonliving components of their environment (things like air, water and minerals). Since ecosystems are a network of interactions they can be of any size, but are usually referred to as specific types found in certain places. A landscape may contain a mosaic of interconnected ecosystems. Ecosystem Services are the processes by which the environment produces resources that we often take for granted such as clean water, timber, and habitat for fisheries, and pollination of native and agricultural plants. Whether we find ourselves in the city or a rural area, the ecosystems in which humans live provide goods and services that are very familiar to us (Banwart, S. et al., 2019).

Although there is no universally agreed upon definition of ecosystem services (ESs), the main ecological functions of soils, beyond technical and cultural aspects, are: C capture and biomass production, storage and filtration of water, storage and recycling of nutrients, habitat for biological activity and C storage (Weismeier, M. et al., 2019; Reicosky, D.C. 2020). The latter can be regarded as a key function of soils, as it is not only decisive for climate regulation, but strongly affects all other functions as well. Clearly, for a given biomass C input to the soil, maximizing preservation of C and maximizing decay of C are mutually exclusive. Managing C for multiple ecosystem functions (Palm, C. et al. 2014; Reicosky, D.C. and Janzen, H.H. 2019) involves careful planning and sometimes compromising between optimizing C stocks and C flows to optimize all ESs.

CARBON MANAGEMENT AND SOIL FUNCTIONS

Soil naturally stores C as a key function of soils that enhances ESs (Wiesmeier, M. et al., 2019). Carbon storage in terrestrial ecosystems is the balance between two major fluxes: photosynthetic inputs and outputs through a variety of processes such as autotrophic and heterotrophic respiration, erosion, dissolved C in the runoff, and fire. Quantification of current and potential SOC storage via a set of suitable indicators could be a promising alternative to precise and accurate determination of SOC storage via field work and laboratory analyses. Wiesmeier, M. et al., (2019) reviewed drivers and indicators that enables a quantification of SOC storage at different spatial scales for prediction of current SOC storage from local to regional scales but also for a spatial SOC storage potential, which is an important aspect for land management decisions and for responses to environmental disturbances. Carbon stays in different ecosystem compartments for a wide range of time scales, from seconds to years in root exudates, leaves, decades in wood, and centuries in stabilized SOM as humus. This large variation in the time that C stays in ecosystems poses challenges to study ecosystem-level processes and quantifying C stocks incentivizing C payments (Wiesmeier, M. et al., 2019).

Soil organic carbon is critical to maintaining soil function and resilience in CA systems (Banwart, S. et al., (2019); Weismeier, M. et al., (2019); Reicosky, D.C. (2020)). A natural equilibrium exists for the retention and loss of OM, with some significant seasonal variability. Soil functions, which develop through formation of soil aggregates as fundamental ecological units, are manifest at the earliest stages of critical zone evolution. Soil functions are flows and transformations of mass, energy, and genetic information that connect soil to the wider critical zone, transmitting the impacts of human activity at the land surface and providing a control point for beneficial human intervention. Within this framework, soil functions are defined as groups of environmental goods and services that depend on dynamic processes occurring in soil as natural assets. Advances in knowledge on the mechanistic processes of soil functions, their connection throughout the critical zone, and their quantitative representation in mathematical and computational models define research frontiers that address the major global challenges of critical zone resource provisioning for human benefit.

Soil functions include biomass production for food, fuel, fiber, and timber; C storage derived from OM that is biologically fixed from atmospheric carbon dioxide (CO_2); and the mass transformation of nutrients and their plant-available storage. Additional soil functions include storing, filtering, and transmitting water, heat, and gases to mitigate flooding and supply plant-available water, attenuate pollution loads, transmit water to aquifers and streams, exchange gases with the atmosphere, provide thermal mass for energy storage, and decompose and recycle waste. Soil functions also include sustaining terrestrial biodiversity of habitat, species, and genes; providing a physical support for built structures and a cultural landscape for human activities, health, and well-being; acting as a source of raw materials including biological resources such as antibiotics; and providing an archive of geological and archaeological heritage.

SOIL STRUCTURE AND CARBON STORAGE

Soil structure is a way to describe how mineral and organic particles are arranged in the soil that also plays an important role in water infiltration, aeration, root penetration, carbon storage, and nutrient cycling critically important ESs in CA systems. Historically, soil structure has been a key factor in the functioning of soil (Rabot, E. et al. 2018), its ability to support plant and animal life, and moderate environmental quality with particular emphasis on C storage and water quality and various other ESs. Kravchenko, A.N. et al. (2017) describe a new mechanism determining how microbes process SOM with C bi-products stored in soil micro-pores that could improve climate resilience of cropping systems and reduce C footprints. This new thinking reveals the importance of soil micro-pore structure for C accumulation and protection for climate mitigation.

The role of soil structure as a control point with C storage as OM is a central supporting function that influences most other soil functions (Wiesmeier, M. et al., 2019). This is due to the important role of SOM in influencing soil aggregate formation, soil structure, biopore networks, and through this, multiple soil functions (Banwart, S. et al., 2019), reflecting the enhanced C management and ESs associated with increased SOM. Soil porosity is fairly well standardized in definition and measurement techniques. Pore size he and continuity, however, is not obvious how to define, much less to measure. Yet it is central to topics like macropores, aggregation, fractures, soil matrix, and solute mobility. Pore size plays a key role in various proposed means of quantifying soil structure. It also has a major practical role in the prediction of hydraulic properties. Majority of air and water fluxes occur via inter-aggregate pores from which air, water, chemicals, and microorganisms can enter the aggregates. New pore size concepts, measurement techniques, and relations to transport phenomena are likely to remain a major emphasis in the study of soil.

SUMMARY

Ecosystem services are the direct and indirect contributions to human well-being that support our survival and quality of life. Conventional tillage agriculture over the last 10,000 years has contributed unintended consequences of soil and environmental degradation and loss of ecosystem services. We now better understand ecology of a "living soil" full of bacteria, fungi, algae, protozoa, nematodes and many other fragile creatures are affected by tillage. Ecosystem services are threatened from tillage-induced degradation that includes soil erosion and sedimentation, decreased soil structure, infiltration, aeration, and soil organic carbon, increasing GHG emissions, point and diffuse nutrient loss, algae buildup in rivers and lakes, soil sealing, compaction and declining soil fauna and bio-diversity with incomplete ecosystem services. Conservation Agriculture (CA) systems, based on three interlinked key principles: 1) permanent minimum mechanical soil disturbance; 2) continuous crop biomass cover on the soil surface; and 3) biodiversification through diverse crop rotations and associations of cover crop mixes, have slowly evolved as a regenerative food production system. Conservation Agriculture systems restores soil health and ecosystem services with crop residues on the surface reducing soil erosion, increasing C in the topsoil, improving soil fertility, structure, nutrient cycling, and water use efficiency through enhanced infiltration, percolation, plant available water storage, groundwater recharge, and decreases in peak flows and flooding. CA systems provide nutritious food, clean air and water, biodiversity, genetic resources, pollinator and wildlife habitat, pest control, natural medicinal products, recreational benefits, and anesthetic benefits. Climate extremes are one set of interconnected trends and risks facing agriculture requiring cover crop mixes capturing C from the air and storing it in the soil providing more resilience to extreme weather. The synergy between earthworms and root extension, in the absence of tillage, creates a bio-pore network for increased water and air flow deeper into the soil. Emphasis must be on the total social, economic and

environmental value of CA to society creating a world in which both nature and people thrive. We owe it to future generations.

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The future of farming
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Soil health checkup of Brazilian Conservation Agriculture farming systems

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Brazil has around 35 M ha of cropland managed under Conservation Agriculture (CA) grain farming placing the country as one of the world's largest area. CA has many advantages in relation to intensive tillage-based farming by providing soil erosion control, organic matter restoration, saves labor, time and fuel and offers competitive yields. Documented effect of CA on soil health at the farm level is still relatively scarce. This study was carried out aiming to investigate the enzyme activity analysis as an indicator of CA soil health in main Brazilian agro-ecoregions. For that, seven fields located in main grain producing regions in South, Central-West and Northeast were selected. In each of them three environments (high, medium and low yield) were defined based on crop yield records and satellite images. The chemical soil analysis (SOM, P, K, Ca, Mg, S, Al, B, Cu, Zn, BS, CEC, pH) and physical analysis (soil texture, electrical conductivity - ECa) were performed. The activity of soil enzymes β-glucosidase and arylsulfatase was evaluated in 63 sampling points spread in four States. These enzyme activities have been recently proposed as key indicators of Brazilian soil health. One field with larger data base was selected for DNA characterization in order to more deeply understand soil health and its relationship with field crop yields. The results show that β-glucosidase and arylsulfatase activities have positive relationships with SOM, clay, silt, Ca content and CEC. Also, these enzyme activities had negative relationship with sand texture. The enzymes were sensitive to soil productive capacity within field. Tropical Brazilian soils usually are acid, with low activity clay, and dystrophic character. As a consequence, soil acidity correction, SOM restoration and soil fertility and CEC increase were important strategies to improve biological activity. In the study, SOM contents higher than 3.5% were associated with high β-glucosidase and arylsulfatase enzyme activities. However, around 37% of the data points had low SOM that were associate with low enzymes activity. The enzymes were also efficient indicators of soil biodiversity assessed by DNA characterization. Finally, the study concludes that following the three integrate principles of CA with focus on crop rotation and cover crop use, SOM restoration, alleviation of soil acidity, and increase in Ca content were key drivers in the restoration of soil health, with positive consequence for crop yield.

Keywords: *Agro-ecoregions, Soil Enzymes, Soil DNA, Soybean Yield, Soil Organic Matter*

1. INTRODUCTION

The projected global population growth over the next decades will increase the demand for food, fiber, biofuel, energy, water and other agricultural products. As a consequence, there will be growing pressure on natural ecosystems and agroecosystems, which are already facing sustainability challenges due climate change, soil degradation and loss of biodiversity, compromising their environmental services at different scales (Kassam et al., 2009). This scenario highlights an imperative need for the development of more sustainable agricultural systems. Therefore, business-as-usual attitude towards agricultural production in most world regions will fail to deliver sustainable production intensification to meet future needs (Shaxson, 2006; Kassam et al., 2009). Therefore, there is an urgent need of redesign agriculture production systems in order to decrease environmental, economic and social costs associate with current intensive tillage and chemical-based cropping systems.

Conservation Agriculture (CA) has been practiced for more than four decades in the pioneers regions in North and South America and based on the positive results obtained, it has been gradually spreading worldwide in filling the important gaps of business-as-usual agriculture in addressing societal challenges. The three principles that define CA are: a) minimizing soil disturbance by mechanical tillage avoiding inversion of soil layers, breakdown and mixing of crop residues into the soil, and minimizing fast residue decomposition and aggregate disruption; b) maintaining year-round diverse organic matter cover with living and dead plant material over the soil; and c) diversifying crop rotations and associations, enhancing a consortium of cover crops to fill up all spare time windows between main cash crops, including nitrogen fixing legumes and soil return of high quality crop biomass (Kassam et al., 2009; 2018; Leal et al., 2020). Currently, Brazil has about 35 M ha under CA cropland spread in different agro-ecoregions, with varying levels of CA implementation due to the continental dimensions of the country (fifth largest t country in the world in terms of area). As a consequence, there is a complex interaction of weather, soil and production management including during the early years of transition into CA that may have consequences for soil health that may not be well understood.

Soil health can be defined as the capacity of a specific soil type to function, with natural or managed boundaries, in order to sustain plant and animal productivity capacity, maintain/enhance water and air quality, support human health and biological diversity (Doran and Zeiss, 2000; Doran and Parkin, 1994; Garbisu et al., 2011). Moreover, 'conservation-effectiveness' encompasses not only conserving soil and water, but also enhance the soil biotic component that is the basis of sustainability (Kassam et al., 2009). In an analogous way, the 'crop production-effectiveness' encompasses not only the maintenance of soil chemical nutrient levels above some critical levels but provide friendly habitat to diverse microbiome that will stimulate nutrient cycling and enhance root uptake of plant nutrients.

Soil health requires that the main soil functions such as productivity capacity, environmental protection and plant and animal health are well balanced through wise management decisions (Kremer, 2017). In addition, soil health can be understood as a subcomponent of a bigger ecosystem health. A healthy ecosystem relies on efficient nutrient cycling, high photosynthesis rate, energy flow, stability and resilience to stress (Van Bruggen et al., 2006; Tripathi et al., 2020). In this sense, there is a solid linkage between ecosystem health and soil heath expressed by microbial activity, biodiversity and community stability (Tripathi et al., 2020). Therefore, building soil health through farming practices is one pathway for ensuring sustainable agriculture. The microbiome living in the rhizosphere is a hot-spot because the microbiota act as plant growth-promoters and plant growth-regulators, affecting root growth with positive effects on plant nutrients uptake, water use efficiency and environmental adaptation (Khan et al., 2020; Mendes et al., 2018). Building a diverse microbiome in the rhizosphere is also needed to suppress or alleviate pressures from plant pathogens, decreasing disease incidence and severity resulting in more vigorous plants that are more resilient to stress (Van Bruggen et al., 1996; Toor and Adnan, 2020; Tripathi et al., 2020).

The soil physical attributes, particularly soil texture, structure, compaction, bulk density, aggregation, porosity and water availability, and chemical attributes, especially pH, SOM, nitrogen, plant exudates, salinity, aluminum, hydrogen, CEC and nutrients interact with cropping system and weather conditions, driving the microbial activities and their functional diversity (Tripathi et al., 2020). The microbial activity and diversity are sensitive bioindicators of soil management quality (Mendes et al., 2018; Leal et al., 2020). Therefore, assessing the soil microbiome and enzymes activity may provide early insights about the quality of soil management and forecasting if it is improving the soil or promoting degradation before advance stages are reached (Tripathi et al., 2020).

The main objective of this study was to assess soil health through enzyme activity of long-term CA croplands in main Brazilian agro-ecoregions. Moreover, in one select field the DNA characterization was investigated in order to capture microbiome diversity in different crop yield environments within the field.

2. METODOLOGY

2.1. Agro-ecoregions, croplands and within-field yield environments

This study was carried out in seven grain fields managed during long-term under CA that are located in the main Brazilian agro-ecoregions: South, Central-West ('Cerrado') and Northeast (Fig. 1 and Table 1). In each one three within-field yield environments (high, medium and low yield) were delineated based on crop yield maps and satellite images (NDVI) according to the available data. The high yield environment was classified as > 110% average crop yield, medium as 80 – 110% and low as < 80%.

Fig. 1 Geographical distribution of the fields sampled in the main agro-ecoregions of Brazil.

Table 1. Fields locations, areas (ha), average annual temperature (T) (°C), annual accumulated precipitation (P) (mm), average altitude (E) (m) and soil texture.

Field	Localization	Area	T	P	E	Soil texture
		ha	°C	mm y-1	m	
S-1	Carazinho – RS	60.1	18.3	1483	565	Clay loam
S-2	Não-Me-Toque – RS	124.0	19.0	1771	500	Clay loam
S-3	Rosário do Sul – RS	25.0	19.5	1493	155	Sandy loam
CW-1	Primavera do Leste – MT	348.8	24.0	1471	650	Sandy clay loam
CW-2	Rio Verde – GO	509.8	23.1	1294	875	Clay loam
NE-1	Luís Eduardo Magalhães – BA	1376.1	23.6	881	830	Sandy clay loam
NE-2	Placas – BA	690.9	25.0	1089	880	Sandy clay loam

*Soil texture classified according to Soil Survey Staff (2014); Meteorological data extracted from the database of nearest INMET weather automatic stations, corresponding to the years 2018, 2019 and 2020. RS- Rio Grande do Sul ; MT- Mato Grosso; GO- Goiás ; BA- Bahia. S= South; CW= Central West; NE= Northeast.

2.2. Sampling strategies to enzyme analysis, DNA characterization and crop yield

In each yield environment of the seven fields, soil at 0-0.10 m depth was collected with three repetitions for chemical and enzyme activity analyses totaling 63 georeferenced sampling points. Soil samples for enzyme activity analysis were collected 40 days after crop emergence using manual shovel. Seven sampling points comprised one in the center of the crop row and three on each side of the row. After sieving (< 2 mm) and removing crop residues, the soil samples were air dried following the Mendes et al. (2019) methodology. The β-glucosidase e arylsulfatase enzymes activity analysis followed Tabatabai (1994) methodology.

The chemical analyses were soil water pH (1:1), potassium (K) and phosphorus (P) extracted with Mehlich-I solution. The K content was determined by flame photometry and the P content by colorimetrically, using molybdenum blue (Embrapa, 2011). Calcium (Ca), magnesium (Mg) and aluminum (Al) were extracted using 1.0 mol L−1 KCl solution. Ca and Mg were determined by atomic absorption spectrophotometry. Al was titrated with NaOH 0.025 mol L^{-1}. The cation exchange capacity (CEC) pH 7 was determined by the sum of the exchangeable bases (K, Ca, and Mg) plus Al+H according to Tedesco et al. (1995). The soil texture was determined by pipette method according Teixeira et al. (2017).

One of the fields of the Aquarius project, that had a large available data base, was used to do DNA characterization. The soil is clayey, kaolinitic and classified as a Rhodic Hapludox (Soil Survey Staff, 2014). The cropland has been managed under CA since 2002 and more details can be found in Pott et al. (2019). In the growing season of 2019/2020 soil samples were collect at 0-0.10 m and sent to Biome Markers® (https://biomemakers.com) in United States for molecular analysis of the microbiota. DNA extraction was performed with the DNeasy 420 PowerLyzer PowerSoil Kit from Qiagen (Imam et al., 2021). To characterize both bacterial and fungal microbial 421 communities associated with bulk soils and rhizosphere samples, the 16S rRNA and ITS marker 422 regions were selected. Libraries were prepared following the two-step PCR Illumina protocol 423 using custom primers amplifying the 16S rRNA V4 region and the ITS1 region described 424 previously (Imam et al., 2021). DNA sequencing was conducted in an Illumina MiSeq instrument using pair-end 425 sequencing (2x300bp). The platform BeCrop® was used in the study, and more details can be found in Imam et al. (2021).

2.3. Statistical Analysis

The results of enzyme activity, chemical analyses and crop yields were submitted to variance analysis ($p<0.01$ e $p<0.05$) and Pearson's correlation. The relationship of SOM and number of species and enzyme activity were analyzed by linear and quadratic adjustments. The enzyme activity and SOM relative average in each within-field yield environment were compared based on the Tukey test ($p<0.05$).

3. RESULTS

3.1. Soil attributes and relationship with soil enzymes activity

According to agro-ecoregion, the soil attributes show differences in their effect on soil enzymes activity (Table 2). Soil texture had an effect on soil enzyme activity in the South and Central-West regions but not in the Northeast. In general, in the South and Central-West regions the increase of sand content was associated with a decrease in enzymes activity. On the other hand, in Northeast where the soils are very sandy and there is a narrow variation in soil texture, this relationship was not verified. Soil texture had influence on structure, CEC, SOM content, soil temperature and water holding capacity. Typically clay soils are expected to have higher microbial biomass and enzyme activity than sandy soils under similar conditions. Ji et al. (2014) reported that the number of soil actinomycetes and fungi in clay soil was 151% and 43% higher than in loam soil. The authors linked this result to fine clay particles that hold water and SOM. Elliot et al. (1980) and Alvarez et al. (2002) highlight the protective effect of clay to microbiome. In our study the clay content had relationship with β-glucosidase in South, and with arylsulfatase in South and Central-West regions (Table 2).

Table 2. Pearson's correlation of β-glucosidase and arylsulfatase with SOM, soil texture, CEC and Ca content. * significant p<0.05; ** significant p<0.01; ns= not significant; n=63

	Region	SOM	Sand	Silt	Clay	CEC	Ca
β-glucosidase	South	0.78*	-0.61*	0.39**	0.48**	0.49**	0.35ns
	Central-West	0.83*	-0.91*	0.85*	0.43ns	0.58**	0.56**
	Northeast	0.67*	-0.07ns	0.24ns	-0.13ns	0.31ns	0.20ns
	Brazil	0.77*	-0.76*	0.70*	0.41*	0.67*	0.59*
Arylsulfatase	South	0.79*	-0.72*	0.35ns	0.67*	0.55*	0.38ns
	Central-West	0.80*	-0.89*	0.82*	0.47**	0.51**	0.53**
	Northeast	-0.13ns	-0.08ns	-0.06ns	0.18ns	-0.14ns	-0.18ns
	Brazil	0.65*	-0.64*	0.49*	0.53*	0.82*	0.72*
SOM	South	-	-0.78*	0.24ns	0.84*	0.37ns	0.13ns
	Central-West	-	-0.83*	0.81*	0.26ns	0.72*	0.75*
	Northeast	-	-0.29ns	0.30ns	0.13ns	0.54**	0.38ns
	Brazil	-	-0.86*	0.78*	0.49*	0.61*	0.46*

The CEC had a positive effect on enzymes activity in the South and Central-West regions. In tropical soils, the CEC is dependent on clay mineralogy and content and SOM. Soares et al. (2005) and Bayer et al. (2000) reported that Oxisols, which are highly weathered, had around 80% of its CEC associated with SOM. The interaction between SOM and clay minerals (organomineral complex) increases soil aggregation and physically protects SOM from microbial degradation. Ferreira et al. (2018) and Xu et al. (2014) reported that CEC and base saturation were drivers of SOM gain in tropical CA soils. These results indicate that nutrient management plays an important role in SOM recovery in dystrophic tropical soils.

In this study, the Ca content had positive relationship with enzyme activity in the Central-West region. In addition, country averaged Ca had relationships of 0.59 and 0.72 with β -glucosidase and arylsulfatase enzyme activity, respectively (Table 2). Previously, Pires et al. (2020) reported that Ca was a driver of β-glucosidase in a South CA long-term experiment. Ca serves as a constituent of cell walls and membranes and can act as a physical barrier against pathogens (Thor, 2019). In addition, Ca increases root growth, mainly of the fine roots that are very active in providing exudates to microbial rhizosphere community. Finally, Ca is important for soil aggregation and carbon stabilization under CA (Ferreira et al., 2018).

The SOM had stronger relationship with enzymes activity in the South and Central-West regions with r values of 0.67 to 0.83, respectively. In the Northeast region the SOM had a relationship with β-glucosidase but not with arylsulfatase. Moreover, in this region the only soil attribute that had a relationship with enzyme activity (β-glucosidase) was SOM. In the Fig. 2 it is shown that SOM had a linear positive relationship with β-glucosidase which explained around 60% of variability of this enzyme activity. The maximum enzyme activity was reached with maximum high SOM content (>5%). The arylsulfatase had a quadratic relationship with SOM, with maximum activity reached at 3.55 %. Xu et al. (2014) reported that SOM had a positive relationship of 0.83 with enzyme activity and N content. The authors explained that microbes need nutrients coming from labile fractions of SOM that they use as energy and nutrient sources. In addition, SOM retains soil moisture, enhances CEC and aggregation that had enhanced microbial biomass and enzyme activity. A recent exploratory study of soil analyses from South Brazil laboratories (n=35,362) reported that 55% of the total had SOM <2.5% (Tiecher et al, 2016). In our study, we had around 40% of the data points with low SOM (<2.5%) that were associated with low enzymes activity (Fig. 2). These data suggest an urgent need to revise the use of cropping system enhancing rotations and cover crops in order to build up soil health in this important parcel of Brazilian CA regions.

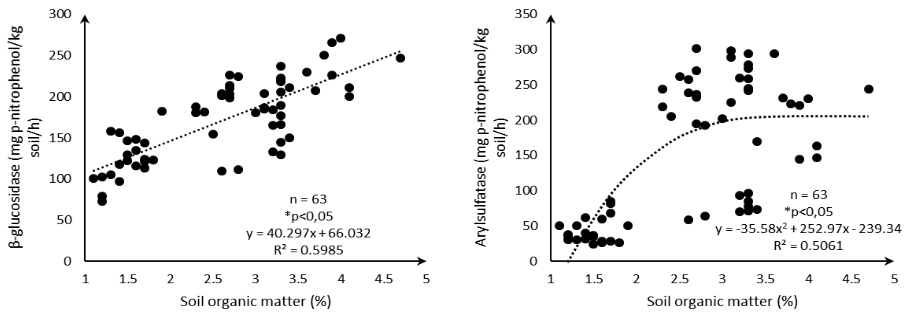

Fig. 2 Correlations between the activity of β-glucosidase and arylsulfatase enzymes and soil organic matter (SOM). * Correlations above are considered significant.

The SOM restoration and enzyme activity are strongly linked with CA principles. Pires et al. (2020) reported that long-term adoption of CA (32 years) increased SOM at the soil surface compared to intensively tilled soils. Moreover, the introduction of crop diversification increased SOM protection and aggregate stability enhancing the soil microbial diversity and enzyme activity. In their study, the β-glucosidase activity was 69% higher in CA than in tillage-based systems. Moreover, β-glucosidase increased by 23% under CA with crop rotation compared to no-till monocropping systems. The biological improvement associated with crop diversification under CA was fully offset by mechanical soil tillage. Soil disturbance avoidance stimulates growth of fungi hyphal networks, which allows fungi to establish bridges at the mulch-soil interface facilitating SOM stabilization.

3.2. Enzyme activity and biodiversity in varying crop yield environments

The β-glucosidase and arylsulfatase enzyme activity were efficient in distinguish high and medium yield environments from the low yield definied base on previous crop yield records and satellital images (Fig. 3). Accordingly, Lorenz et al. (2020) reported that β-glucosidase had a relationship with corn yield but arylsulfatase did not show a relationship with soybean yield.

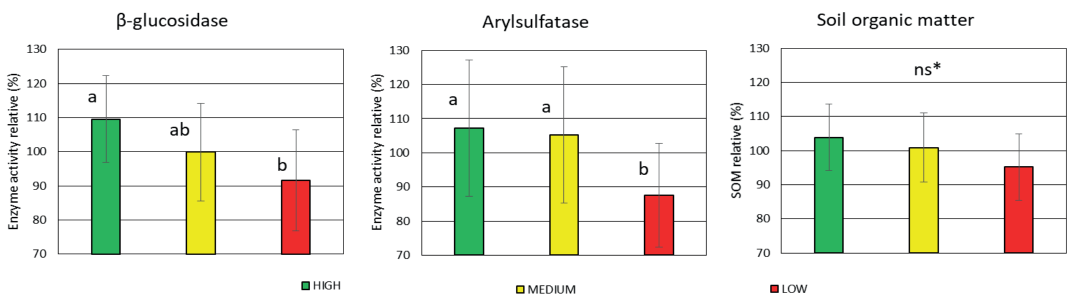

Fig. 3 Relation of β-glucosidase and arylsulfatase enzyme activity under Conservation Agriculture with varying yield environments in main Brazilian agroecosystem regions.

The β-glusosidase and arylsulfatase had a positive linear relationship with the biodiversity assessed by DNA characterization (Fig. 4). The coefficient of determination between β-glucosidase and arylsulfatase with the number of microbiome species were 0.85 and 0.79, respectively. These results support the enzyme activity level to be a sensitive indicator of soil health (Mendes et al., 2018).

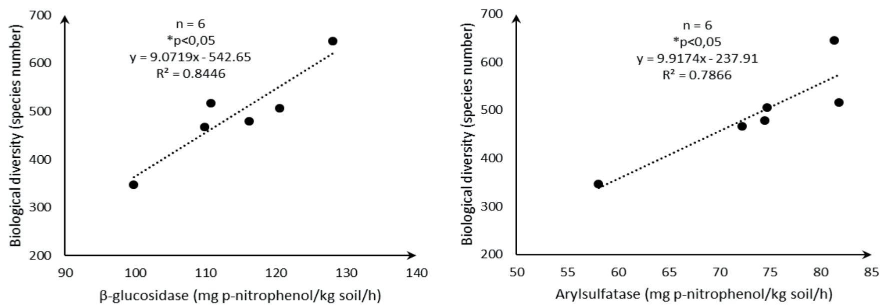

Fig. 4 Relation of β-glucosidase and arylsulfatase enzymes activity under conservation agriculture and biodiversity assessed by DNA characterization. * p<0.05.

4. CONCLUSIONS

In general, the fine soil particles (clay and silt), CEC, calcium content and SOM had a positive relationship with β-glucosidase and arylsulfatase activity in the Brazilian agro-ecoregion investigated.

The β-glucosidase and arylsulfatase enzymes activity were efficient indicators of biodiversity under Conservation Agriculture. Also, the enzyme activity was an efficient tool to distinguish the variation between within-field yield environments.

A large proportion of data points investigated (40%) had low SOM content that causes low enzymes activity and restricts biodiversity. These results reinforce the conclusion that the three principles of Conservation Agriculture operate synergistically in order to build up soil health in production systems.

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Impact of conventional soil tillage and raised- bed cultivation method on growth of winter wheat varieties

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Agriculture is an important part of the economy of the Republic of Azerbaijan and makes a significant contribution to ensuring food security for most of the population. Stable development of agriculture, increase production and the growth of the well-being of the population largely depend on the condition and fertility of the soil. However, over the past decades, agricultural land has been increasingly subject to degradation, which is steadily leading to a loss of fertility, and subsequently to a decrease in yield and production efficiency as a whole. In this regard, the impact of raised bed cultivation technology on the development of grain varieties, which contributes to the improvement of soil structure and fertility compared to traditional cultivation technology has been studied by us. The experiments were conducted at the Tartar regional experimental station of the Institute of Crop Husbandry Research work to study the effect of conventional soil tillage and raised bed cultivation on growth of winter wheat varieties "Azamatli 95", "Murov-2", "Tale-38" under different rate of fertilizer application. The effect of different tillage and sowing methods applied during the research on the following development characteristics of the plant was studied: seed germination percentage, number of productive tillers in the plant; the number of main stem leaves in the plant; plant height (cm) during the maturity phase; spike length (cm); the number of spikelets in the spike; the number of grains in the spike; the number of roots in the plant; root length (cm); dry weight of the root in the plant; weight of 1000 grains (g) and grain yield. Different effects of various soil cultivation methods on the development characteristics of winter wheat varieties were found. The most profitable option has proven itself in the technology of raised-bed cultivation and under $N_{120}P_{90}$ fertilizer application rate.

Keywords*: tillage, raised-bed, conventional tillage, profitable, maturity phase*

The experiment was conducted during 2010-2011 and 2011-2012 crop season at the Tartar Regional Research station located in Tartar district to determine the effect of conventional soil tillage and raised bed cultivation of wheat on growth characteristic of local winter wheat varieties. This study consisted of following soil treatments: conventional soil tillage commonly used by the most farmers and raised-bed cultivation technology with more than 30% crop residues remained on the surface from previous crop.

The conventional tillage was performed disk plow with 10-12 cm in depth without any residue retention, application of fertilizer before plowing, moldboard plow and harrowing. Operations used for cultivation of winter wheat under raised-bed technology include making raised-beds with more than 30% crop residue maintenance on the soil surface and planting seeds in one operation. Seeding was undertaken by seed drill with model of "Oztekin" manufactured by Turkey.

Seedling emergence

Effect of different tillage methods on seedling emergence percentage was measured two weeks after irrigation for each study years separately. The results show that the seedling emergence was not affected by the tillage treatments during both the wheat growing seasons. Maximum seedling emergence percentage (i.e. 88 and 91 percent) was noticed under raised-bed treatment. There was non-significant linear and quadratic response in seedling emergence under various tillage treatments during both the study years. The comparison between two years data suggests that slightly higher seedling emergence was observed during 2012 as compared to 2011. Acceptable percentage ratio for seedling emergence under ZT treatment for the second season may be caused by organic matter which may improve soil physical and chemical characteristics particularly soil water holding capacity.

The measurements have been carried out under $N_{120}P_{90}$ fertilizer application rate for both treatments.

Tiller production

The number of tillers plant^{-1} under various tillage treatments was investigated during 2011 and 2012 and the data are given in Table 1.

Table 1. Effect of tillage treatments on seedling emergence, number of tillers plant-1 and the number of leaves plant-1 in wheat crop grown during 2011 and 2012.

Tillage treatments	Seedling emergence,%		Bitkidə zoğların sayı		Bitkidə yarpaqların sayı	
	2011	2012	2011	2012	2011	2012
	n=9	n=9	n=9	n=9	n=9	n=9
Conventional tillage	87	90	17,0	18,3	12	14
Raised-bed tillage	88	91	15,7	16,8	11	13

The data indicated that the number of tillers plant per hectare was significantly affected by tillage treatments during both the years. During 2011, the highest number of tillers plant^{-1}(17.0) was noted under conventional tillage, and the number of tillers plant-1 declined raised-bed treatment (15.7). Almost similar trends were observed during 2012, the highest number of tillers plant^{-1} (18.3) was noted under conventional tillage, and it decreased raised-bed treatment (16.8).

During 2011, the differences in number of tillers plant^{-1} between conventional and raised-bed treatments were statistically non-significant. The number of tillers plant^{-1} during 2012 tended to be greater than that observed during 2011.

Leaves

The number of main-stem leaves plant^{-1} under different tillage treatments was counted for the 2011 and 2012 wheat growing seasons and results are presented in Table 1. Results reveal that the number of main-stem leaves plant^{-1} was significantly influenced by tillage treatments during both the study years. During 2011 and 2012, the maximum number of leaves was 12 and 14 plant-1 under conventional tillage, whereas, this number decreased under raised-bed tillage (11 and 13 plant-1) respectively. During 2012, the differences in the number of leaves between conventional and raised-bed treatments were statistically non-significant. The year wise comparison suggests that the total number of leaves plant^{-1} tended to be greater in 2012 as compared to 2011.

Roots

The number of roots per plant (Table 2) was significantly affected by tillage treatments during both the years.

Table 2. Effect of tillage treatments on number of roots, root length and root dry weight.

Tillage trtreatments	No of roots counted at 0-10 cm depth		No of roots counted at 11-20 cm depth		Root length, cm		Root dry weight (g/plant)	
	2011	2012	2011	2012	2011	2012	2011	2012
	n=9	n=9	n=9	n=9	n=9	n=9	n=9	n=9
Conventional tillage	41	44	8	9,3	16	17	6,1	6,9
Raised-bed tillage	42	45	8,2	9,5	17,2	18,1	6,5	7,3

As can be seen from the table, the maximum number of roots at a depth of 0-10 cm was observed in both treatments in 2012 (44 and 45). In addition, it was found that the number of roots in the raised-bed tillage system at a depth of 0-10 cm was 2.4% greater in the 1st study year and 2.2% greater in the 2nd study year compared to the conventional tillage system. In a conventional tillage system, at a depth of 11-20 cm, the number of roots was 8 and 9.3 in both study years respectively. At the same depth, the number of roots in raised-bed tillage system was 8.2 and 9.5 in the both study years, which was 2.5% and 2.1% higher than in the conventional tillage system, respectively. The year wise comparison indicated that during 2009 the number of roots plant-1 was relatively greater than the number of roots plant-1 recorded during 2008.

The root length of wheat plants as influenced by various tillage treatments was measured for two cropping seasons (2011 and 2012) and the data are given in Table 2. A seen from the Table 2, in raised-bed tillage system the root length was 7.5% and 6.4% greater respectively in both years than in the conventional tillage system. Results indicated that tillage treatments significantly affected the root length during the both seasons. The maximum root length of 17,2 and 18,1 cm was recorded under raised-bed tillage, whereas, a reduction in root length was recorded under conventional tillage (16 and 17 cm), during 2011 and 2012, respectively. The seasonal comparison between two years indicates that the roots were relatively longer during 2012 than those measured during 2011.

The roots of selected wheat plants under various tillage treatments were collected, oven-dried weighed and the results are presented in Table 2. Results indicate that the root dry weight was significantly affected by the tillage treatments. The dry weight of the root was also found to be 6.5% and 5.7% higher under raised-bed tillage in both study years respectively compared to the conventional tillage. The maximum root dry weight (6.5 and 7,3 g plant^{-1}) was observed under raised-bed tillage, whereas, the root dry weight plant^{-1} was decreased considerably under conventional tillage (6.1 and 6,9 g) during 2011 and 2012 respectively. Root's dry weight during 2012 was slightly higher as compared to 2011.

Spikelets, per spike

The results (Table 3) indicate that the number of spikelet spike^{-1} was significantly affected by tillage treatments during the both years. The great number of spikelets spike^{-1} (17.8 and 18.4) was observed under raised-bed conventional tillage, and the number of spikelet spike^{-1} declined under conventional tillage (15.9 and 16.8 spike^{-1}) during 2011 and 2012, respectively

Table 3. Effect of different tillage treatments on number of spike-lets per spike, spike length and number of grains per spike

Tillage treatments	Number of spikelet spike^{-1}		Spike length, cm		Number of grain spike^{-1}	
	2011	2012	2011	2012	2011	2012
	n=9	n=9	n=9	n=9	n=9	n=9
Conventional tillage	15,9	16,8	10,8	11,4	46,4	48,2
Raised-bed tillage	17,8	18,4	12,1	13,0	48,3	50,0

The comparison between two study years reveals that the number of spikelet spike^{-1} during 2012 tended to be greater than 2011.

The spike length of wheat plants sown under different tillage treatments was measured for two study years and the results are presented in Table 3. The data reveal that the spike length was significantly affected by tillage treatments. The maximum spike length (12.1 and 13.0 cm) was measured under raised-bed tillage, whereas the spike length declined under conventional tillage (10.8 and 11.4 cm) during 2011 and 2012, respectively. The comparison between study years showed that the spike length during 2009 tended to be greater than 2008.

Number of grains per spike

The results showed that the number of grains spike^{-1} was markedly influenced by tillage treatments during the both study years (Table 3). Maximum number of grains spike^{-1} (48.3 and 50,0) was noted under raised-bed tillage, while this number declined under conventional tillage (46.4 and 48.2). The comparison between two study years shows that the number of grains spike^{-1} during 2012 was greater than 2011.

Conclusions

A two years field study conducted to investigate the effect of conventional soil tillage and raised-bed cultivation method on growth of winter wheat varieties showed that compared to conventional tillage, raised-bed cultivation method caused substantial improvement in almost all the growth, yield and yield component traits of winter wheat varieties in both the years, particularly it improved seedling emergence percentage, plant height, root system, number of main-stem leaves per plant, number of productive tillers per plant, number of spike-lets per spike, spike length, number of grains per spike and grain and straw yields per hectare.

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Soil moisture suction in no-till and tilled soils: analyzing long-term tensiometer measurements in the Swiss Central Plateau

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Fertile soils are crucial for human well-being, yet the intensification of agriculture and use of heavy machines increasingly threatens their quality. Agricultural practices with heavy machines expose soils to a high risk of irreversible subsoil compaction. Research has shown that from a sustainable land management perspective, soils should not be trafficked with heavy machines when soil conditions are wet (soil moisture suction <6 cbar at a soil depth of 35 cm). However, there is a lack of knowledge about the frequencies of wet soil conditions in Swiss agricultural soils and about potential influences of soil management systems on soil moisture. This study aims at closing these research gaps by analyzing the long-term (1996–2019) dataset of the Canton Bern including 13 different locations on six sites in the Swiss Central Plateau. Soil moisture suction data measured with five tensiometers per location at a soil depth of 35 cm and precipitation sums per site for three measurement days (md) per week are used. On every site, at least one permanent grassland and one crop rotation location are present. Furthermore, two tillage systems (no-till and mouldboard plough) and 11 different crops occur in the dataset. After data correction and validation, 22’947 md with available soil moisture suction data are analyzed. To put the results into a larger context, spade tests are performed at every location, and a climate and weather characterization of the years 1996–2019 is undertaken. Periods with wet soil conditions (<6 cbar at 35 cm soil depth) during the vegetation period from April to October range from 41 to 48% of the md for different locations (average over all sites), while site-specific differences range from 31 to 76% on permanent grassland locations. The duration of wet soil conditions can exceed three months in extreme cases. Furthermore, a seasonal curve in soil moisture suction is found and influences of the longer-term (≥3 months) weather conditions, as well as of single precipitation events on soil moisture suction fluxes are apparent. Differences in soil moisture suction fluxes are big between different sites and years: comparing a specific md over different sites and years shows that soil moisture suction values can cover the whole measurable range between 0 and 80 cbar. While the seasonal curve and the annual fluctuations likely originate from climate and weather influences, the differences between the sites cannot be attributed to a specific influence factor. Differences between permanent grassland and crop rotation locations can mostly be attributed to different crops’ seasonal evapotranspiration rates. Other systematic differences which hold for all sites and years cannot be identified. Differences between no-till and mouldboard plough are present, but non-systematic based on the analysis on one site. The spade tests show that tillage systems impact physical soil properties. In conclusion, the results point to a highly complex human-climate-soil-system. This study lays a valuable basis for future research, among others, by providing concrete recommendations for future study designs. Further research about soil moisture suction is needed to promote sustainable land management in Switzerland.

Keywords: *Soil Moisture, Tensiometer, Soil Compaction, Tillage Systems, Sustainable Land Management*

INTRODUCTION

Soil moisture data is of great interest in various fields of research. In agronomy, it influences plant growth and is also crucial for predicting soil trafficability and workability (Bell, K. R.; Hamza, M. A.; Batey, T.; Dobriyal, P.; Obour, P. B.). To prevent subsoil compaction, heavy machines should not be used if the so-called “wheel load carrying capacity” (WLCC) of the soil is exceeded by the real wheel load of a machine. As the WLCC decreases with the increase of water-filled pores in the soil, soil moisture is directly linked to the risk of subsoil compaction (Soane, B. D.; Kondo, M.; Batey, T.; Stettler, .; Gut, S.).

Various measurement technologies are available for soil moisture. Using tensiometers has a long tradition (Richards, L. A.; Or, D.) and multiple advantages (cf. Lekshmi, S. U.), while the measuring range is restricted by the saturation vapor pressure (limits are 0 to about -80 kPa). Tensiometers measure soil moisture suction (SMS) which characterizes the binding of soil moisture to the soil matric (Schmugge, T. J.; Seneviratne, S. I.) and is defined as the absolute value of the soil matric potential. It is impacted by soil properties, vegetation, land management, topography and weather conditions (Quiroga, A. R.; Chervet, A.; Mittelbach, H.; Zhu, Q.; Gut, S.; Prasuhn, V.; Durner, W.; Dong, J.), hence it shows a hardly predictable spatio-temporal variability (Dobriyal, P.; Mittelbach, H.; Zhu, Q.; Hu, W.; Vereecken, H.). Long-term measurements allow to address this challenge (Bell, K. R.; Mittelbach, H.).

From 1996-2019, the Soil Conservation Office of the Canton Bern (SCOB) collected SMS data measured with tensiometers on agricultural fields, resulting in a unique dataset. By analyzing it, this study aims to compare SMS in Swiss agricultural soils (a) under different farming practices (permanent grassland (PG) vs. crop rotation (CR)), (b) under different tillage systems (no-till (NT) vs. mouldboard plough (MP)) and (c) under different crops. It provides insights into the frequency and seasonality of wet soil conditions (and the associated risk of irreversible subsoil compaction) in dependence on soil management.

Materials and Methods

The six sites Grasswil, Langnau, Oberacker, Rubigen, Schlosswil and Treiten are all situated in the Swiss Central Plateau. This region is in a transition zone between humid oceanic climate and continental temperate climate. Table 1 The six sites’ locations, general properties and years with available data (T = temperature) (own analyses and SCOB; Chervet, A.; Cantons Solothurn Aargau, and Basel-Landschaft; FOMC).1 provides an overview of sites’ properties and years with available SMS data. At least one PG and one CR location are present per site. The tillage system NT was applied only in Rubigen and Oberacker, while MP was applied on all sites except Rubigen. Oberacker is the only site with two CR locations. Mean annual precipitation is highest in Langnau (1438 mm) and lowest in Treiten (1023 mm) (SCOB).

Table 1 The six sites' locations, general properties and years with available data (T = temperature) (own analyses and SCOB; Chervet, A.; Cantons Solothurn Aargau, and Basel-Landschaft; FOMC).

Site	Locations	Soil Type	Water Influence	Slope, Exposition	Altitude [m a.s.l.]	1981–2010 March to Oct T [°C]	Years with Data
Grasswil	PG, CR-MP	Cambisol	slope water	PG: 3% E CR: 6% E	522	12.6	1997–2017
Langnau	PG, CR-MP	Cambisol	ground-water	PG: 0%, flat CR: 0%, flat	654	11.5	1996–2017
Ober-acker	PG, CR-MP, CR-NT	Cambisol	none	PG and CR: mostly 0% and flat	555	12.6	1996–2019
Rubigen	PG, CR-NT	Cambisol	none	PG: 4% SW CR: 6% SW	554	12.6	1996–2017
Schloss-wil	PG, CR-MP	Cambisol	slope water	PG: 4% NW CR: 4% SW	742	11.5	1996–2016
Treiten	PG, CR-MP	Fluvisol	ground-water	PG: 0%, flat CR: 0%, flat	434	13.8	1996–2006 2011–2017

SMS was measured with 5 "standard tensiometers" (Eijkelkamp Soil and Water) per location at a soil depth of 35 cm. Measurements were performed trice a week (Mon, Wed, Fri); in the same temporal resolution, precipitation sums per site were assessed using a Hellman rain gauge. Documentation about farming practices, agricultural activities (ploughing, seeding, harvesting, mowing, mulching and cattle pasture), tillage systems and crops is available. All locations were managed according to standards for proof of ecological performance (FOAG). In Oberacker, collaborators of the SCOB collected the data; on all other sites, farmers were responsible therefor. In Oberacker, the tensiometers were moved on the CR so that they were always placed where winter wheat was cultivated. This made it possible to measure SMS over multiple years for the same crop (on all other sites, this is not the case). In total, 11 different crops are present in the dataset (unequally distributed in the dataset).

The dataset was reduced to the vegetation period from 1st April to 31st October to focus on crops' growing seasons and on periods of agricultural activities. Tensiometer measurements were qualitatively validated with intersubjective validation; implausible values were deleted.

To provide a framework for the correct interpretation of SMS data, site- and soil-specific properties, as well as climate and weather conditions were assessed. A spade test (spade length: 45 cm) was taken per location (Hasinger, G.). Climate and weather conditions were characterized using the homogenized precipitation and temperature data series at the meteo station "Bern/Zollikofen" (FOMC).

Only the median SMS per measurement day (md) was considered. This "median" can consist of either 1, 2, 3, 4, or 5 single tensiometer measurements, whereas the occurrence of medians based on only one or two measurement(s) is rare (0.1% and 1.2% of all md). These medians are referred to as "SMS values" and were divided into four categories (FOEN):

- <6 cbar: wet soil conditions; high risk of irreversible subsoil compaction (Wyler, R.)
- 6–10 cbar: very moist soil conditions; malleable soil

- 11–25 cbar: moist soil conditions; brittle soil
- >25 cbar: dry soil conditions; firm soil; low risk of irreversible subsoil compaction

In total, the dataset consists of 24’310 md, of which 1’363 (or 5.6%) are data gaps. Thus, there is a total of 22’947 md with an available SMS value. A frequently used data subset for analysis consists only of the years 2001–2006 and 2011–2016, in which data is available on all sites (“common years”). The common years have 12’475 md with an available SMS value.

3. results

Site- and soil-specific properties

The spade tests (cf. Fig. 1 Spade tests for CR-NT (left), CR-MP (center) and PG (right) in Oberacker.1 for Oberacker) reveal big differences between the sites and the locations on one site. In Oberacker, the soil under MP shows iron concretions (ca. 30-45 cm soil depth). Very few iron concretions are visible at this depth in the soil under NT, and none in the PG. Soil color and other physical soil properties differ between the three locations, too.

Fig. 1 Spade tests for CR-NT (left), CR-MP (center) and PG (right) in Oberacker.

Climate and weather characterization

Fig. 2 March to October precipitation and temperature anomalies relative to the norm 1981-2010 for the meteo station “Bern/Zollikofen” of the FOMC. Norm values: 12.6 °C and 793.8 mm.2 shows the precipitation and temperature anomalies for March to October for all analyzed 24 years compared to the norm 1981-2010. Comparing the two halves in common years (2001-2006 vs. 2011-2016) reveals that a precipitation surplus of +308.8 mm was reached in the first half, while precipitation was deficient with -556.1 mm in the second half as compared to the long-term average 1981-2010.

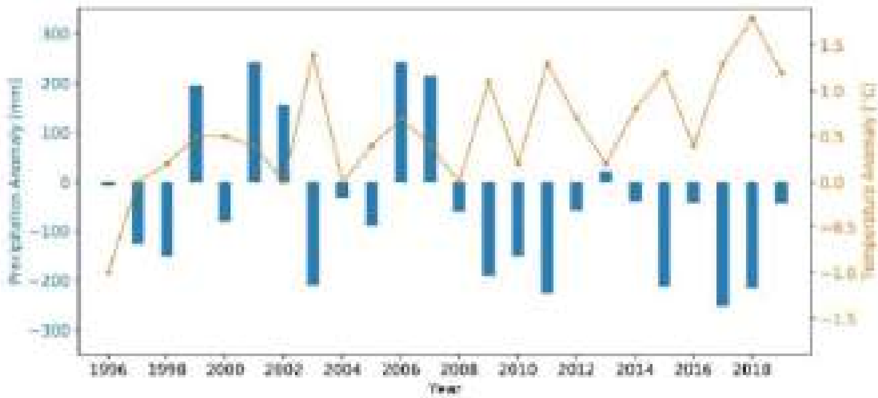

Fig. 2 March to October precipitation and temperature anomalies relative to the norm 1981-2010 for the meteo station “Bern/Zollikofen” of the FOMC. Norm values: 12.6 °C and 793.8 mm.

Wet soil conditions

Wet soil conditions occur on 41% to 48% of the md for different locations (average over all sites), while site-specific differences range from 31% to 76% on PG locations and from 34% to 69% on CR locations with Schlosswil being the wettest and Oberacker the driest site (see Table 2 Relative frequencies of soil moisture suction values in the defined categories for different data subsets (n: number of measurement days with an available soil moisture suction value) in common years.2). Wet soil conditions are less frequent (45% compared to 49%) in the first than in the second half of common years (average over all sites on PG locations).

Table 2 Relative frequencies of soil moisture suction values in the defined categories for different data subsets (n: number of measurement days with an available soil moisture suction value) in common years.

Data Subset	Sites	n	Wet (<6 cbar)	Very Moist (6-10 cbar)	Moist (11-25 cbar)	Dry (>25 cbar)
PG	Grasswil	1’035	41%	23%	15%	21%
	Langnau	1’052	55%	17%	16%	12%
	Oberacker	1’087	31%	18%	11%	40%
	Rubigen	1’077	39%	21%	17%	24%
	Schlosswil	983	76%	9%	9%	6%
	Treiten	1’061	43%	11%	11%	35%
	All Sites	6’295	47%	17%	13%	23%
CR-MP	Grasswil	1’001	43%	13%	12%	33%
	Langnau	1’007	54%	20%	16%	10%
	Oberacker	1’082	35%	14%	14%	37%
	Schlosswil	948	69%	10%	9%	13%
	Treiten	989	42%	9%	11%	38%
	All Sites	5’027	48%	13%	12%	27%
CR-NT	Oberacker	1’084	34%	18%	14%	35%
	Rubigen	1’069	48%	17%	15%	21%
	All Sites	2’153	41%	17%	14%	28%

The maximum duration of wet soil conditions is 44 md (= ca. 102 days) (PG location in Grasswil 2007). In common years on PG locations, the average duration of periods with wet soil conditions is 5.4 md (= between 12 and 13 days). Relative frequencies of SMS values in the category "wet" (for PG locations in common years) show a seasonal curve: Soils are wet more often in April, May and October than in June, July, and August.

Influence of farming practices

The SMS fluxes and precipitation sums presented in Fig. 3 Average precipitation sums and SMS fluxes 2013. Line: PG, dashed line: CR-MP, dotted line: CR-NT.3, as well as similar plots for other years, suggest that differences between farming practices on one site are mostly smaller than between different sites.

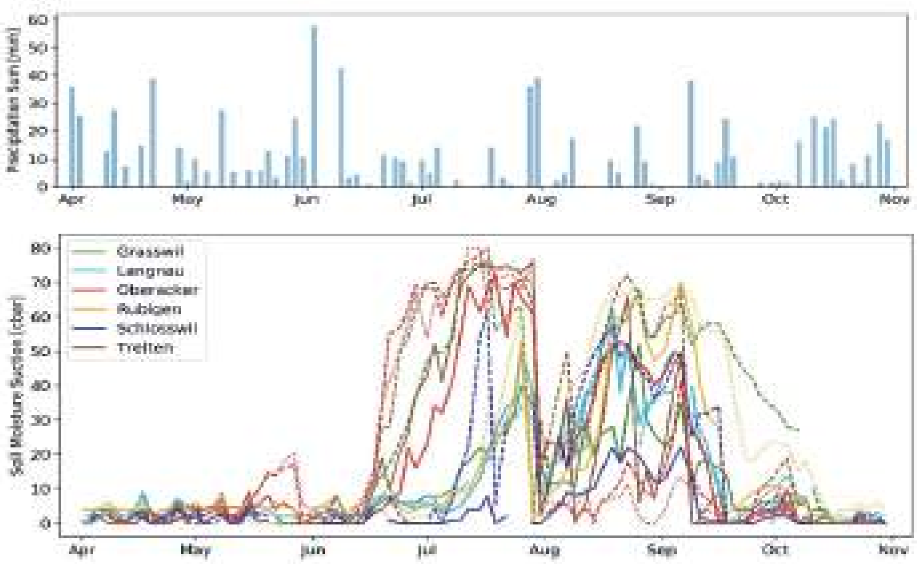

Fig. 3 Average precipitation sums and SMS fluxes 2013. Line: PG, dashed line: CR-MP, dotted line: CR-NT.

There is a difference in SMS fluxes between PG and CR in Oberacker (cf. Fig. 4 Average SMS fluxes and precipitation sums for Oberacker in common years (WW= winter wheat).4): the PG location is wetter from June to mid-July, while it is drier from August to November. Yearly SMS fluxes show that absolute differences between the farming practices mostly lie between 0 and ca. 30 cbar; in extreme cases, differences of up to 70 cbar are possible.

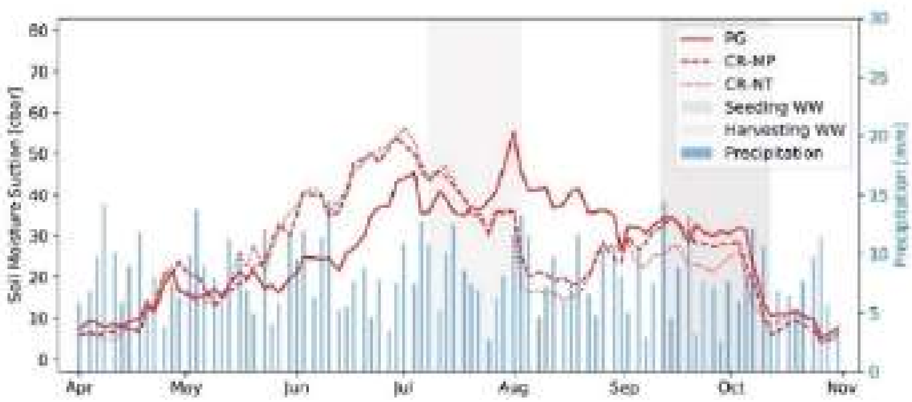

Fig. 4 Average SMS fluxes and precipitation sums for Oberacker in common years (WW= winter wheat).

Influence of tillage systems

The only possibility for a comparison of MP and NT on the same site is Oberacker. Fig. 4 Average SMS fluxes and precipitation sums for Oberacker in common years (WW= winter wheat).4 shows that the average absolute difference between MP and NT is smaller than between PG and CR. From April to July, almost no difference between MP and NT is visible, while small (<10 cbar) absolute differences become apparent in August and September. Meanwhile, Fig. 3 Average precipitation sums and SMS fluxes 2013. Line: PG, dashed line: CR-MP, dotted line: CR-NT.3 reveals that absolute differences in SMS between MP and NT can be >10 cbar for single years. They occur in both directions, meaning that MP is sometimes wetter and sometimes drier than NT. However, a systematic pattern is lacking.

Influence of crops

Due to the big differences in SMS fluxes between sites and years, comparing different crops on the same site and in the same year would be advantageous. However, the dataset does not allow therefor. Comparing SMS of a specific crop (on different sites and in different years) with SMS of the PG on the same site in the same year reveals systematic patterns, like, e.g., a change in the direction of differences around mid-June or in the beginning of July for 4/5 examples of sugar beets in common years (higher SMS of sugar beets before the changing point, but lower SMS of sugar beets after the changing point compared to PG).

DISCUSSION

Wet and dry soil conditions

SMS values in the category "wet" (<6 cbar at a soil depth of 35 cm) occur on 31%-76% of the md on PG locations and on 34%-69% of the md on CR locations in common years. They are also frequent in years with precipitation sums below the average of 1981-2010. This could be challenging in agricultural production. However, SMS is not the only factor determining the WLCC of soils. Further physical soil properties (e.g., bulk density or further physical soil structure attributes) are also expected to be crucial (HAFL; Marbot, B.; Stettler, M.).

SMS at 35 cm soil depth follows a seasonal curve – a result which is in line with other studies (e.g. Wu, W.; Wyler, R.; Gut, S.; Lee, E.). The analysis of yearly SMS fluxes shows a direct impact of precipitation sums ≥30 mm on SMS, as well as of longer-term (≥ 3 months) weather conditions. Comparing a specific md over different sites and years shows that SMS values can cover the whole measurable range between 0 and 80 cbar. The big annual differences in SMS are in line with results from similar research (Wyler, R.; Gut, S.; Prasuhn, V.).

The differences between sites could be caused by local climatic and weather influences. However, based on the temperature and precipitation data per site (cf. chapter 2), one would expect Treiten to be the site with lowest frequencies of wet soil conditions, while the opposite would be true for Langnau – neither of these expectations were confirmed. A possible reason could be the influence of slope water on the PG location in Schlosswil leading to more frequent wet soil conditions than in Langnau. Topography and microrelief also influence soil moisture (Seibert, J.; Lee, E.), and the analysis of annual SMS fluxes in Treiten hints at such influence of microrelief: SMS rises very fast in dry periods in Treiten compared to the other sites, while at the same time, it stays at 0 cbar longer in rainy periods. A small soil volume with plant available water above a layer with low permeability could explain these properties and why Treiten is not the site with the lowest frequency of wet soil conditions, as suggested by precipitation and temperature data. Differing physical soil properties can be another reason for differences in SMS fluxes between the sites (e.g., English, N. B.; Chervet, A.; Dong, J.; Martínez-Fernández, J.).

Influence of farming practices

Relative frequencies of wet and dry soil conditions in common years do not reveal a farming-practice-specific pattern valid for all sites. SMS fluxes in Oberacker (cf. Fig. 4 Average SMS fluxes and precipitation sums for Oberacker in common years (WW= winter wheat).) reveal seasonal differences between CR and PG, while similar plots for other sites show distinct patterns. In Oberacker, the seasonal pattern of differences in SMS fluxes can be explained by higher ET rates of winter wheat compared to PG from May to mid-July (Gut, S.). The point at which the CR locations in Oberacker are no longer drier than the PG location coincides with the harvesting dates of winter wheat. A similar pattern can also be seen in annual SMS fluxes in Oberacker and on other sites: in 12/14 years in common years with cereals on the CR location, a systematic difference between PG and CR can be identified.

In general, if SMS fluxes are analyzed for every year and site separately, most of them can be explained considering various interacting factors: precipitation distribution, applied farming practices and tillage systems, cultivated crops and/or site-specific characteristics.

Influence of tillage systems

The relative frequency of wet soil conditions in Oberacker is almost equal (difference of 1%) on the NT and on the MP soil. Also, the average SMS fluxes in Oberacker show almost no difference between the tillage systems from April to July. SMS is slightly (around 5 cbar) lower on the NT than on the MP soil, only after harvesting winter wheat. This could be explained by higher evaporation on the MP soil through the partly uncovered soil after ploughing. However, this pattern is not visible in annual SMS fluxes. Generally, tensiometers were removed from the fields during the harvest of winter wheat and reinserted thereafter, whereby wet soil was applied around the measurement instrument to ensure a good contact to the soil. This process could explain the non-existence of systematic patterns, as the applied wet soil was not standardized for all locations.

Yearly SMS fluxes show partly big differences (up to ca. 60 cbar in extreme cases) between the tillage systems. However, no systematic pattern can be found over all the years. In general, differences in SMS between the tillage systems often lie between 0 and 5 cbar.

The spade tests show a clear difference between NT and MP. Rooting density is higher in NT than in MP. This is likely caused by soil compaction due to ploughing in MP. Iron concretions are present in MP from a soil depth of ca. 30-45 cm, which points to more frequent anoxic conditions, although wet soil conditions were found to be almost equally frequent under both tillage systems. Perhaps, the selected category for "wet soil conditions" (<6 cbar) is not sufficiently detailed: 0 cbar points to anoxic conditions, while 1-5 cbar do not necessarily indicate anoxic conditions. Thus, while NT and MP might both be categorized as "wet", anoxic conditions could only occur on the MP soil. As this study proves that physical soil properties differ between the tillage systems, the WLCC of the two compared soils is expected to be different, too (cf. chapter 4.1.).

Influence of crops

SMS is influenced by ET (Eagleson, P. S.). ET rates are crop-specific and change during the different stages of seasonal plant growth (e.g., Allan, R. G.; Prasuhn, V.), hence, crop-specific differences in SMS could be expected. From an agronomic perspective, it makes sense that sugar beets have lower ET rates than the PG until ca. mid-June, but then gradually increase their ET until September (Prasuhn, V.). For other crops, systematic patterns are visible, too, but some uncertainties in interpretation remain. Three main problems complicate the interpretation of annual SMS fluxes: (a) it is unclear if animals grazed directly around the tensiometers or only further away, (b) it is unclear if mowing was performed directly around the tensiometers or only further away and (c) it is unclear during which agricultural activities tensiometers were removed.

Limitations

There are limitations to this study's findings. First, only SMS at a soil depth of 35 cm was analyzed. Second, the six analyzed sites in the Swiss Central Plateau are not sufficient to fully represent agricultural soils in Switzerland. Third, all analyzed locations were managed according to standards for proof of ecological performance (cf. FOAG). Results might differ for locations managed according to different agronomic standards such as organic production. Finally, the analyses only include the vegetation period from April to October.

Conclusions and outlook

The analysis of the long-term dataset of the SCOB reveals that md with SMS values <6 cbar at 35 cm soil depth are frequent. However, the WLCC of soils is not only dependent on SMS. Thus, this study's results do not suffice for an assessment of the WLCC of soils. A seasonal curve in SMS values is visible, which can be attributed to monthly norm precipitations and temperatures. In general, differences in seasonal SMS are big between different sites and years: comparing a specific md over different sites and years shows that SMS values can cover the whole measurable range between 0 and 80 cbar. Differences between farming practices are small and can mostly be attributed to different crops' ET rates. While seasonal SMS fluxes and physical soil properties differ between the two tillage systems in Oberacker, no reliable systematic pattern could be found. It is possible that additional data on the removal and reinsertion of the tensiometers might reveal further insights. Comparing crops' seasonal soil moisture fluxes to the PG location at the same site in the same year shows crop-specific patterns, but some uncertainties in interpretation remain.

The results based on the analysis of the dataset of the SCOB allow to give general recommendations for future studies: long term-research should be fostered, temperature and precipitation data should be collected at every site, crops' SMS should be compared in the same year on the same site and details about tensiometers' maintenance should be provided. Three especially interesting approaches for future research going beyond the performed analyses can be highlighted: Model water balances in agricultural soils along the profile, model crop water use, improve calculation of the WLCC.

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Mid and long term effects of Conservation Agriculture on soil organic matter, physical properties and biological activity in rainfed Mediterranean Soils

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In Morocco, a recent study of the soil fertility status at national level, based on the analysis of more than 36,000 samples, showed that the majority of these soils, under conventional agriculture, have low levels of organic matter (less than 2%). To reverse this degradation of organic matter, the use of Conservation Agriculture is a promising alternative. In this article, we will present the results of two sites under No Tillage (NT) on the mid and long term (16 and 32 years) in two clay soils (Vertisol) under different agroclimatic conditions (Sub humid and semi-arid) representing the rainfall cereal-based system. These result shows an increase in MO of up to 44% in the site in the long term up to 14% in the second site mainly in soil surface (0-20 cm). The analysis of the soil structural stability showed a significantly more stable aggregation under NT in the mid and long term compared to conventional tillage. The study highlighted that the soil compaction measured by the bulk density, which was higher at the start of the NT trial, was significantly reduced after 14 years under SD. This is explained by the soil biological activity which was quantified using enzymatic indicators and this activity was significantly higher under NT trial compared to conventional tillage.

***Keywords**: Mid and long term, No tillage, soil organic matter, aggregate stability, biological activity*

Introduction

The sustainability of agricultural lands in the Mediterranean region appears to be threatened due to inappropriate soil management techniques. In the case of Morocco, several studies reported that intensive tillage strongly contributed to the depletion of the soil organic matter (SOM), causing fragility and therefore instability of these soils, which results in low resistance to climatic hazards (Gomiero 2018; Lal 2015). As a result, the improvement of the soil aggregation could help in the restoration of their fertility and their protection against soil erosion and degradation.

The SOM, which derived from fresh and old decomposed plant or animal residues and roots (Mehra and al. 2018), is a principal indicator of soil quality (Zhao and al., 2015). It has beneficial effects on soil physical (soil structural stabilization), chemical (fertility), and biological properties (substrate and supply of nutrients for microbes), and therefore, it influences the productive capacity of the soil (Wang and al., 2017). The improvement of SOM is thus, the most essential criteria for sustainable soil management practices (Nyirenda 2020; Campbell and Paustian, 2015). Nath et al. (2018), reported that The "4 per Thousand" proposed during the 21st Conference of Parties (COP_{21}) in Paris is intended to highlight that even small increases in SOC can play a crucial role in improving soil fertility, productivity and achieving the long-term objective of limiting global warming to 1.5 °C.

Several studies have adopted approaches that enhance soil quality and ensure the sustainability of agricultural production while protecting this natural resource (Lal, 2004; Nyirenda 2020). Conservation Agriculture including no tillage (NT), is an approach which constitutes a reliable, efficient and sustainable solution (Mrabet and al. 2011; Moussadek and al. 2011; Sheehy and al. 2015). NT's usefulness has prompted researchers at the National Institute for Agricultural Research (INRA) and at the International Center for Agricultural Research in the Dry Areas (ICARDA) to adopt NT widely in this country. This began in the Jemaat Shaim region of Morocco in 1983 and then at the Sidi El Aidi Chaouia, and finally NT was implemented in Merchouch in Zaer-Rabat since 2004 (Mrabet 2008; Moussadek and al. 2011, Laghrour et al. 2016).

This work aims to present the last findings concerning the effects of the NT system on the physical, chemical, and biological properties of Moroccan soils versus the conventional tillage (CT) under a Mediterranean climate. It was conducted on two sites with the same soil type (Vertisol) under med and long-term conditions.

Material and methods

II.1. Site of study

Two experimental sites were chosen. The first is located at the experimental station of Merchouch INRA in Zear (in Rabat region). While, the 2nd experimental site is located at the village of Jamaa Shaim (in Safi region). The precipitations of Merchouch and Jemaat Shaim sites are respectively 450 mm and 300 mm. The figure 1, shows that the Jemaat Shaim site is characterized by a higher annual temperature and less rainfall than those recorded in the Merchouch site. The climate in the first site is subhumid to semiarid, while the climate in the second site is classified as semiarid to arid.

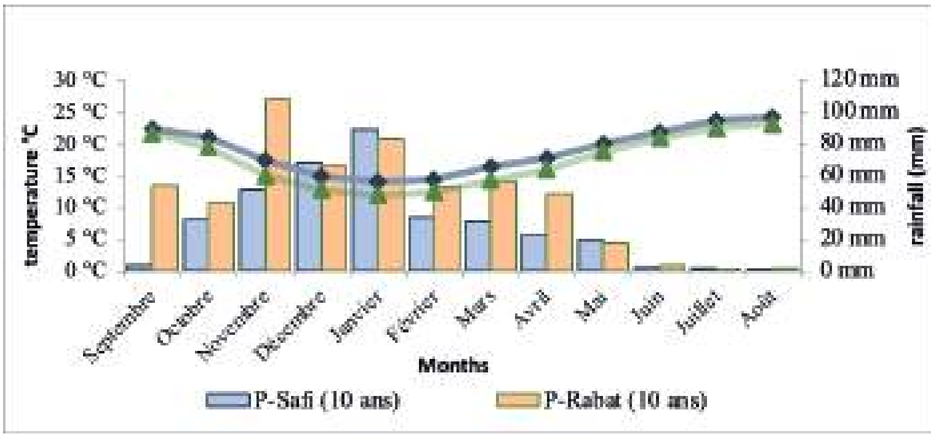

Fig 1: Monthly average of rainfall and temperature (10 years) at Merchouch and Safi Stations in Morocco.
P: Precipitations; T: Temperature. Source: INRA of Rabat.

II.2. Methodology

The experiments system were differentiated with two tillage methods: NT and CT, where the first consists on plowing up to 30 cm deep then proceeding to a shallow tillage (10–15 cm) in order to prepare seedbeds and to bury crop residues. However, the NT method is a single operation which holds an opening of 5 cm from the ground with a special NT drill allowing to place the seed. Both sites are based on cereal system with wheat/food legumes rotation. The NT and CT plots received the same fertilization based on a complex fertilizer (14% N, 28% P_2O_5, 14% K_2O).

The samples were collected for this study, based on repetition according to the measure of parameter.

II.3. Methods

The main parameters of the soil were measured according to the following procedures: The soil organic matter content (in g. Kg-1) was estimated using the method proposed by Walkley and Black (1934) by multiplying the rate of the carbon content by 1.724. The Bluk density (in g/cm^3) was determined according to the method of Grossman and Reinsch (2002). For Structural stability, it was evaluated by a method proposed by Le Bissonnais (1996), which combines three tests describing the behavior of the soil under different climate and water conditions that we can meet at the soil surface. (i) Treatment of fast wetting by immersion; (ii) treatment wetting slow capillary; (iii) treatment of mechanical disaggregation agitation after rewetting.

In addition, little is known about the impact of agricultural practices on soil microbial communities in semi-arid agrosystems, and their role in soil biological functioning. The recent development of culture-independent molecular tools based on soil DNA extraction and characterization and of in silico meta-analysis have enabled the systematic analysis of soil microbiota leading to a better understanding of the ecological impact of land use management (Maron et al.2011).

Results and Discussion

III.1. Soil organic matter under soil tillage practices

Table 1: Tillage effect on SOM content (Mean ± standard deviation) (Laghrour et al. 2016).

Field	Soil depth (cm)	Organic matter content ($g.Kg^{-1}$) NT	CT	CT to NT % SOM change
Site I	0-10	22.23 ± 0.20a*	17.13 ± 0.25b*	30
	10-20	19.11 ± 0.03a	17.38 ± 0.12a	10
	20-40	17.23 ± 0.10a	16.43 ± 0.05a	5
	40-60	15.80 ± 0.04a	15.36 ± 0.03a	3
Site II	0-10	16.44 ± 0.22a	10.97 ± 0.17b	50
	10-20	12.68 ± 0.06a	9.42 ± 0.10b	35
	20-30	12.48 ± 0.09a	9.58 ± 0.10b	30
	30-40	13.22 ± 0.17a	9.80 ± 0.10b	35
	40-60	11.18 ± 0.06a	9.440 ± 0.17a	19

*In the same row, the values followed by different letters are significantly different within each study site

In the mid-term, the statistical analysis shows a significant difference only in 0-10 cm between tillage systems (Pv = 0.01 <0.05) and no significant effect in the soil profile (from 10 to 60 cm of depht) under NT. While, the results obtained in long-term experiment; shows significant effect up to 40 cm deep. These is can be explained by the accumulation of organic carbon at soil surface and its long-term distribution in the deeper layers. Similar results are obtained by Dimassi and al. 2014.

III.2. Bulk density under NT and CT tillage practices

Table 2: Tillage treatments effect on bulk density (BD) (Mean ± standard deviation) (Laghrour et al. 2016).

Field	Soil depth (cm)	BD ($g\ cm^{-3}$) NT	CT
Site I	0-10	1.29 ± 0.04a	1.15 ± 0.14a
Site II	0-10	1.41 ± 0.07a	1.37 ± 0.22a
	10-20	1.45 ± 0.05a	1.35 ± 0.14a

Despite that the Bulk density is higher under NT system than CT system, but, no significant differences between the two tillage systems at soil surface 0-10 cm found. DeMoraes et al. (2016) compared the BD of Oxisols under NT to that obtained under CT after 11 (NT_{11}) and 24 years (NT_{24}). These authors found a significant difference in comparing the NT system to that of CT and didn't find a significant effect between NT_{11} and NT_{24}, but the BD was low compared with the NT_{24} and NT_{11} (BD NT_{11} > BD NT_{24} > BD CT).

III.3. Structural stability under soil tillage practices

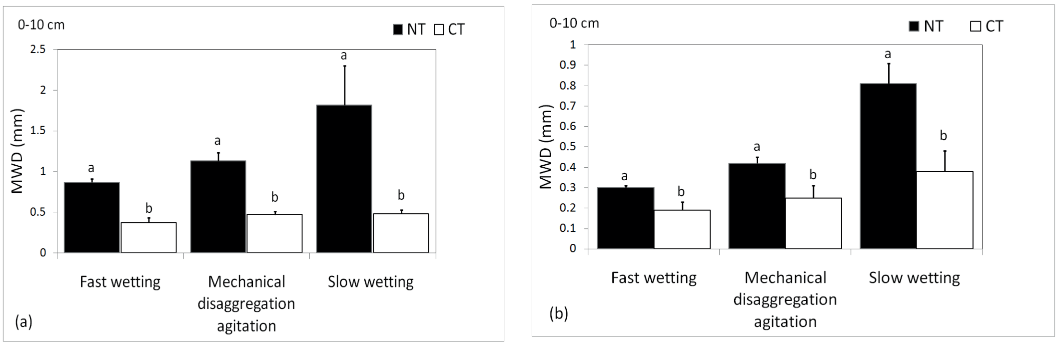

Fig. 2: Effect of tillage treatments on structural stability at soil surface for both sits located in Morocco.

(a): Mean weight diameter (MWD) for each test of structural stability for the 1st site at 0-10 cm of depth; (b): Mean weight diameter for 2nd site at 0-10 cm of depth. Bars represent standard deviation, the difference letters above the column show significant difference between no tillage (NT) and Conventional tillage (CT) practices.

III.3. Biological activities under soil tillage practices

From figure below, NT have a high microbial biomass compared to CT. This is in line with the findings of (Frey et al. 1999 and Spedding et al. 2004). Those researchers concluded that tillage affects soil temperature and humidity which in turn strongly influence soil microbial biomass, and could explain the lowest microbial biomass observed in CT system.

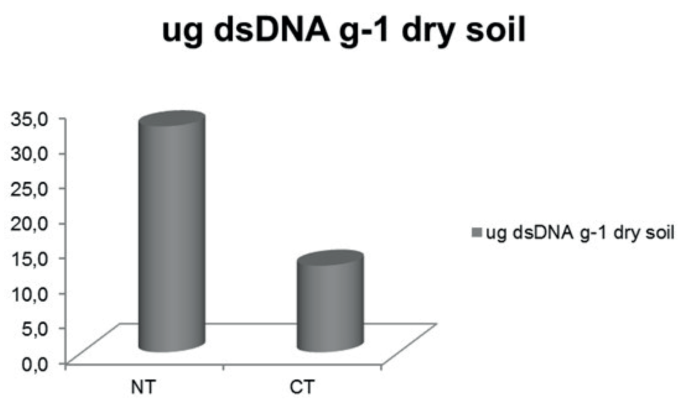

Fig. 3. Top soil (0–10 cm layer) representation of a molecular biomass (in micrograms of DNA per gram of soil) under No tillage (NT) vs Conventional Tillage (CT) in Merchouch site (soil under NT since 2004)

Conclusion

A significant effect was observed for the tree tests and for both experiments (after 11 and 32 years). These results show that CT is more susceptible to degradation by erosion, and runoff, but under NT soil have stable aggregates as shown in the test of structural stability and this difference can be explained by the duration of this new agricultural practice.

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LivinGro-A holistic approach to improving biodiversity and conservation in agricultural landscapes

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While above-ground biodiversity has been a topic of significant public interest over the last decades, soil biodiversity did not generate wide attention beyond the scientific and agronomic world. Syngenta's initiative called LIVINGRO™ takes a holistic approach to improving all dimensions of biodiversity related to agricultural activities in a given ecosystem.

Three-year pilots took off in Spain and Chile in 2020 and will start in Argentina, Mexico, and Germany this year. The aim is to generate robust, comprehensive scientific data that reliably measures how agricultural technologies and best farm management practices applied on crops grown in proximity to multifunctional areas consisting of indigenous annual flowering plants, can boost both sustainable food production and healthy, diverse ecosystems above and below ground, in and beyond the field. Together with scientists from public and private research organizations, Syngenta set off on a journey to study all insect orders from the surface and below ground. In addition, we also examine the soil microbiome and structure, as well as its ability to make nutrients bio-available for plants and to sequester carbon.

By taking a holistic view of biodiversity, including the soil microbiome, LIVINGRO™ has the potential to provide scalable measures for regenerative agriculture systems and improved food production sustainability in biodiverse, thriving, and healthy ecosystems, protecting our most precious agricultural resources, soil and water.

Keywords: *Biodiversity, conservation, regenerative agriculture, soil health, crop benefits*

Since World War II, governments have been supporting farmers to increase their productivity. Despite rising costs of production, agricultural output has been increasing continuously since, with an associated cost to biodiversity. Rapid intensification and industrialization of agriculture is often cited as a contributing factor in insect declines (Stoate et al., 2001; Robinson & Sutherland, 2002; Smith et al., 2008; Wesche et al., 2012; Nowakowski & Pywell, 2016).

Land-use changes in the 1950–1970's notably impacted modern intensive agricultural practices, resulting in a substitution of heterogeneous agricultural landscapes by homogeneous ones. Land consolidation led to the elimination of edges and other ecologically valuable structural elements that had provided floral resources and nesting sites (Kremen et al., 2002; Memmott et al., 2007; Goulson et al., 2008; Morrison et al., 2017; Sánchez et al., 2020). Habitat loss caused vital changes in the natural communities of birds, insects, and mammals. In addition, the intensification of farming and the reduction in crop diversity have also led to soil quality losses (Smith et al., 2008; Haddaway et al., 2016; Castle et al., 2019; Holden et al., 2019).

Within the class of beneficial insects, pollinators, mainly bees, have been severely affected and suffered the highest decline, reaching up to 50% (Richards 2001; Biesmeijer et al. 2006; Westphal et al. 2008; Ricketts et al. 2008; Potts et al. 2010; Montero-Castaño and Vilà 2012; McKechnie et al. 2017; Hallmann et al. 2017). Reviews carried out on bees demonstrate that six key factors explain the reduction of insect abundance and diversity: (1) habitat loss, fragmentation and degradation, (2) invasive species; (3) parasites and diseases; (4) non-sustainable use of pesticides; (5) extinction cascades; and (6) climate change (Mckechnie et al. 2017).

Over the last decades, several options were considered to reverse the situation. These include the creation of multifunctional margins, hedgerows, field margins, floral margins or flower and herb strips to increase the abundance of wild flowers (Marshall & Moonen, 2002; Smith et al., 2008; Haddaway et al., 2016; Nowakowski & Pywell, 2016). Subsequently, we refer to all these measures under the term Multifunctional Areas (MA). These are created with the sowing of seed mixtures containing autochthonous species that provide significant biodiversity benefits within farmed landscapes. MA are offering resources, reservoirs and habitats for biodiversity conservation and for an enhanced diversity and abundance of insects, birds, and small mammals (Smith et al. 2008; Tschumi et al. 2015; Haddaway et al. 2016; Holland et al. 2016; Castle et al. 2019; Kremen et al. 2019; Holden et al. 2019; Albrecht et al. 2020) (Fig 1).

Several preliminary studies showed that MA have a beneficial impact on insect conservation (Miranda-Barroso et al. 2021) because of the significant increase of

Fig. 1. Multifunctional Areas (MA). A. Stone fruits. B. Wheat.

natural enemies (Paoletti et al. 1997; Rodríguez-Gasol et al. 2019) and insect biodiversity (Nielsen et al. 2011; Sánchez et al. 2020).

However, while above-ground biodiversity has been a topic of significant interest over the last decades, soil biodiversity (arthropods and microbiota) did not generate wide attention beyond the scientific and agronomic world.

To fill this gap, Syngenta's initiative called LIVINGRO™ takes a holistic approach to improve all dimensions of biodiversity related to agricultural activities in a given ecosystem.

The aim of LIVINGRO™ is to generate robust and comprehensive scientific data that reliably measures how agricultural technologies and best farm management practices applied on crops grown in proximity to multifunctional areas consisting of indigenous annual flowering plants, can boost both sustainable food production and healthy, diverse ecosystems above and below ground, in and beyond the field.

A multidisciplinary team of biologists, agronomists, entomologists and microbiologists from Syngenta and various independent research organizations is conducting an in depth examination of the agrarian ecosystem and its multiple interactions with soil microbiota (involving fungi, bacteria, protozoa, etc.) and macrobiota (invertebrates). The team closely studies fundamental processes such as pollination, pest-predator relationships, the process of organic matter decomposition and the ability of the soil microcosmos to make nutrients bio-available for plants. In addition, LIVINGRO™ also examines the physico-chemical soil parameters such as erosion, infiltration, carbon sequestration or nitrification to assess and further promote soil health (Fig. 2). To establish a solid and comprehensive database and basis for the assessment of the effects from LIVINGRO™, the scientists working for this initiative are conducting more than 100 trials in multiple crops such as stone fruits, grapes, corn, wheat, or soybean in five countries (Argentina, Chile, Germany, Mexico, and Spain).

While there is no comprehensive scientific definition of regenerative agriculture (Elevitch et al. 2018) there is a common understanding that "the soil is the base" (Schreefel et al. 2020). The specific focus on soil health embedded in the LIVINGRO™ initiative has the potential to promote productive farming practices that are improving the long-term sustainability of agriculture, improving farmer livelihoods, protecting and enhancing soil fertility, as well as ecosystem resilience and biodiverse habitats.

By applying a holistic view to biodiversity, including the soil microbiome, LIVINGRO™ has the potential to provide scalable measures for regenerative agriculture

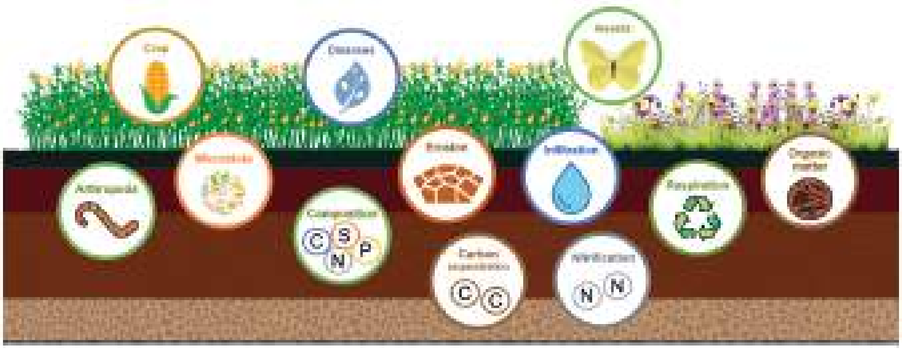

Fig. 2 Main parameters studied in LIVINGRO™.

systems and improved food production sustainability in biodiverse, thriving, and healthy ecosystems, protecting our most precious agricultural resources, soil and water.

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Minimum tillage and no-tillage effects on VSA indicators at different pedoclimatic zones in Europe and China

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Under the H2020 project iSQAPER, 29 sites with min-till and 12 with no-till practices were identified across 7 and 5 pedoclimatic zones, respectively. These fields/plots were paired with nearby control fields/plots, sharing similar farming features but cultivated using topsoil inversion tillage. All plots were georeferenced and in 2016 a visual soil assessment (VSA), with a convenient score system (poor, moderate and good), of various components of soil quality was conducted on the soils of all fields/plots, complemented by measurements of soil organic matter, labile organic carbon content, pH and texture. Climate variables and indices (mean annual temperature, precipitation and potential evapotranspiration, aridity index, net primary production potential, and Gorczyński Continentality Index) were estimated using the software New_LocClim_1.10 for all locations.

No-till fields/plots have a statistically significant higher proportion of good scores ($p<0.05$, chi-square test) with respect to soil structure and consistency, soil porosity, soil stability (slake test), and susceptibility to wind and water erosion when compared to control fields/plots; the strength of the effect, given by Crámer's V for these VSA indicators, being V=0.85, 0.51, 0.43 and 0.43 respectively. The min-till group shows no statistically significant differences in VSA indicator scores with control fields/plots. Measured soil properties show no statistical difference between both conservation tillage groups and respective control groups.
Due to an insufficient number of no-till sites further statistical analysis was performed only for the min-till and control groups. Spearman's rank-correlation coefficients between VSA indicator scores and climate variables, within each group (min-till and control), show important differences between the two groups with respect to soil structure and consistency, porosity and colour. Correlation coefficients between VSA indicators scores and soil properties also show important differences between the two groups, especially the correlations of the VSA indicators soil

structure and consistency, porosity, colour, susceptibility to erosion, and surface ponding, with one or more measured soil properties.

We used Spearman's rank-correlation to detect potential interactions between climate variables and soil properties, by calculating the correlations with VSA indicator scores within min-till and control groups. The potential interactions detected are distinct between min-till and Control. Despite the small sample (n=29 per group and missing data for some variables reduced n further (e.g. for soil organic matter n=13)), exploratory analysis using Linear Discriminant Analysis, show that an important error reduction in the scoring classification, in comparison to a random classification (prediction of the VSA indicators' scores), can be achieved for most VSA indicators with few variables and/or interactions (e.g. presence of tillage pan, n=18, we achieved an error reduction of 83.3%, using penetration resistance and mean annual temperature as explanatory variables).

We argue that min-till practices effects on VSA indicators scores, although not statistically different from those with conventional tillage, may have, at particular locations, a less negative impact on soil quality and soil conservation than conventional topsoil inversion practices; we also argue that a dataset with a higher number of records would allow the development of equations to accurately predict the effect of conservation tillage (no-till and min-till) and conventional tillage practices (topsoil inversion) on VSA indicator scores.

Keywords: *soil quality; soil management; climate effect; VSA*

INTRODUCTION

Depending on the tillage system, soils will be subject to different loads causing different soil stresses and deformations. Contrasting tillage systems, applied to soils with different physical, chemical and biological properties, under different temperature and moisture regimes, will have different effects on soil structure (e.g., Hadas, 1997).

It is central to the understanding of these effects induced by the tillage systems or by no-till the assessment of appropriate soil structure features and their relationship with measured soil properties, climate variables, and their interactions at different pedoclimatic zones. Common lab and field-measured soil morphological features are expensive and time-consuming, and often the simple observation of the magnitude of a feature may be sufficient to provide the information needed for a specific purpose. To study the effects of tillage on soil structure, visual soil assessment (VSA) methods may provide an expedited and cheap approach. To be effective in this role, the visual soil quality indicators (the soil morphological features) of these methods must be sensitive to the changes in the soil structure induced by the tillage systems.

In this study, we assessed the effect of minimum tillage and no-till on visual soil quality indicators of the New Zealand VSA method (Shepherd, 2000) and on aggregate stability (slake test, Tongway and Hindley, 1995) in different pedoclimatic zones of Europe and China, using data from a survey that took place in 2016. We further studied the effect of minimum tillage and respective topsoil inversion control on the relationship between the magnitude (score) of each visual soil quality indicator and measured soil properties and climate variables.

MATERIALS AND METHODS

This study was conceived to assess if the visual soil quality indicators of the New Zealand VSA method would be able to detect the differences between conservation tillage systems and conventional tillage systems with topsoil inversion. To assess possible explanatory variables, we measured the soil properties and estimated the climate variables with the software "Local Climate Estimator" (New Loc_Clim) (FAO, 2005).

The dataset used was recorded at a survey in the spring/summer of 2016, across Europe and China (Table 1). The survey recorded 12 no-till and 29 minimum tillage practices. At each location, a control, consisting of a similar soil sharing the same farming features but under conventional tillage was recorded.

Table 1. Case Study Sites (CSS) and climate.

No-till		Minimum tillage	
CSS	Climate	CSS	Climate
Portugal	Mediterranean temperate	The Netherlands	Atlantic
Spain	Mediterranean semi-arid	France	Atlantic
Greece	Mediterranean temperate	Portugal	Mediterranean temperate
Poland	Northern Sub-Continental	Spain	Mediterranean semi-arid
Estonia	Boreal to Sub-Boreal	Slovenia	Southern Sub-Continental
China (Gong-zhuling)	Middle Temperate Zone	Hungary	Southern Sub-Continental
		Romania	Northern Sub-Continental
		Estonia	Boreal to Sub-Boreal
		China (Suining)	Central Asia Tropical Zone

Visual soil assessment

The New Zealand VSA method (Shepherd, 2000) was adopted and comprised of 7 visual soil quality indicators: “soil structure and consistency”, “soil porosity”, “the presence of tillage pan”, “soil colour”, “earthworm count”, “surface ponding” and “susceptibility to wind and water erosion”. Additionally, the aggregate stability in water, given by the slake test (Tongway and Hindley, 1995), was recorded.

Soil properties

The soil properties measured were soil texture, soil organic matter (SOM), labile organic carbon (LOC), pH (in water), and penetration resistance (PR) (Table 2). The lab analyses were performed on soil samples from the top 0.2 m of the soil profile. Soil texture was measured following different methods at different CSS (“sieving and sedimentation” and “interaction with radiation”). Soil pH was measured with a soil to water ratio of 1:1. Penetration resistance was measured with Eijkelkamp penetrologgers. LOC content was measured with a diluted solution of 0.02 M of $KMnO_4$ (Weil et al., 2003, adapted by Alaoui and Schwilch, 2016). SOM was measured following different methods at different CSS (Walkley-Black and other wet oxidation methods and dry combustion methods).

Table 2. Soil properties range (number of measurements; minimum, maximum and median values).

	No-till (n=12) + Control (n=12)				Minimum tillage (n=29)+Control (n=29)			
	Records	Min.	Max.	Median	Records	Min.	Max.	Median
Sand (%)	22	6.7	56	33	44	9.2	91.7	50.6
Silt (%)	22	23.7	73	38	44	5.8	77.8	29.6
Clay (%)	22	4.76	52	19	44	0.0	43.7	16.1
pH	24	5.14	8.3	7.3	54	5.2	8.7	7.1
PR (MPa)	8	1.1	4.1	2.2	36	0.5	5.5	1.8
LOC (mg/g)	24	0.14	6.90	0.80	52	0.5	6.9	0.8
SOM (%)	22	0.77	7.20	2.45	26	0.6	4.3	2.5

PR: penetration resistance; LOC: labile organic carbon; SOM: soil organic matter.

Climate variables

The following climate variables and indices were estimated (New Loc_Clim, see FAO, 2005): i) mean annual temperature (°C); ii) mean annual precipitation (mm); iii) mean annual potential evapotranspiration (PET) (mm); iv) aridity index (dimensionless); v) net primary production potential (NPP), temperature and precipitation limited (g (DM) m^{-2} yr^{-1}); vi) Gorczynski's continentality index (GCI).

Statistical analysis

The relationships between ordinal variables (visual soil quality indicators) and other variables were assessed with Spearman's rank correlation coefficient. The relationships between numerical variables were assessed with Pearson's correlation coefficients. To determine if the correlation coefficients were statistically significant, the t-values of the correlations were calculated. The chosen significance level for both correlations was $\alpha=0.05$. In the next sections, we defined no-correlations for $r < |0.10|$, weak correlations for $|0.10| \le r \le |0.3|$, moderate correlations for $|0.3| < r \le |0.7|$, and strong correlations for $r > |0.7|$.

To test if the arithmetic means of measured soil properties were equal for the fields/plots of the no-till, minimum tillage and respective control groups, we used Welch's unequal variances t-tests, one-tailed test, for a level of significance $\alpha=0.05$.

To test the null hypothesis that there were no differences between expected and observed frequencies of the scores of the visual soil quality indicators of no-till and minimum tillage, and respective control groups, we used the chi-square test for a level of significance $\alpha=0.05$. Because of an insufficient number of observations to meet the criteria to use the test, the categories "poor" and "moderate" were combined in a single category. To validate the approach, the exact p-values were calculated with Fisher's exact test and, where differences were statistically significant, the p-values calculated with the chi-squared test were lower and differ by less than 0.01. The strength of the effect was calculated with Cramér's V test (based on the chi-squared test). All calculations were performed using Excel (Microsoft Office 2016).

RESULTS AND DISCUSSION

No-till. There was a statistically significant difference between tillage treatment (no-till and conventional tillage (control)) and the scores of the following visual soil quality indicators (meaning that they are not independent): "soil structure and consistency", "soil porosity", "soil stability" (slake test), and "susceptibility to wind and water erosion" (left side of Table 3). The strength of the effect, given by Crámer's V for these visual indicators, being V=0.85, 0.51, 0.43 and 0.43 respectively.

Table 3. Frequencies of the scores of the visual soil quality indicators of no-till (left side), minimum tillage (right side) and respective controls. Chi-square test, p-value and Crámer's V.

	No-till							Minimum tillage						
	Observed							Observed						
	No-till		Control			p	Crámer's	MT		Control			p	Crámer's
	G	C	G	C	χ2	value	V	G	C	G	C	χ2	value	V
Str	12	0	2	10	17.14	0.00	0.85	8	21	9	20	0.28	0.84	0.07
Por	10	2	4	8	6.17	0.01	0.51	14	15	12	17	0.28	0.60	0.07
Sta	7	5	2	10	4.44	0.04	0.43	8	21	5	24	0.89	0.34	0.12
Pan	6	6	2	10	3.00	0.08	0.35	14	15	13	16	0.07	0.79	0.03
Col	6	6	4	8	0.69	0.41	0.17	11	18	7	22	1.29	0.26	0.15
Ear	6	6	2	10	3.00	0.08	0.35	9	20	4	25	2.48	0.12	0.21
Ero	10	2	5	7	4.46	0.03	0.43	20	9	17	12	0.67	0.41	0.11
Pon	11	0	9	2	2.20	0.14	0.30	23	6	20	9	0.81	0.37	0.12

G: class Good; C: combined class of moderate + poor scores. Str: Soil structure; Por: Soil porosity; Sta: Soil stability (Slake Test); Pan: Presence of a tillage pan; Col: Soil colour; Ear: Earthworm count; Ero: Susceptibility to wind and water erosion; Pon: Surface ponding.

The measured soil properties showed a higher mean of SOM content and a slightly higher pH under no-till, both arithmetic means are not statistically significant (Table 4). Due to an insufficient number of records of no-till sites, no further statistical analysis was performed.

Table 4. Measured soil properties, arithmetic mean and variance of no-till (left side) and minimum tillage (right side). Welch's t-test one-tailed (α=0.05).

	No-till		Control			Minimum tillage		Control		
	X	s^2	X	s^2	p	X	s^2	X	s^2	p
SOM	3.7	5.3	2.9	4.0	0.17	2.6	0.9	2.5	1.2	0.37
LOC	1.8	5.6	1.8	4.9	0.48	1.8	4.6	1.9	4.8	0.46
pH	6.1	3.72×10-12	5.8	8.27×10-12	0.21	6.3	1.63×10-12	6.2	1.04×10-12	0.37
PR						1.9	1.2	2.0	1.3	0.46

The variance of pH was calculated with $[H^+]$. PR: penetration resistance; LOC: labile organic carbon; SOM: soil organic matter.

Minimum tillage. There was no statistically significant difference between tillage treatments (minimum tillage and conventional tillage (control)) and the scores of the visual soil quality indicators (right side of Table 3), although, and except for "soil structure and consistency", the frequencies of class "good" were slightly higher under minimum tillage. No statistically significant differences were found between the arithmetic means of measured soil properties of the tillage systems (right side of Table 4).

The study of the correlations between the scores of the visual soil quality indicators and soil properties, and climate variables/indices, allowed insight to comprehend how these variables affect tillage-induced soil structure. For space-saving, Table 5 and 6 summarize only the correlation coefficients of the visual soil indicators with at least one statistically significant. For "soil structure", within the Control group only weak, or no correlations, were found with climate variables (Table 5). Within the Minimum tillage group, negative and moderate correlations were found with mean annual temperature and precipitation and with net primary production. These correlations suggest that, with minimum tillage systems, a trend for a better "soil structure" can be expected at locations with drier, colder climates. Contrastingly, within the Minimum tillage group only weak, or no correlations, were found with measured soil properties while, within the Control group, moderate correlations were found with clay (negative) and LOC (positive). Given that "soil structure" is a measure of the magnitude of friability, these results suggest that within the Control group (plough), higher clay increases clod formation, while higher LOC promotes microbial activity, improving aggregation.

Concerning "soil porosity", both groups show a similar negative, moderate correlation with mean annual temperature. However, within the Control group, it was observed a negative moderate correlation with potential evapotranspiration and a positive one with aridity index (AI= P mean/ PET mean), suggesting that tillage systems with topsoil inversion will show higher "soil porosity" scores where a lower deficit of available water occurs. Correlations between the scores of "soil porosity" and soil properties also showed different relationships within each group: in the Minimum tillage group, soil penetration resistance had a moderate, negative and statistically significant correlation with "soil porosity", while, in the Control group, "soil porosity" showed a moderate, positive and statistically significant correlation with LOC. These results suggest that, for soils with higher shear strength, minimum tillage may not be adequate and no-till, by preserving soil's macroporosity and its continuity, can be a better choice. On the other hand, within the Control group (topsoil inversion), the scores of "soil porosity" seems to be related to the mass of crop residues that are incorporated into the soil, to the extent that soil's LOC content, although dynamic, is connected to the incorporated residues' mass.

Table 5. Spearman's correlation coefficients between the scores of the visual soil quality indicators (min. tillage & control) and climate variables and indices. Coefficients in bold are statistically significant (α=0.05).

	Minimum tillage					Control				
	Str	**Por**	**Sta**	**Pan**	**Col**	**Str**	**Por**	**Sta**	**Pan**	**Col**
T mean	-0.40	-0.47	-0.18	-0.59	-0.19	0.02	-0.46	0.12	-0.63	-0.63
P mean	-0.42	-0.11	0.71	-0.31	0.04	-0.04	0.09	0.70	-0.31	0.05
PET mean	-0.27	-0.29	-0.27	-0.28	-0.03	-0.19	-0.50	-0.17	-0.26	-0.50
AI	-0.08	0.13	0.49	-0.06	-0.02	0.16	0.41	0.54	-0.16	0.32
NPP lim	-0.46	-0.10	0.70	-0.25	0.08	-0.13	0.05	0.67	-0.22	0.07

T mean: mean annual temperature; P mean: mean annual precipitation; PET: mean annual potential evapotranspiration; AI: aridity index; NPP lim: net primary production potential, temperature and precipitation limited.

Within both groups, the scores of "soil stability" were similarly correlated with mean annual precipitation, net primary production, both positive and strong correlations, and the aridity index (Table 5). Concerning the correlations between the scores and soil properties, only the correlation with pH, within the Minimum tillage group, was statistically significant, positive and moderate (Table 6). The strong correlations of the scores, with both precipitation and net primary production, support the assumption that higher aggregate stability scores are closely related to higher biomass production.

Table 6. Spearman's correlation coefficients between the scores of the visual soil quality indicators (min. tillage & control) and measured soil properties. Coefficients in bold are statistically significant (α=0.05).)

	Minimum tillage							Control						
	Str	Por	Sta	Pan	Col	Ero	Pon	Str	Por	Sta	Pan	Col	Ero	Pon
Sand	0.25	0.24	-0.05	0.49	0.09	-0.32	0.11	0.03	0.16	-0.22	0.42	0.47	-0.08	0.05
Silt	-0.24	-0.23	0.01	-0.49	-0.14	0.26	-0.04	0.12	-0.04	0.24	-0.40	-0.40	0.18	0.13
Clay	-0.20	0.06	-0.10	0.15	-0.20	0.00	-0.46	-0.46	-0.34	-0.08	0.06	-0.45	-0.30	-0.39
PR	-0.08	-0.58	-0.22	0.04	-0.30	-0.16	-0.22	0.13	-0.18	-0.34	-0.07	-0.21	-0.54	-0.66
LOC	0.29	0.31	0.00	0.01	-0.01	-0.10	0.12	0.56	0.57	-0.11	0.16	0.38	-0.12	0.29
SOM	0.06	0.30	0.48	-0.16	0.49	0.03	0.05	-0.03	0.41	0.37	-0.49	0.10	-0.45	0.02
pH rank	0.13	0.26	0.55	0.22	0.20	-0.13	0.40	0.14	0.33	0.37	0.20	0.15	0.23	0.38

PR: penetration resistance; LOC: labile organic carbon; SOM: soil organic matter; pH rank: ranked according to the following thresholds: 1 (poor; pH<5.5 or pH>8); 2 (moderate 5.5≤pH≤6.5 or 7.5≤pH≤8); and 3 (good, 6.5<pH<7.5).

The correlations between the scores of the "presence of tillage pan" and climate variables within both groups were very similar and statistically significant only with mean annual temperature: moderate and negative correlation coefficients (Table 5). The correlations between the scores and soil properties within both groups were very similar, although only statistically significant with sand and silt within the Minimum tillage group (Table 6).

The correlation coefficients between "soil colour" scores and climate variables were only statistically significant with mean annual temperature and evapotranspiration potential, both moderate and negative, and within the Control group (Table 5). Similarly, only correlations between the scores and soil properties within the Control group were statistically significant: with sand (moderate, positive), clay (moderate, negative) and LOC (moderate, positive) (Table 6). These results suggest that the lack of surface plant residues, and the disruption of pore continuity within the Control group, are possibly at the origin of lower "soil colour" scores with increasing mean annual temperature. The rationale for this assumption resides in that lower water diffusion hinders microfauna and microbial activity. This rationale is supported further by the negative correlation coefficient of the scores with soil's clay content and the positive and moderate correlation coefficient of the scores with labile organic carbon content, but not with organic matter.

Within both groups, weak or no-correlations were observed between the visual soil indicators "earthworm count", "surface ponding" and "soil erosion" and climate variables. Also, no statistically significant correlation coefficients were observed between the scores of "earthworm count" and soil properties, within both groups, and between the scores of "soil erosion" and soil properties within the Minimum tillage group. Within the Control group, for both correlations of the scores of "soil erosion" and "surface ponding" with soil properties, only the correlations with penetration resistance were statistically significant, moderate and negative (Table 6). Within the Minimum tillage group, only the correlation between the scores of "surface ponding" with clay content was statistically significant, moderate and negative (Table 6).

CONCLUSION

The observed positive effect of the No-till treatment on the scores of the visual soil quality indicators "soil structure and consistency", "soil porosity", "soil stability" (slake test), and "susceptibility to wind and water erosion" support the assumption that where it is practised, where farmers experience a benefit from using no-till, no-till systems induce a better soil structure.

The effect of minimum tillage practices on the scores of the visual soil quality indicators, although not statistically different from those with conventional tillage (the frequencies of the scores seem to be independent of the tillage system), may induce, at particular locations, better scores of the visual soil quality indicators. Nonetheless, minimum tillage practices that allow a proper soil cover has a positive impact on soil conservation, regardless of the lack of differences with conventional tillage concerning the frequencies of the scores of the visual soil quality indicators selected.

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Conservation Agriculture practices: an alternative to improve and stabilize crop yields and soil quality in rainfed Mediterranean region

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Crop yield in the rainfed Mediterranean environment, hot-spot for climate change, is highly affected by the rainfall variability, heat, and temperature extremes. With the declining rainfall amount, increasing rainfall variability and temperature extremes, and declining soil quality, crop production is affected, hence threatening food security in the region. Conservation Agriculture (CA) practices such as reduced tillage, soil cover, and crop rotation, are recognized as a set of adaptive agricultural systems in climate-sensitive regions. CA helps to conserve soil and water resources, enhance crop yield and stabilize crop production and improves soil health. Yield stability of major food crops, i.e., barley, wheat, chickpea, and lentil, grown under CA in variable rainfall conditions of the Mediterranean environment in Morocco, is not well understood. We have analysed the medium-term effect of CA in four major crops (barley, chickpea, lentil, and wheat) on grain yield, stability, and effect on soil quality while comparing the conventional tillage (CT) system (i,e. soil tillage, residue removal). The experiment was conducted in the International Center for Agriculture Research in the Dry Areas (ICARDA) research station in Morocco under CA and CT system for five growing seasons (2014/15-2018/19) contrasted in the rainfall amount, i.e., 480, 255, 276, 519 and 299 mm, respectively, and its distribution. The experimental station has clay soil. The commercial variety of each crop was used in the experiment and fields were uniformly managed for fertilizer, weeds, pests, and disease. On average, across the crops and years, grain yield was significantly higher under CA (by 19%; 0.29 t ha^{-1}) than in CT. Conservation Agriculture significantly increased the grain yield of chickpea by 18.8% and wheat by 42.7% than CT, while a similar yield was observed in barley and lentil between CA and CT. In chickpea and wheat, the relative yield stability of CA was higher than those of CT, indicating a transition to CA increase yield stability in wheat and chickpea. However, in barley and lentil, the relative stability of CA does not differ significantly from those of CT. Higher soil organic matter (higher by 11 and 7%), available phosphorus (higher by 13 and 3%), and exchangeable potassium (higher by 5 and 15%), in top 5cm and 30 cm soil profile, respectively under CA than in CT, indicating the adoption of CA practices leads to improve soil quality. All this evidence indicating that the adoption of CA technology provides i) higher and stable yield for wheat and chickpea and no yield penalty for barley and lentil and ii) improve soil quality in the rainfed Mediterranean environment in Morocco.

***Keywords**: yield stability, conservation tillage, soil quality, wheat, barley, chickpea, lentil*

INTRODUCTION

Crop yield in the rainfed Mediterranean environment, the hot spot for climate change, is highly affected by the rainfall variability, temperature extremes, and low soil organic matter. Conventional agriculture (CT) practice – i.e., intensive soil tillage, residue removal, and mono-cropping – has a negative effect on soil properties, resulting in its degradation and erosion (Sombrero and De Benito, 2010; Mrabet *et al.*, 2012). Healthy soils with high water holding capacity, improved crop production practices, and crop rotation are essential for sustainable crop production in such climatic conditions (López-Bellido *et al.*, 1996; López-Bellido *et al.*, 2011). Conservation Agriculture (CA) practices − i.e., minimum soil disturbance, permanent soil cover, and diversified crop rotation − has advantages over conventional tillage (CT) by reducing cost, increasing water use efficiency, reducing run-off, and soil erosion and increasing soil organic matter without compromising yield (Mrabet, 2002; Devkota *et al.*, 2013; Moussadek *et al.*, 2014).

The advantage of CA is more pronounced in rainfed drylands than in humid tropics (Kassam *et al*., 2012; Pittelkow *et al*., 2015). The CA system is not only effective in enhancing soil quality and increasing farm income (by reucing production costs), but has also been identified by some governments as a solution to the serious environmental problems that currently affect crop production is becoming a major research need in the 21st century for the major food crops. For adoption at scale, it is important to understnd the short- medium- and long-term effect of CA practices on yield performance and soil quality. To understand the the medium-term effect of CA in four major crops (barley, chickpea, lentil, and wheat) on grain yield, stability, and effect on soil quality while comparing the CT system (i,e. soil tillage, residue removal) a field experiment was established in the International Center for Agriculture Research in the Dry Areas (ICARDA) research station in Morocco.

Methodology

The field experiments were carried out in Merchouch located in 75 km east of Rabat (Morocco) (33°36'41''N, 6°42'45''W, 390 m a.s.l.) at the International Center for Agriculture Research in the Dry Areas (ICARDA) experimental station during five consecutive growing seasons: 2014/15, 2015/16, 2016/17, 2017/18, 2018/19. Growing seasons 2014/15, 2015/2016, 2016/2017, and 2017/2018 are hereafter referred to as 2015, 2016, 2017, 2018, and 2019, respectively. The climate of the region is typically Mediterranean with hot/dry summers and cold/wet winters, and highly variable annual rainfall across years. The 45-year (1974–2018) average annual rainfall is 398 mm with a maximum of 665 mm and a minimum of 181 mm. The average rainfall during the growing season was variable (Fig. 1). The mean annual air temperature is 18°C with monthly minimum and maximum temperatures ranging within 10−12°C and 20−24°C, respectively. The soil in the experimental site is classified as a Vertisol of clay-loam texture (47.6% clay and 41% loam content), with large cracks appearing during the dry season. The soil is low in organic matter content (1.8%) and available K_2O (105 mg kg^{-1}) and high in P_2O_5 (60.6 mg kg^{-1}) on the top 30 cm soil profile.

The experiment was conducted for four different crops, i.e., barley *(Hordeum vulgare*), chickpea (*Cicer arietinum* L.), and lentil (*Lens culinaris,* Medik.) and wheat (*Triticum aestivum L.*) under conventional (CT) and Conservation Agriculture (CA) methods in a cereal−legume rotation. All four crops were planted in a sizeable plot size of 2000 m^2 for each crop species and tillage methods. The plots were divided into two equal parts, half part, i.e., 1000 m^2 was used for genotype evaluation and the rest half was seeded with the commercial variety of the same crop. The commercial variety of barley (Amalou), chickpea (Moubarak), lentil (Bakriya), and wheat (Arihane) were used for this study.

In CT, the land was prepared according to the farmers' practice: disk plowing for about 10−15 cm in September followed by one or two shallow tillages using a tine cultivator before seeding. In CA, seed and fertilizers were directly drilled into the undisturbed soil using a zero-till planter. A tractor-mounted six-row heavy plot seeder (Wintersteiger Plotseed XXL) was used for seeding and basal fertilizer application in both CA and CT plots each year. All crops were seeded on the same row spacing of 25 cm, but the seed was calibrated to maintain the number of seeds per m^2: 300 seeds m^{-2} for wheat and barley; 150 seeds m^{-2} for lentil; and 50 seeds m^{-2} for chickpea. All crops were seeded on the same day, and seeding was carried out between 15-20 December for all years except in the 2017-18 cropping season where all crops were seeded on 7 January 2018. Fertilizer application was based on the initial soil nutrient content and crops received a complex fertilizer (15% each of N, P_2O_5, and K_2O) at the time of seeding: 330 kg ha^{-1} for cereals (50:22:42 kg of N, P, and K ha^{-1}); and 200 kg for legumes (30:13:25 kg of N, P, and K ha^{-1}). Cereals received an additional 50 kg N through ammonium nitrate (33% N) at the active tillering stage. Weeds during the growing season were controlled by applying selective pre- and post- emergence herbicide and occasional hand weeding. In CA plots, weeds were killed by the application of 1 L ha^{-1} glyphosate before sowing. After seeding, pre-emergence herbicide Stomp (455 g L^{-1} pendimethalin) was used immediately after seeding and post-emergence Fusilade (0.75 L ha^{-1} Fluazifop-p-butyl) at 2–3 leaf stage of weeds was applied in lentil and chickpea in both CA and CT plots. In cereals, Mustang 306 SE (2,4-D + Florasulman) was used at the tillering stage to control broad and narrow leaf weeds in both CA and CT plots.

To measure grain yield crops were harvested from 4 m^2 of land area (four rows with 4 m length) from six different points in each crop species and tillage methods and converted to kilograms per hectare. After harvesting quadrats to measure yield, crops were harvested by plot-harvester leaving around 20 cm straw height from the ground for cereal and 5–10 cm for legumes; and most of the loose residues were removed from both CA and CT plots.

Soil moisture at top 30 cm soil depth was measured for all four crops from both CT and CA plots just before flowering and at harvest for two years. Soil moisture was measured from six points each from CA and CT plots of each crop species. The gravimetric moisture content was calculated by dividing the mass of water by the mass of dry soil. The gravimetric moisture was then converted to volumetric moisture content by multiplying the soil bulk density of the respective depth.

After four crop growing seasons, i.e., in June 2019 (after crop harvest) soil samples were taken from two depths (0-5 cm and 0-30 cm) in the CA and CT plots with four different points in each plot to determine soil chemical properties of soil. Soil samples were air-dried at room temperature. The SOC content was determined according to Walkley and Black method wet oxidation procedure. Total nitrogen was determined using semi-micro-Kjeldahl digestion method. Available phosphorus was measured Olsen P method and exchangeable potassium was measured using the method of Kundsen et al. (1982).

Results and discussion

3.1 Weather conditions

During the crop growing season (November–June) for 2015, 2016, 2017, 2018, and 2019 the total rainfall was 434, 239, 271, 494, and 181 mm, respectively. Compared to the mean annual rainfall of 398 mm at the experimental station for 1974–2018, 2019 was the driest year followed by 2016 and 2017, and 2018 was the wettest (Fig. 1). The monthly rainfall had high variability between and within years, which are the characteristics of the region's climate.

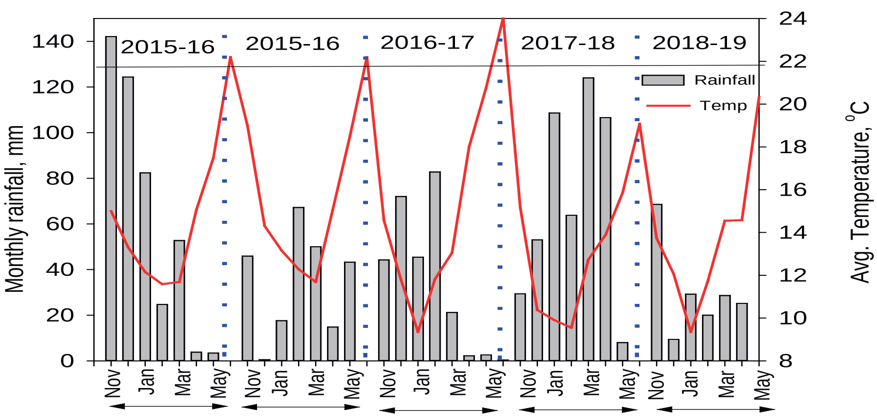


Figure 1. Monthly rainfall and mean temperature during the crop growing seasons (November–June) at the experiment site in Merchouch, Morocco. Each bar in X-axis represents months of the growing season (November-June).

3.2 Soil moisture content

Volumetric soil moisture content on top 30 cm soil depth was higher under CA plots than in CT for all crops in both crop-growing seasons (2016 and 2017). On average, the soil moisture at flowering under CA was higher by 16-20% in barley, 12-19% in wheat, 16-29% in lentil, and 22-25% in chickpea than in the CT plot (Fig. 2). This suggested that CA plots can hold more moisture than in CT and which could justify the higher yield under CA than in CT.

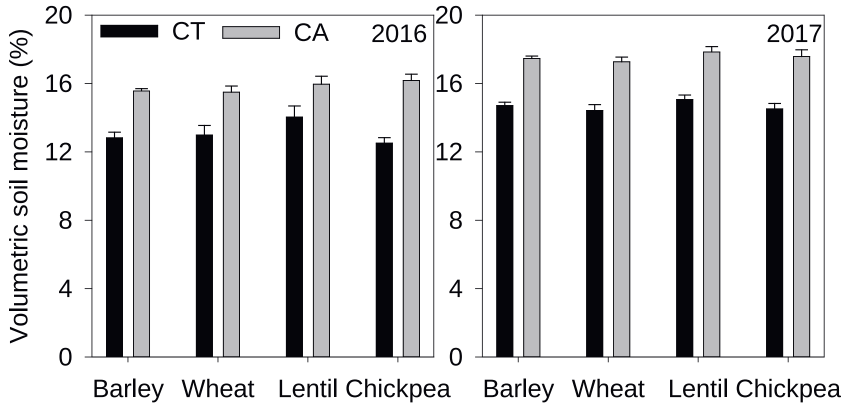


Figure 2. Volumetric moisture content (%) at top 30 cm soil depth at flowering stage under conservation (CA) and conventional tillage (CT) system for barley, wheat, lentil and chickpea for two years (2016 and 2017) at Merchouch, Morocco.

3.3 Grain yield performance and yield stability

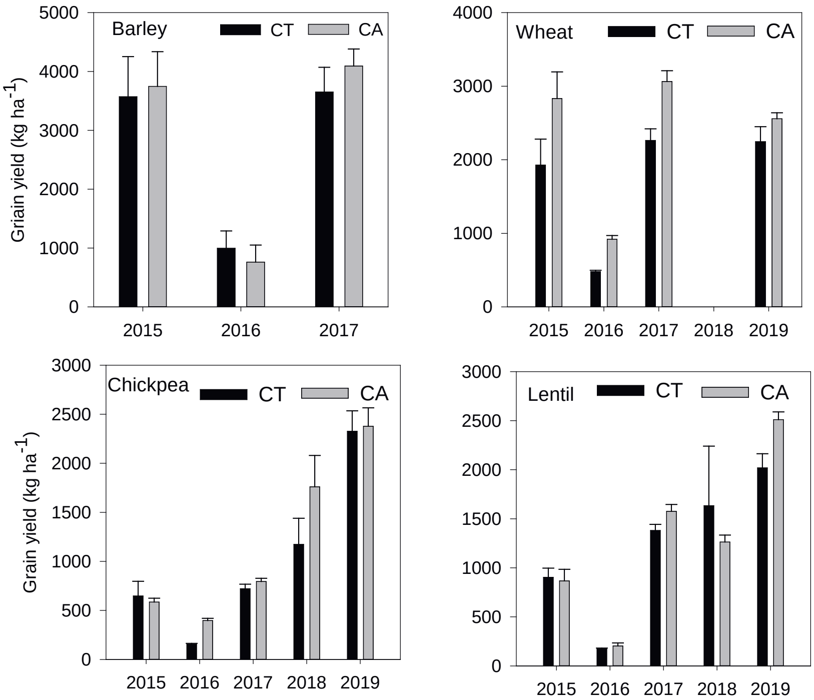
The strong inter-annual rainfall variation caused significant differences in the grain yield of all four crops. For all crops, grain yield was significantly low in the year with extreme early-season drought (2016), i.e., no or very little rainfall in December and January. The average yields in 2015, 2016, 2017, 2018, 2019 were: 617, 275, 758, 1466, 2352 kg ha^{-1} for chickpea; and 886, 188, 1479, 1448, 2265 kg ha^{-1} for lentil, respectively. The average yields for barley were 3690, 880 and 3873 kg ha^{-1} in 2015, 2016 and 2017, respectively; and for wheat were 2381, 699, 2664, and 2441 kg ha^{-1} during the growing season of 2015, 2016, 2017, and 2019, respectively.

Across over the growing season, barley under CA produced 4.7% higher grain yield than in CT, while a significant yield advantage was observed in 2017, growing season with low but well distributed rainfall. In wheat, grain yield was significantly higher under CA in all four years. Average across the growing season, wheat under CA produced 40% higher yield compared to the CT system. Similarly, average across the five growing seasons chickpea and lentil grown under CA system produced 16% and 8% higher yield, respectively than in CT. The higher yield under CA plots could have been associated with high moisture content.

3.4 Mean yield ratio under CA and CT plot

The mean yield ratio was calculated for grain yield of barley, wheat, lentil and chickpea under the CA and CT system while combining the multiple set of data available in pair comparison for CA vs. CT. In Barley, out of the 57 multiple paired comparison 56% (32 observations) had higher yield in CA than in CT. In wheat, out of 69 multiple paired comparison, 97% (67 observations) has more yield in CA than in CT. In lentil, out of 104 multiple paired comparison, 65% (67 observations) has more yield in CA than in CT. In chickpea, out of 106 multiple paired comparison, 82% (87 observations) has more yield in CA than in CT (Fig. 4). All these indicating that all

Figure 3. Grain yield of chickpea, lentil, barley and wheat under conventional (CT) and conservation (CA) agriculture system in different years in on-station experiment at Merchouch, Morocco.



major crops grown under CA produced either similar or higher yield than in CT. Comparatively, higher yield of wheat and chickpea with low coefficient of variation under CA system indicated that wheat and chickpea produced higher and stable yield under CA than in CT system (Table 1)

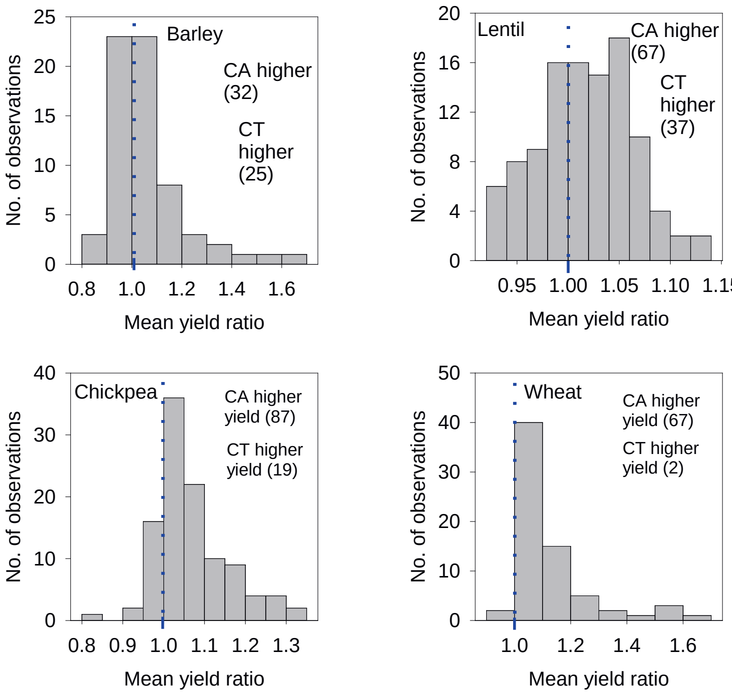


Figure 4. Mean yield ratio of chickpea, lentil, barley and wheat under conventional (CT) and conservation (CA) agriculture system in different years in on-station experiment at Merchouch, Morocco.

Table 1. Average grain yield (kg ha^{-1}), standard deviation (Std) and coefficient of variation (CV) for barley, wheat, chickpea and lentil grown under Conservation Agriculture (CA) and conventional agriculture (CT) system.

Crop	Mean yield		Std (kg ha^{-1})		CV %	
	CT	NT	CT	NT	CT	NT
Barley	2667	2878	1648	1845	62	64
Wheat	1617	2308	967	1056	61	46
Chickpea	777	923	644	622	80	61
Lentil	1026	1135	756	873	77	77

3.5. Soil nutrient content under CA and CT

Although no significant difference in SOM content between CA and CT plot, the CA plot had higher SOM by 11% and 7% in the top 5 and 30 cm soil depth respectively. Similarly, the available phosphorus was higher under CA by 13% and 6% in top 5 and 30 cm soil profile, respectively than in CT. There was a negligible difference between CA and CT plots on exchangeable potassium and total nitrogen content on topsoil (Table 2). Higher level of SOM, available phosphorus, and exchangeable potassium under CA in top 30 cm soil profile indicating that the adoption of CA can improve soil quality overall fertility for vertisol in medium to long-run than in plowed soil.

Table 2: Soil organic matter (SOM), available phosphorus (P_2O_5), exchangeable potassium (K_2O) and total nitrogen content at top 5 cm and 30 cm soil profile under conservation (CA) and conventional (CT) system after four years of in Merchouch, Morocco.

Soil component	Top 5 cm			Top 30 cm		
	CT	CA	Change over CT	CT	CA	Change over CT
Soil organic matter (%)	1.77±0.43	1.97±0.65	+0.2(11%)	1.5±0.38	1.61±0.6	0.11(7%)
Phosphorus (mg/kg)	74.2±25.1	84.1±24.9	+9.9(13%)	60.1±24	63.7±30	3.6 (6%)
Potassium (mg/kg)	427±110	417±231	-10 (2.3%)	292±129	304±180	12 (4%)
Total nitrogen (%)	0.12±0.06	0.13±0.12	+0.01(8%)	0.13±0.06	0.13±0.12	0

Conclusion

In summary, this medium-term study on CA in vertisol indicated that the adoption of CA technology provides i) higher and stable yield for wheat and chickpea and no yield penalty for barley and lentil and ii) improve soil quality in the rainfed Mediterranean environment in Morocco

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Impacts of post-sowing compaction on temporal variation of soil temperature for different wheat growth period in North China Plain

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Temporal changes induced by post-sowing compaction in soil temperature are not yet well understood, as they might significantly affect the soil–vegetation–atmosphere transfer system. Soil temperature temporal variation during the whole growing season is important because of its potential influence on the crop growth and yield. Therefore, on-farm field trials were conducted in Beijing of North China Plain to study the impact of post-sowing compaction treatments on temporal change of soil temperature from sowing to green stage during wheat growing season from October to February in the second year. Three different post-sowing compaction devices were used to test: (1) compaction wheel of rubber (CW), (2) compaction roller consisting of welded steel bars (CR) and (3) two kinds of compaction rollers (traditional roller behind compaction roller consisting of welded steel bars, soil was compacted twice in this treatment) (TCR). Soil temperature was progressively determined with soil temperature sensor to a depth of 60 cm from sowing to green stage. Five soil moisture sensors from each plot were inserted into soil surface of intra-row and inter-row, 20cm, 40cm, and 60cm to monitor soil temperature. Effects of the three compaction methods on temporal dynamics of soil temperature within different soil depth (0-60mm) in different growth period of wheat was measured with. soil temperature was not significant on the surface soil profile among three post-sowing compaction devices for both the intra- and inter-row at the sowing stage. After one month of sowing, for the intra-row surface soil, the highest temperature has been measured in CW treatment, and the temperature variation in a 24-hour cycle was smaller than that under CR and TCR treatment. the temperature under CR treatment was higher than that under TCR treatment one and two months after sowing and lower than that under TCR treatment three and four months after sowing in the night time; and the result in the daytime in contrast to that in the night time. The soil temperature in different soil depth was almost stable in 20-60cm soil depth in a 24-hour cycle, and the deeper the soil depth, the higher the soil temperature. This may be caused by the thermal insulation provided by vegetation, water, and surface soil layers, and the variation in soil temperature was lower at deeper soil than surface soil. Results of this study demonstrated that measuring temporal variation of soil temperature in different growth period will provide theoretical support data for soil and crop management.

Keywords: *Soil temperature; Post-sowing compaction; Different growth period*

1. Introduction

Soil temperature plays an important role in the soil–vegetation–atmosphere transfer system. It affects soil physical properties which are important in the surface water and energy exchange during land-atmosphere exchanges. It can also affect soil microbial processes and the nutrient movement in the soil, which will further have a great influence on plant growth (Liao et al., 2016). Besides, soil temperature influences crop growth and yield directly, Blake et al., 2011 found that it is a crucial soil property of great important during crop germination and early development; Wang et al. (2005) showed that soil temperature influences potato plant growth and tuber production; even tiny temperature variation would affect crop growth. Mark et al. (2005) showed that 1.2-1.4 ◦C increase in soil temperature contributed to an improvement in plant emergence rate index. Lower temperature delay corn emergency and growth and higher temperature decrease the number of days required for emergency and increase corn yield (Haytham et al., 2015).

The reason of soil temperature variation has become a major concern considering the numerous impacts on soil physical properties, microbial process, nutrient movement, crop growth and yield. Many researches showed that soil temperature is influenced by soil management. According to Haytham et al. (2015), soils under zero tillage and reservoir tillage treatments usually resulted in lower soil temperature than minimum tillage and conventional tillage treatments at both soil depths regardless of the entire observation period. Similar soil temperature response to tillage was reported by Mark et al. (2005), who found that strip-tillage increased soil temperature in the top 5 cm 1.2-1.4 ◦C than no-tillage.

Post-sowing compaction is one important part of soil management, which may influence soil temperature, other soil properties and crop growth. Appropriate post-sowing compaction can create suitable soil conditions (including soil temperature, soil moisture etc.) for planted seeds by compacting soil particles to a proper density, providing better soil-seed contact and reducing the moisture loss rate for planting (Tong, 2015). Johnston et al. (2003) reported that a packing compactionure of 333 N per compaction wheel could provide adequate emergence and grain yield under varied conditions of surroundings. However, excessive compaction can affect soil aeration, temperature and root growth, which due mostly to excessive mechanical impedance (Croissant et al., 1991). The restrictive effect of soil compaction can be physically and physiologically constraining to overall plant growth and yield through poor development of the root system (Stanisław et al., 2013). Therefore, suitable post-sowing compaction device is necessary to guarantee appropriate compaction for soil and crop.

Relevant literature highlights that compaction can significantly affect soil temperature (Reichert et al., 2014). However, the researches mainly focus on the compaction caused by traffic effect on soil temperature only a few days after compaction. The effect research of post-sowing compaction on soil temperature in the growing season is rare, especially temporal variation of soil temperature for winter wheat, which is important for wheat growth. The objective of this research is to evaluate the effects of three post-sowing compaction devices (compacting wheel, compacting roller and two kinds of compacting rollers) on temporal variation of soil temperature with different depth (0-60mm) for different growth period of wheat in Beijing of North China Plain.

2. Materials and methods

2.1 Site description

A study was conducted in Beijing suburb of China, which has a temperate continental climate with four distinct seasons. Mean annual temperature in the region is 11ºC, with a frost-free period of around 190 days. Rainfall is widely variable across the different seasons, and 75% of the annual precipitation occurs during summer with an annual average of 600 mm. Typically, winter wheat is sown in October and harvested in June. The rainfall and air temperature from sowing date (October 4, 2015) to green stage (February 10, 2016) are shown in Fig. 1. The site is consisting of a loam soil with organic matter 18.7g/kg, total nitrogen 0.115%, available phosphorus16.7 mg/kg and available potassium 96 mg/kg.

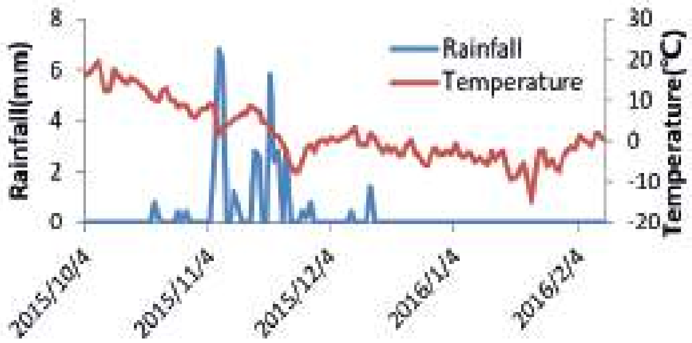


Fig. 1 Distribution of rainfall and temperature

Fig. 2 Post-sowing compaction devices

2.2 Experimental design

This study assessed three types of post-sowing compaction (Fig. 2): (1) compaction wheel of rubber (CW), (2) compaction roller consisting of welded steel bars (CR) and (3) two kinds of compaction rollers (traditional roller behind compaction roller consisting of welded steel bars, soil was compacted twice in this treatment) (TCR), which installed on planter with disc openers, were applied to the experimental plots. CW worked only on the intra-row soil surface; both CR and TCR worked on the whole soil surface, both intra- and inter-row. For each treatment, uniform rotary tillage, levelling and fertilizing were undertaken to prepare the site for the experiment. The post-sowing compaction was implemented after sowing. All in-crop fertilizer of NPK was applied at rate of N 150 kg/ha, P 140 kg/ha and K 85 kg/ha. The winter wheat was sown at rate of 187.5 kg/ha.

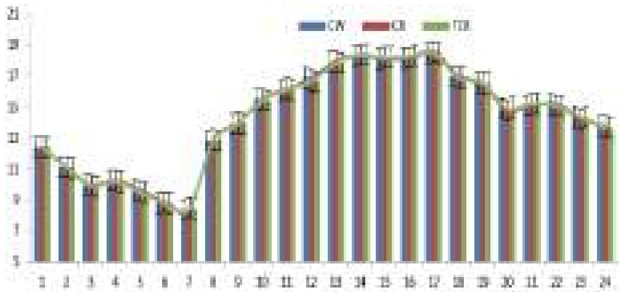
2.3 Measured parameters and statistical analysis

Rainfall, air temperature and moisture were monitored throughout the experiment by a public solar-powered automatic weather station, and data were recorded automatically by data loggers. Soil temperature was progressively detected with sensors from sowing to green stage. From each plot, five sensors were inserted into soil surface of intra-row and inter-row, 20cm, 40cm, and 60cm soil layers. And they were installed on a solar-powered automatic weather station in each plot, and data were recorded hourly automatically. However, only a few data sets were selected to use, the data of one day (October 5, 2015), one month (November 5, 2015), two months (December 5, 2015), three months (January 5, 2016) and four months (February 5, 2016) after post-sowing compaction were extracted and analysed. Mean values were calculated for each of the measured variables, and ANOVA was used to assess the treatment effects. Statistical analyses were conducted with SPSS 17.0.

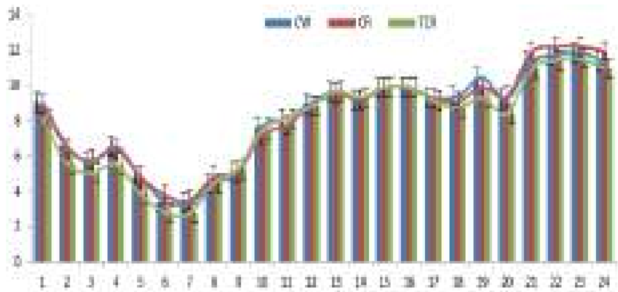
3. Results and discussion

3.1 Soil temperature on intra-row soil surface

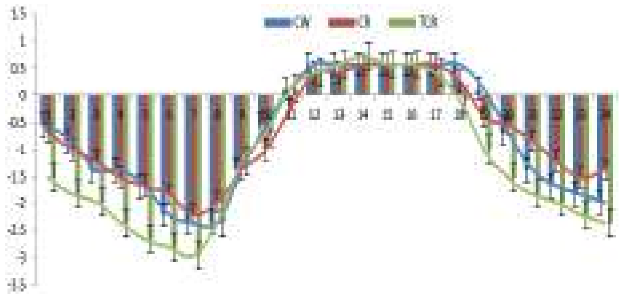
As shown in Fig. 3, the highest soil temperature occurred in 14pm and lowest soil temperature occurred in 5-7am except November 5. Similar result was reported by Zhou, et al. (2015). The soil temperature has no significantly differences under different treatments on October 5 (Fig.3a). One month later (Fig.3b), the soil temperature under TCR was lower than that under CW and CR among 1am to 7am, and went up to as high as CW and CR, but decreased to lower than CW and CR once again after 18pm. But all the soil temperature had no significantly difference. For the day, the highest soil temperature occurred at 21pm and 22pm. This is a potential reason for rapid increment of air temperature on November 5 and the next few days (Fig. 1). Similar results were reported by Awe et al. (2015). Two months later (Fig.3c), as the air temperature lower, the differences among different treatment became significant. For 1am to 7am and 18pm to 24pm, the soil temperature under TCR treatment was dramatically lower than that under CW and CR treatment. Three months later (Fig.3d), for 1am to 10am, and 19pm to 24pm, the soil temperature under CW treatment was significantly higher than two other treatments. And there was no significant difference for other treatments in other time. Four months later (Fig.3e), for 1am to 9 am, and 18pm to 24pm, the soil temperature was higher under CW treatment than two other treatments. The difference was significant between CW and TCR treatment at 2am, 4am, 5am, 18pm to 24pm; and the difference was significant between CW and CR treatment at 1am, 4am to 7am, and 19pm to 22pm. The soil temperature under TCR treatment was significantly lower than CW and CR treatment for 10am to 18pm.



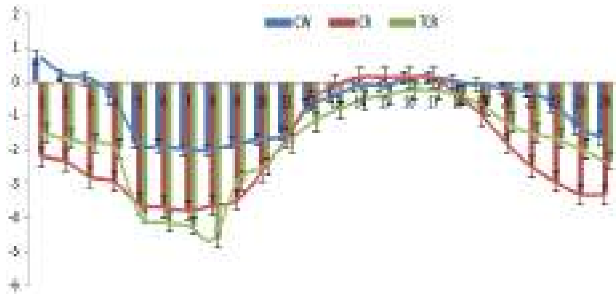
(a) October 5, 2015



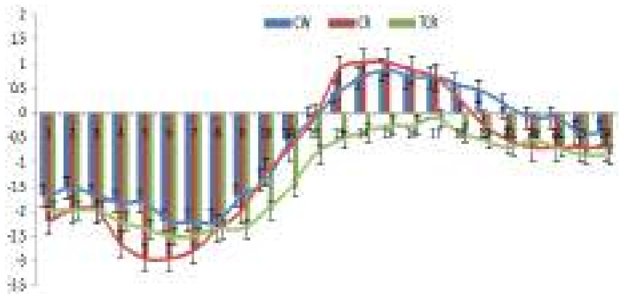
(b) November 5, 2015



(c) December 5, 2015



(d) January 5, 2016

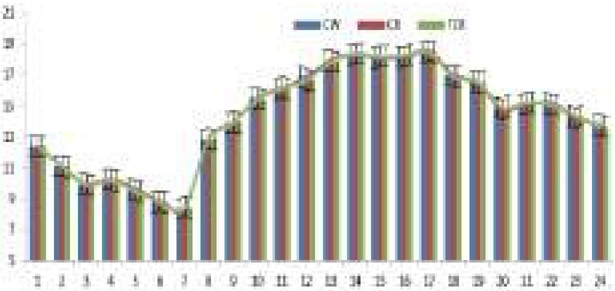


(e) February 5, 2016

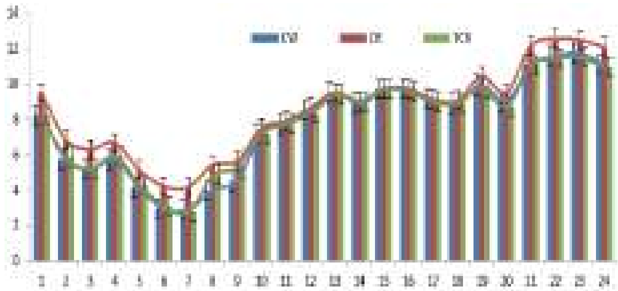
Fig. 3 Soil temperature on intra-row soil surface under different post-sowing compaction treatments

3.2 Soil temperature on inter-row soil surface

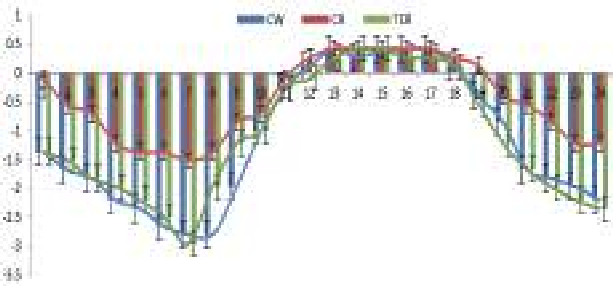
For inter-row soil surface, the highest soil temperature also occurred in 14pm, and the lowest occurred in 5-7am in the extracted date except November 5. There was no significant difference under different treatments on October 5 (Fig.4a). However, one month later (Fig.4b), the soil temperature under CR was higher than that under CW and TCR for 1am to 9am and 19pm to 24pm, and difference between CR and CW was significant at 3am, 6am to 9am and 21pm, and the difference between CR and TCR was significant at 3am, 6am, 7am, 20pm to 24pm. For the day, the highest soil temperature occurred at 21pm and 22pm. Two months later (Fig.4c), soil temperature was dramatically higher under CR treatment than other treatments. As soil temperature increased, the differences among the three treatments became smaller. The result of three months later (Fig.4d) showed that soil temperature under CW treatment was significantly higher than CR and TCR treatment for 1am to 11am, and 19pm to 24pm. For CR and TCR treatment, soil temperature was dramatically higher under CR treatment than TCR treatment at 2am, 4am, 8am, and 21pm to 24pm. For four months later (Fig.4e), soil temperature was significantly higher under CW treatment than TCR treatment at 4am to 7am, and dramatically higher under CW treatment than CR treatment at 12, 14pm and 15pm. The soil temperature under CR treatment was higher than that under TCR treatment for 1am to 10am, and surpassed for 11am to 18pm. TCR treatment had the largest change rate in a 24-hour cycle, then CW treatment, and CR the last. This result indicated that once compaction had stronger response capacity to temperature change than no compaction and twice compaction in bare soil.



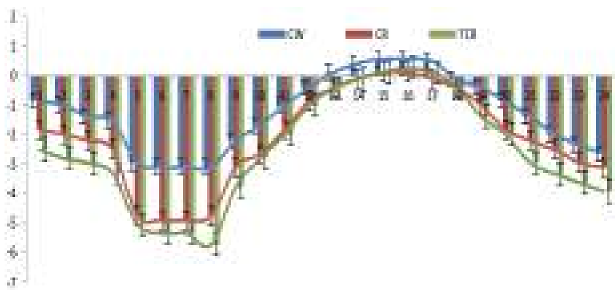
(a) October 5, 2015



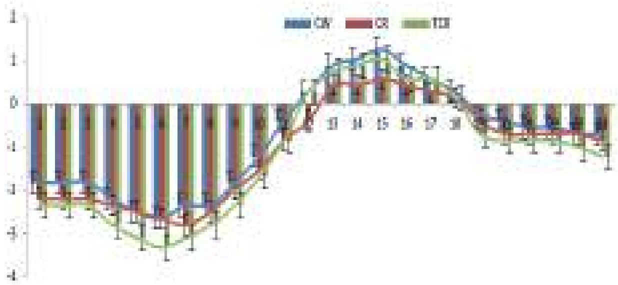
(b) November 5, 2015



(c) December 5, 2015



(d) January 5, 2016

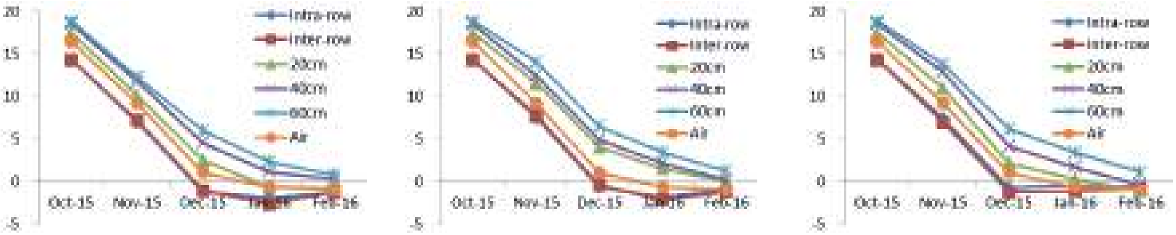


(e) February 5, 2016

Fig. 4 Soil temperature on inter-row soil surface under different post-sowing compaction treatments

3.3 Soil temperature in different soil depth

The average soil temperature had similar change regularity in the 20-60cm soil depth than that in the surface soil (Fig. 7). Liao et al., 2016 also reported that variation in soil temperature was lower at deeper soil as compared to that in the surface soil, which indicates thermal insulation provided by vegetation, water, and surface soil layers. Under TCR treatments (Fig.7a), the differences for intra- and inter-row soil surface were existing seedlings. In the first two months after sowing, the average soil temperature on the intra-row soil surface was lower than inter-row surface, however, as the weather became colder in the three and four months after sowing, the soil temperature on the intra-row soil surface became higher than inter-row surface in the night-time. This indicated that seedlings had the warm effect in colder weather. Similar result was found by Ramakrishna et al. (2006), who reported that ground covering could increase the soil temperature since the sun's energy passes through the mulch and heats the air and soil beneath the mulch directly and then the heat is trapped by the "greenhouse effect". Under CR treatment (Fig.7b), the differences for intra- and inter-row soil surface were also existing seedlings; however, the soil temperature on the intra-row soil surface was lower than on the inter-row soil surface for all the extracted growth period. This discrepancy was probably due to less compaction than the TCR treatment. Under CW treatment (Fig.7c), the differences for intra- and inter-row soil surface were not only existing seedlings, but also existent compaction. And the soil temperature on the intra-row soil surface was higher than on the inter-row soil surface in the night-time for all the extracted growth period. This was probably caused by the dual effect of seedlings and compaction.



(a) TCR treatment (b) CR treatment (c) CW treatment

Fig. 7 Average soil temperature in different depth under different treatments in different growth period

4. Conclusions

The soil temperature affected by different post-sowing compaction devices in different soil depth was measured during different wheat growth period in order to evaluate the temporal changes in soil temperature. We found that soil temperature was not significant among three treatments for both the intra- and inter-row surface soil. However, as the time goes on, the differences under different treatment appeared. For the intra-row surface soil, CW has the highest temperature, and the temperature variation in a 24-hour cycle was smaller than that under CR and TCR treatment; the temperature under CR treatment was higher than that under TCR treatment one and two months after sowing and lower than that under TCR treatment three and four months after sowing in the night-time; and the result in the daytime in contrast to that in the night-time. For the inter-row surface soil, CR treatment had the highest temperature, and it was similar under CW and TCR treatment in the first two months after sowing; however, sowing after three and four months, the soil temperature regulation in different treatments was: CW>CR>TCR. The result of soil temperature in different soil depth showed that soil temperature under CW treatment on the intra-row soil surface was higher than on the inter-row soil surface in the night-time and this was probably caused by the dual effect of seedlings and compaction. Further work is required to confirm these results across a wider range of field soil conditions and to evaluate the impacts of ground cover.

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Is Conservation Agriculture 'female friendly'? learnings from the Eastern Gangetic Plains of South Asia

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Conservation Agriculture (CA) has proven benefits for poverty-stricken smallholder farmers in the Eastern Gangetic Plains (EGP) of South Asia, but there has been limited analysis of how gender implicates on CA adoption, roles, agency and impact. Using three interrelated data sources (in depth interviews of female decision makers; in depth interviews with female spouses of male decision makers; and a novel photo dairy/photo voice activity) across six locations in Nepal, Bihar, West Bengal and Bangladesh, we explore how gender dynamics influence CA uptake and benefits, with a particular focus on addressing the as yet clearly unexplored research question: is CA 'Female friendly'?

Answering this across the region is complicated by various cultural norms. In most locations, women have minimal involvement in agricultural decision making at household level (except some parts of West Bengal). Despite this, females were engaged in substantial farm activities that could be potentially influenced by the implementation of CA. Females farmers broadly identified that CA directly led to labour savings that were reallocated to other purposes, due mainly in part to less burden and drudgery in weeding activities. They also identified that with herbicide use, their husbands or male labourers were tasked with spraying allowing for more supervisory roles. Additional time was usually repurposed to both economic and non-economic activities, mainly: [1] spending time with children and domestic tasks; [2] attending community classes; [3] mushroom cultivation; [4] rice seed bed raising economic activities; [5] cattle breeding and poultry. Beyond labour, females identified that money was particularly saved at the early stages of crop production through zero tillage and where possible they allocated these financial resources to cattle.

In terms of agency and empowerment, females broadly identified that they had an ambition to step away from agricultural duties, which was facilitated through CA. In North Bengal and northern Bangladesh, females also expressed interest in machinery operation, but usually in the context of mechanical rice trans planters and two-wheel tractors and not with four-wheel tractors. However, this was hampered not by any perceived stigma, but a lack of training opportunities and a reliance on male spouses to obtain agricultural information. Conversely, there was an acknowledgement in the potential loss of agency with an increasing knowledge gap -particularly around herbicides and operation of machinery that could potentially lead to disempowerment. Females also highlighted concern with transitioning to maize and away from wheat using CA, as poor performance on a crucial cash crop would implicate on household budgets and support to children. Hence, females were likely to be negative towards zero tillage maize production.

Exploring if CA is 'female friendly' is complex, particularly noting the varying levels of agency and empowerment across the EGP. Overall, there was more positivity than negativity, particularly from the perspectives and lived experiences of females in this study. This highlights a need to review extension mechanism that engage with females and address some of the highlighted concerns to ensure equitable promotion, benefits and uptake across the region. Future research also needs to encompass intrahousehold (beyond female spouses and decision makers) and intracommunity (female labourers) perspectives to further understand the impact of CA adoption on women.

Keywords: *Gender; Equitable development; female friendly; female workload*

INTRODUCTION

The Eastern Gangetic Plains (EGP) has experienced limited economic prosperity and is characterized by resource poor farmers with small land holdings with comparatively low agricultural productivity compared to the Western Gangetic Plains. Poverty, climate change, low literacy, seasonal migration and other institutional constraints add to the region's challenges (Pokharel *et al.*, 2018). Given these challenges Zero Tillage (ZT) as part of a Conservation Agriculture based Sustainable intensification (CASI) package is being promoted in the region to achieve sustainable agricultural intensification and has demonstrated potential benefits alongside savings in water, energy, labour and production costs, increased net returns and reduced climate related emissions (Gathala *et al.*, 2020, 2021).

However, the established benefits of CASI have not resulted in high uptake partly due to the relative novelty of ZT in the EGP but also due to constraining factors during implementation that impact long-term use. Weed management under CASI remains a challenge to CASI adoption by farmers (Bajwa, 2014) and weeding continues to be ranked high amongst problems faces by farmer under a transition to a CASI system (Poddar et al., 2017) despite the promotion of a weed management package to mediate pre-emergent and post-emergent herbicides (Bell, 2019).

The impact of weed growth and management under CASI are experienced differently by household members depending on their gender. Literature focused in Sub-Saharan Africa found that herbicide use is a key factor to achieving success under CASI system (Brown, Nuberg and Llewellyn, 2020) and farmers spent time saved engaged in other income generating opportunities (Kaumbutho *et al.*, 2017). However, studies also indicate more effort is required for weeding, a task typically performed by females (as opposed to land preparation that is traditionally done by males) (Baudron et al. 2017) and the unavailability or high costs of herbicide can undo the potential benefits of CASI and can actually increase labour burden for women (Giller et al. 2009) since many regions have predetermined tasks depending on gender which are not interchangeable due to existing socio-cultural norms (Farnworth *et al.*, 2016).

Literature from South Asia and the EGP continue to focus heavily on the agronomic impacts of CASI and its implication on weed management, without interrogation of the humanised aspects of roles, responsibilities and agency exchange. There have been limited work on CASI and gendered workload where in some cases women benefit from ZT use in terms of time (Singh, Kumar and Chand, 2007) whereas in male-led households the need to ploughing, a male task, decreased while there was an increase in labour requirements for weeding (Lai et al., 2012). But there are no studies that focus specifically on how gender interacts with changed weeding requirements and practices in any depth. This is particularly problematic as agricultural innovations that focus on productivity may potentially have unintended consequences that limit female farmers as they tend to lose control over resources traditionally managed by them once it becomes lucrative for men to take over the production and marketing (Doss, 2001; Berti, Krasevec and FitzGerald, 2004). It is imperative to explore the gendered impacts on the roles and responsibilities within a household when a decision is taken to adopt CASI and the subsequent consequences in adapting to changing weed dynamics. To explore the implications of CASI adoption on women and men is hence the objective of this study, with specific efforts to explore two hypotheses, that the adoption of herbicide based zero tillage in South Asia [1] mimics observed increased female burden (roles, time contribution, and responsibilities) experienced in Sub-Saharan Africa; and [2] leads to one gender of the household spouse becoming a knowledge holder for weed management.

METHODS

Site and Respondent selection

Study locations across Nepal, India and Bangladesh were selected based on prior and current project engagement with communities who have been engaged in CASI activities since 2014. Before implementing the study, a pre-screening process was undertaken to identify households that: [a] intended to plant either maize or wheat during the 2019 Rabi (non-monsoon season) season; and [b] had both decision making spouses engaged in crop management during first 5 weeks of post Rabi planting. Pirgunj and Birgunj in Rangpur/Dinajpur (Bangladesh) and Dinhata in West Bengal (India) were selected for Maize while Ghughumari in West Bengal (India) and Bokhara in Sunsari (Nepal) selected for Wheat. Only one node was selected in Nepal as the pre-screen indicated insufficient households to meet selection criteria in a second community accessible for this study. In total, fifty individuals in five communities took part in this study.

The type of CASI implemented varied based on location with a two-wheel tractor strip-till attachment in Bangladesh due to existing norms in the minimal management of weeds in maize crops and a four-wheel Zero-Tillage Multi-Crop planter attachment in India and Nepal. In Bangladesh with a more comprehensive weed management. Herbicide use outside of zero tillage production systems was minimal in all locations.

The survey adopted a gender-neutral design with the intention to study comparisons on spousal gendered knowledge, as well as perceived and experienced labour changes due to transition from a conventional tillage to zero tillage land preparation system. In total, each of the 5 locations had 5 household pairs participate for a total of 25 households and 50 participants. One exception occurred in Nepal where a mother and son were paired as spouses due to the refusal of the husband at late notice to participate in the study.

Survey Design

This study collected quantitative, qualitative and visual data using mobile phones to deeply assess weed identification and knowledge skills and changing roles and responsibilities due to ZT implementation using 'kobo collect' Open Data Kit form and implemented through four purposively trained facilitators. In addition, a 'Photovoice' method was employed to collect data as the primary method to collect quantitative, qualitative and visual data. The photovoice method facilitates engagement of individuals seldom involved in the decision-making process despite the subsequent impact on their livelihoods. Developed by Burris and Wang (1997) this methodology deepens the understanding of explored issues and promotes critical dialogue and knowledge through photographs and community discussions to eventually influence policy makers. Facilitators selected were already working in their respective communities and received training on data collection, basic photography skills along with a manual of standard protocols to ensure ethical compliance throughout the study period. Potential participants were prescreened to ensure match criteria for the purposes of the study. Facilitators conducted similar training with male and female participants in the selected sites and seek written consent to participate in the study and grant access to use their photographs from the study. The only provision to participants was the gifting of printed photos of their choice that were taken each week after they had completed their research activities.

The study was conducted once a week on the same day for five weeks post planting, with the first instance two weeks after planting in their respective ZT plot. Facilitators provided a separate mobile phone to male and female participant for the entire day to complete the tasks assigned at a suitable time depending on their work schedule. Each participant was asked to independently visit the ZT field identify the presence of plants that they did not sow in their assigned ZT plot (hereafter 'weeds') and pluck the weeds along with its roots and bring back for further discussion. For validation participants were also tasked to take a 'selfie' and a photo from the assigned position and interrow at their plot. At the end of the day the facilitator photographed each weed separately on a laminated numerical scale and asked the participant to identify and provide further information for each weed on Kobo collect form. Participants were also asked to compare roles, responsibilities and activities in this plot with the non-ZT experience of the same plot. Additionally, on weeks three and five of the study period, participants were asked to identify, visually capture and discuss the 'most significant change' in their livelihoods due to CASI. Participants took a representative photograph and their responses were collected by the facilitator and their verbal responses were audio recorded.

Data Size, Collection and Analysis

The 25 pre-screened household level Kobo entries paired with 247 Kobo forms encompassing weekly weeds diary for a period of five weeks (there was attrition for three weekly inputs due to sickness in one household). A total of 898 weed photos were collected by participants across all sites. All data was downloaded and analysed in Microsoft Excel. Three agronomists with regional expertise identified the scientific names of each weed for cross reference. Later the weeds and their local names identified by each participant during the five-week period were cross-checked with agronomist data to analyse the level of weed knowledge of the participants.

RESULTS

Time contributions to Weed Management in first five weeks

All respondents benefitted in total time spent weeding (includes personal weeding and supervision of others weeding) when transitioned from Conventional Tillage (CT) to ZT. Only four out of 50 respondents, male farmers from Pirganj, experienced increased time spent weeding. Findings are similar for individual weeks with only 10 out of 247 weekly entries with an increase in time spent weeding in a ZT field compared to if the same field were a CT field (primarily the same respondents as above). There was an 85% reduction in total time spent weeding reduced from 51.3 hours in CT to 7.7 hours in ZT in the first five weeks. This reduction was highest in the wheat system in India (from 131.7 hours to 13.6 hours) and lowest in Bangladesh (from 5.7 hours to 3.1 hours) indicating low personal weeding engagement and more supervisory tasks in Bangladesh compared to India and Nepal (Figure 1).

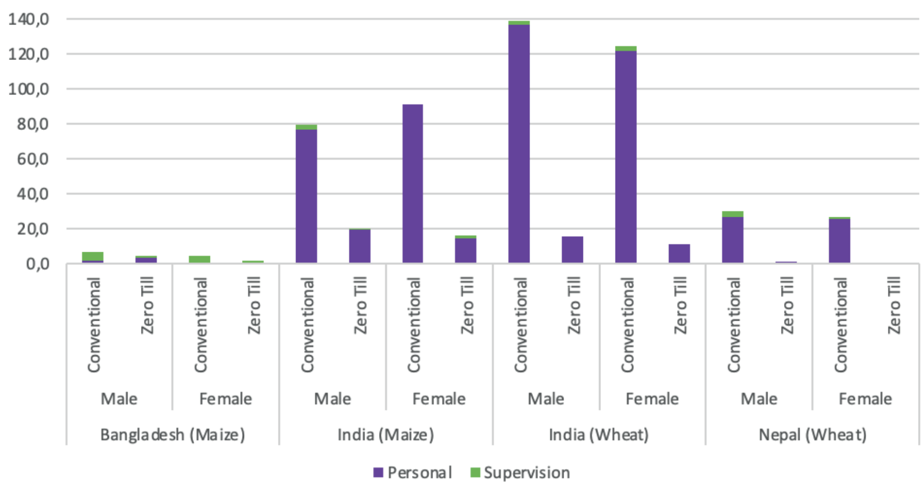

Figure 1: Comparison of total hours spend on weeding related activities in first 5 weeks post planting.

Male farmers in Bangladesh transitioned from supervisory to personal weeding roles, while still experienced reductions in overall time spent on weeding activities, while female farmers experienced no personal engagement in weeding tasks as well as time reduction in supervisory tasks. In India and Nepal, personal weeding time was substantially reduced by 84% except for one case and female farmers tend to save more time compared to their male spouses. In wheat systems, both men and women experienced no personal engagement in weeding tasks while female farmers under maize systems gained a new task, supervision of weeding activities, but still managed to save time overall.

Contrary to the common narrative that has emerged around weed management as a major constraint to the out scaling of ZT and CASI in South Asia (e.g. Bajwa, 2014; Poddar, Uddin and Dev, 2017), our results suggest that weed management aligns positively with reduced time and no reallocation of roles or burden when herbicides are used. Likewise, the situation of ZT being female un-friendly and adding burden to females, particularly in sub-Saharan Africa (e.g. Baudron *et al.*, 2009;

Farnworth *et al.*, 2016) is also contradictory to our findings for South Asia. Our respondents indicate that ZT saves substantial time in India and Nepal, and on balance more so for women.

Based on time savings alone, very few in the study were disadvantaged by a transition from CT to ZT. The only participants to be disadvantaged were men in one community in Bangladesh, where increased time was marginal and already low. This partly reflects similarities between normalised weed management between CT and ZT activities in Bangladesh, whereby weeds in maize systems are not managed via manual weeding or herbicides due to the perception that maize will outgrow the weeds and they will not affect production. There is also use of strip tillage machinery as opposed to zero tillage machinery in Nepal and India. Hence, CT and ZT in Bangladesh returned very similar labour inputs.

Weed Identification Skills

Based on the scientific name of the identified weeds, substantial differences in weed identification skills between spouses were evident, and males and females tended to identify different weeds in the same ZT fields. Of the 898 weeds submitted, 654 weed incidents were identified (i.e. an incident meaning either spouse identified a weed in a particular week), yet only 28% of weed incidents were identified by both spouses (Figure 2). This divergence in identification skills was more substantial in maize than wheat locations, and in Bangladesh compared to other locations investigated. In Nepal, males appear to have a higher likelihood of identifying weeds their spouse did not, but this gendered trend did not emerge in other locations.

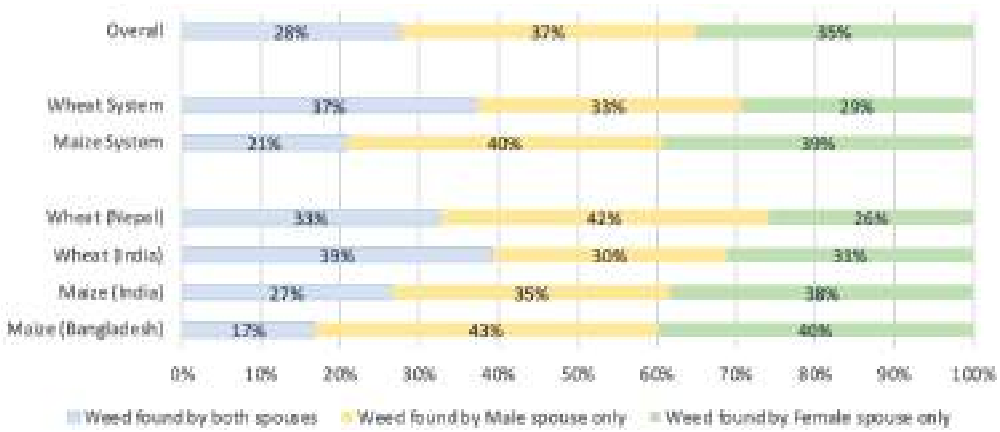

Figure 2: Identification patterns based on if both or only one spouse identified the presence of a weed in their ZT field. A higher proprotion of plants found by both spouses (blue) indicated a higher common identification of the weeds present in their ZT field.

There was substantial incidence of an inability of participants to nominate a local name for an identified weed (27% of all identified weeds), suggesting a substantial knowledge gap in weed identification and management. This knowledge gap was more evident in maize (33%) as opposed to wheat (21%), and substantially higher in Bangladesh than other locations (37%).

Regardless of gender, respondents have overall limited understanding of the weeds that were in their ZT fields. Respondents often dual identified the same weed with different names and were often unable to provide names for identified weeds. This indicates an overall information gap in how to manage weeds. This was more strongly prevalent in maize systems, and in Bangladesh which likely reflects the relatively recent introduction of maize as compared to wheat in the region, as well as a tendency for weed management activities in Bangladesh to be supervisory, as compared to India and Nepal were personal weeding dominates.

Perception of Exchanged Roles and Responsibilities

Within the household, there was no identified perception that responsibility for weeding (either personally weeding or spraying or finding, managing or cooking for hired labour) or role in personally or supervisory weeding activities changed between CT and ZT systems (94% of the 350 comparisons between CT and ZT recorded the same responsibility when compared by respondents). Bangladesh participants were nearly unanimous in indicating no changes in roles, both supervisory and personally weeding with the transition from CT to ZT. This suggests no inequitable reallocation of roles between spouses, and especially from males to females.

How do spouses assess 'most significant change' due to CASI?

Unstructured recordings based on reflections of participants on the 'Most Significant Change' provided various interpretations on what the most important change or benefit due to CASI adoption was. However, a commonality was found in time savings (44 out of 50 respondents mentioned saved time due to CASI). Both genders across all locations identified utilizing their additional time to grow fresh vegetables for both sustenance and selling produce.

Other trends observed include that females were more likely to respond that they spent increased time with children and had additional time for household chores through adopting ZT. Many female respondents across all three countries had diversified their livelihood portfolio by rearing cattle. Alternatively, some men were seen to invest back in agriculture. It was common to invest in machinery with the profits their household generated and use the machinery to help others irrigate or plough their field, taking rent and thereby generating more profit.

Location specific trends were also evident. In Bangladesh, households tended to identify utilizing profit generated towards either their children's education or diversifying their livelihood portfolio. Particularly in India families purchased TVs and motorbikes, built concrete homes and sheds for cattle and women were involved with mushroom cultivation. In Nepal, households collectively agreed that overall investment decreases while productivity increases as they spend less on irrigation and fertilizers.

Life has generally improved for respondents (e.g., "after practising ZT, time is saved and I do mushroom farming with my hands. I am getting income from this and I am using it for my kids expenses, spending on farming. Now it is not difficult for us"). From a gendered analysis, it can be seen that additional time can be used either to address culturally expected norms (e.g., "Zt will finish in one hour, then I can cook food in the kitchen, send kids to school and help them study"), but can also provide new opportunities for independence (e.g. "I use this income from my won need sand I don't have to ask for money from my husband").

LIMITATIONS

It should be noted that this is a small, in-depth study with a limited number of participants and no sweeping recommendations are possible. Further, due to COVID-19 researchers were unable to return to the investigated communities and explore findings with them, and hence this study should be seen as a first step towards closing a gendered knowledge gap on how transitioning to CASI impacts household knowledge and labor allocation, previously uninvestigated in South Asia.

CONCLUSION

This in-depth analysis indicates that ZT as part of a CASI based land preparation system has substantial benefits in time saving in India and Nepal, and that in all study locations there is no shifting of burden in weeding from males to females. There is reason to suggest that South Asia may not fit the same category as Sub-Saharan Africa in increasing female roles, responsibility and burden. Despite this, knowledge on weeds that occur in ZT fields was limited and indicates that more extension efforts should be focused on weed management and herbicide use as it becomes normalised in the agricultural production systems of the EGP. In terms of significant changes due to CASI, location specific trends indicate diversity in the utilization of financial and time savings. Overall, this study highlights that CASI systems in South Asia appear to be equitable in terms of time savings during crop production, pointing positively to the plans for subsequent scaling out in the region. However, diversity does exist across the EGP and particularly in Bangladesh a different set of benefits and drivers may alter future promotional efforts.

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Agro-economic performance of mechanized Conservation Agriculture in Zambia

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Conservation Agriculture (CA) is depicted as a climate-resilient and sustainable practice capable of enhancing food security in sub-Saharan African (SSA) countries. However, its continued promotion and adoption has been predominantly on a non-mechanized small-scale basis. Despite the ample evidence of the positive benefits of CA, including enhanced yield, carbon sequestration and minimal soil degradation, its adoption remains low in Zambia. Improved mechanization results in increased agricultural productivity; yet, this potential has not been harnessed in Zambia, making CA labour intensive and unattractive to farmers. The objective of this study was to investigate the potential differences between mechanized conventional and conservation tillage practices on operation time, fuel consumption, labour costs, soil moisture retention, soil temperature and crop yield. On-farm mechanized CA experiment in a randomised complete block design with four replications was employed on a 15ha plot with two crops, maize and soyabeans. The three tillage treatments were: residue burning followed by disc harrowing, ripping tillage and no-till. The crops were rotated in two subsequent seasons. All operations were done using a 60hp 2-wheel tractor, a disc harrow, a two-tine ripper and a two-row planter. Soil measurements and the agro-economic factors were recorded for two farming seasons. The results showed that the yield of maize and soyabean under no-till and ripping tillage practises were not significantly different from the conventional burning and discing. There was a significant difference in soil moisture retention per cubit unit of soil between no-till (0.300±0.198 m^3/m^3) and disc-harrowed (0.168±0.011 m^3/m^3) plots at depths from 10-60 cm. Soil temperature in no-till plots was significantly lower compared to the disced plots at the depths 15 cm and 45 cm. For maize, there was a significant difference in operation time between both disc-harrowed and ripped and no-till plots, and a significant difference in fuel consumptions between disc-harrowed (18.67±1.25 l/ha) and ripped (14.46±1.82 l/ha) and no-till (8.90±1.52 l/ha) plots for the two seasons. There was no significant difference in the cost of labour between disc-harrowed (102.7±20.7 $/ha) and no-till (76.6±14.6 $/ha) plots. For soyabeans, operation time on no-till (2.50±0.28hr/ha) plots was significantly different from the ripped (3.99±0.54 hr/ha) and disc-harrowed (3.72±0.64 hr/ha) plots for the two seasons. Further, fuel consumption on no-till plots was significantly lower than both the ripped and disc-harrowed plots but not the labour. The high maize plant densities were not significantly different between the treatments for the two seasons. There was a significant difference between soyabean plant densities in the no-till and ripped plots compared to the disc-harrowed plots. These results indicate that MCA is economical and time-saving. Its yields are also viable compared to conventional farming. This research fills the gap on the potential of mechanized CA in the context of Zambia and its feasibility to incentivise policymakers to invest in appropriate and sustainable machinery and implements for improved small and medium-scale agricultural production.

Keywords: *Climate-smart Agriculture, Mechanized Conservation Agriculture, Soil moisture, Yield, Zambia*

INTRODUCTION

Conservation Agriculture (CA) has been widely promoted in SSA among farmers and various stakeholders as one of the sustainable and resilient practices capable of improving agricultural productivity and reducing climate change impacts (Corbeels et al., 2014; Thierfelder et al., 2017; González-Sánchez et al., 2018). Despite this promotion, CA's adoption is still considered low. SSA's cropland area under CA is 1.55 Mha (2015/16) while Zambia is 316,000 ha compared to the total cropland area of 3.8 Mha (Kassam et al., 2020). CA's promotion and adoption in Zambia have predominantly targeted smallholder farmers who heavily rely on hand tools and operate relatively smaller farm sizes. Nevertheless, CA research outputs centering on these smallholder farmers have reported remarkable benefits in terms of enhanced yield, socio-economic improvements and environmental conservations compared to conventional farming systems (González-Sánchez et al., 2018).

The majority of smallholder CA farmers in Zambia are dependent on human labour and animal draft power for production. Thus, the approach of promoting CA through smallholder farmers is reportedly constrained by high labour and time demands as well as cross-cultural issues that deter farmers from operating large pieces of land or make them abandon the practice altogether. Besides, the three principles of CA as minimal soil disturbance, permanent soil cover and crop rotation does not always fit the farmers' conditions and thus are prone to some degree of modification. However, even though the use of tractors (both two and four-wheeled) is still limited (Corbeels et al., 2014), mechanization and market-oriented production systems are on the rise in Zambia. Emerging small and medium-scale farmers are increasingly buying or hiring tractors for land preparation (Adu-Baffour et al., 2019). The emergent farmers tend to carry out agricultural operations on farm sizes ranging from 5-20 ha (Sitko & Jayne, 2014; Banda et al., 2018). Researchers have noted the use of tractors as a foundation for the uptake of mechanized CA among smallholder, emergent and large-scale farmers in Zambia (Grabowski et al., 2014; Thierfelder et al., 2016).

However, despite the steady growth of emergent farmers in Zambia, less research has examined the potential of mechanized CA to improve productivity as opposed to the conventional ploughing and disc-harrowing commonly done by emergent farmers (Sitko & Jayne, 2014). Thus, this experimental research seeks to investigate the potential of medium-scale mechanized CA in order to inform discussion on its potential for developing sustainable agriculture in the region. Specifically, the study seeks to:

investigate the short-term agronomic and yield differences of maize and soyabean grown under mechanized CA and mechanized conventional disc-harrowing practice, and evaluate the socio-economic performance of mechanized CA compared to conventional disc-harrowing tillage in terms of the operation time, labour costs and fuel use.

MATERIALS AND METHODS

2.1 Study site

The study was carried in the Central Province of Zambia at the German-Zambian Agricultural Knowledge and Training Centre (AKTC) located within the Golden Valley Agricultural Research Trust (GART) in Chisamba district, 65 km north of Lusaka city. AKTC is located in the Zambian agricultural ecological zone IIa, which is characterized by fertile red-brown acrisols (clay soil) (Fig. 1). The experiment was done in two consecutive seasons 2019/2020, and 2020/2021 and maize and soyabean crops were planted, maize being the staple food crop while soyabean as a cash crop (Mofya-Mukuka & Hichaambwa, 2018). Before the trial establishment, soyabean had been continuously planted on the plot but was then left fallow for three years due to poor yields that ensured. The total in situ rainfall recorded was 714mm and 1068mm for the 2019/2020 and 2020/2021 seasons respectively.

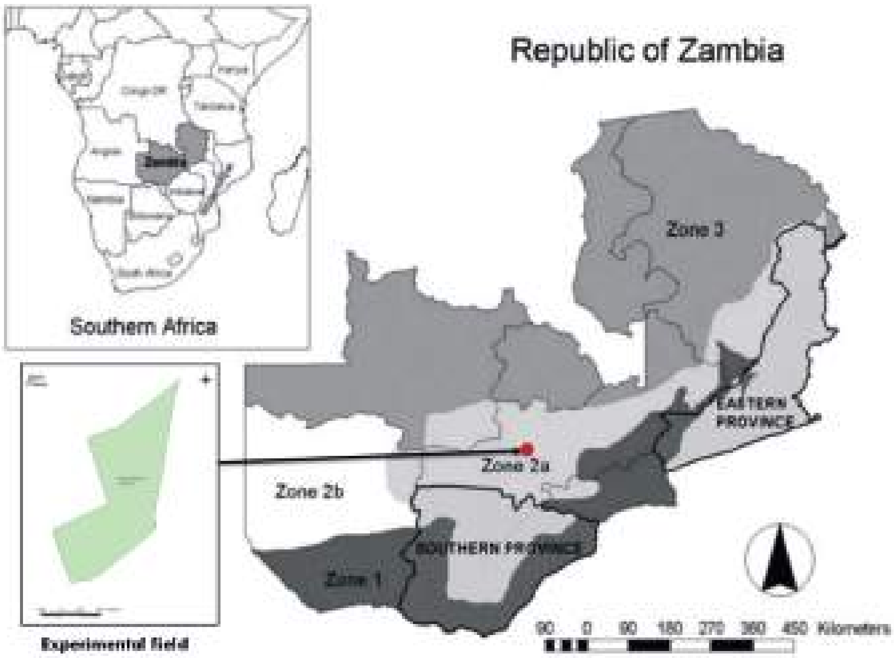


Fig. 1: A map showing agro-ecological zones of Zambia and the study area location.

2.2 Experimental design

The 15 ha on-farm experiment was based on both Mechanized Conventional Farming (MCF) and Mechanized Conservation Agriculture (MCA) under the rainfed farming system for two seasons. All farm operations were fully mechanized: a disc harrow and a planter were used for conventional farming while a ripper and a no-till planter used for conservation farming. To ensure internal validity and reproducibility of the experiment, the land was divided into two main plots (8 ha maize and 7 ha soya bean) and a randomized complete block (RCBD) design was adopted to assign the treatments within the blocks (Piepho et al., 2011). Three tillage treatments (disc-harrowing, ripping tillage and no-till) were replicated four times totaling 12 experimental units per crop. The conventional disc-harrowed treatment included the burning of crop residues before discing while ripped and no-till treatments ensured at least 30% residue retention (Inagaki et al., 2017). The average size of maize experimental units was 0.60 ha (24m x 265m) while soya bean was 0.50 ha (24m x 220m). Medium maturing maize (SC633) and drought-tolerant soyabean (SC safari) varieties were planted. Subsequent operations like fertilizer applications, herbicide, fungi and pest control were done using a 2WD 60 hp MF tractor, and the crops rotated in the subsequent season. The maize plant spacing of 75x25 cm with an expected population of 53,000 plants per hectare at a seed rate of 25kg ha^{-1} and soyabean spacing of 75x5 cm with an expected population of 266,000 plants per hectare at a seed rate of 80 kg ha^{-1} were used (Mupangwa et al., 2017). The operation time recorded using the 'Time-Tracker App' (Daum et al., 2018), fuel consumption measured using 'DUT-E S7'fuel level sensor installed on the tractor's fuel tank (Technoton, 2020) and labour charges based on the local market rates, were recorded for all the operations across the three treatments.

2.3 Agronomic considerations and data collection

Uniform application of basal fertilizers, phosphate compound WMB (Wheat, Maize with Boron) for maize applied at the rate of 300 kg ha^{-1} (36 kg N ha^{-1}, 61.8 kg P ha^{-1}, 43.2 kg K ha^{-1}, 1.5 kg Zn ha^{-1} and 0.3 kg B ha^{-1}) and phosphate compound MDC06 (Mpongwe Development Company, 2006) for soyabean at the rate of 225 kg ha^{-1} (14.7 kg N ha^{-1}, 50.6 kg P ha^{-1}, 53.1 kg K ha^{-1}, 4.5 kg S ha^{-1}, 1.1 kg Zn ha^{-1} and 0.7 kg B ha^{-1}) were used for two seasons. Maize was top-dressed using ammonium sulphate applied at the rate of 200 kg ha^{-1} (42 kgNha^{-1} and 48 kg S ha^{-1}) and green sulphur applied at the rate of 300 kg ha^{-1} (84.5 kg N ha^{-1}, 15.6 kg S $ha^{-1}$and 16.25 kg Ca ha^{-1}) 4-5 weeks after germination (Mupangwa et al., 2016; Kiboi et al., 2017). Potassium chloride was applied to soyabean plots at the rate of 100 kg ha^{-1} (60 kg K ha^{-1}), four weeks after germination as a top dressing (Mupangwa et al., 2017). Weeds, pests and fungi control on both the CA and conventional plots were done using appropriate herbicides, pesticides, insecticides and fungicides applied using a 12m wide 600-litre boom sprayer mounted on a 60-hp tractor and the applications were kept constant across the three treatments (Mupangwa et al., 2016). Two ADCON SM1 soil moisture sensors were installed on the no-till and disc-harrowed plots to record daily soil moisture content at every 10 cm depth from the soil surface to 60 cm depth and daily soil temperatures at depths of 15 cm and 45 cm. Both crops' plant population at germination were determined for the two seasons and crops harvesting done at physiological maturity and recommended grain moisture contents. The yield measurement of the two crops was established by plot sample harvesting of 10 points of area 7.5m2 in each treatment, then extrapolated to give the yield per hectare (Mupangwa et al., 2019). Once the total yield in every plot for the two crops was done, rainfall use efficiency (kg/mm) for the two crops and the three treatments was computed as the ratio of the total yield and the total rainfall recorded (Thierfelder & Wall, 2009).

Data analysis

The measured variables per crop, plots and treatments were done using Minitab 18 statistical software. The crops yield data were subjected to normality tests and analysis of variance (ANOVA) using the randomized complete block design (Mupangwa et al., 2016). The effect of season and tillage treatment on yield were evaluated using ANOVA, and the F and least significant difference (LSD) tests done at the $p \leq 0.05$ (Jat et al., 2019). Data regarding labour costs, time, fuel consumption, plant population, soil moisture content and temperature soil were also tested for normality and subjected to analysis of variance.

RESULTS

3.1 Soil moisture contents and temperature

No-till plots recorded higher soil moisture retention at 10cm, 30cm and 60cm while disc-harrowed plots recorded relatively high moisture contents at 20cm, 40cm and 50cm (Fig. 2a). The highest moisture content at maximum depth was 0.300±0.198 m^3/m^3 in no-till plots compared to 0.168±0.011 m^3/m^3 disc-harrowed plot. This denoted a 44% significant difference of soil moisture available for crops in the no-till plots compared to disced plots throughout the season. On the other hand, soil temperatures were higher in disc-harrowed plots both at 15cm and 45cm compared to the no-till plots for the two seasons (Fig. 2b).

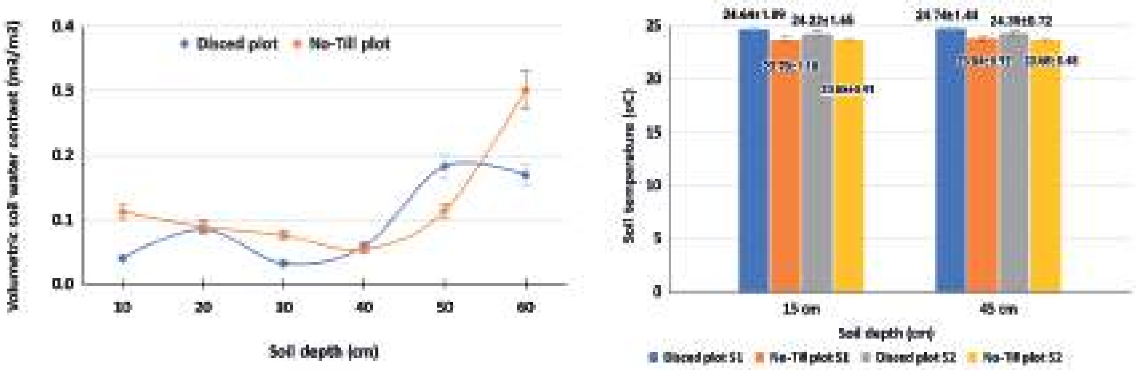


Fig. 2: Volumetric soil moisture content (m^3/m^3) and temperature (°C) comparison between no-till and disc-harrowed plots across 10-60 cm soil profile throughout the 2019/20 and 2020/21 seasons.

3.2 Plant population and yield

The maize population densities at germination were not significantly different across the three tillage treatments and the targeted population for the two seasons. Nevertheless, the no-till plot recorded higher plant density compared to disc-harrowed plots for the seasons (Table 1). For soyabean, plant population densities in the disc-harrowed plots were significantly lower than the ripped plots in the first season and both ripped and direct-seeded plots and the targeted population in the second season. However, there was no significant difference between the soyabean plant densities in the ripped and no-till plots.

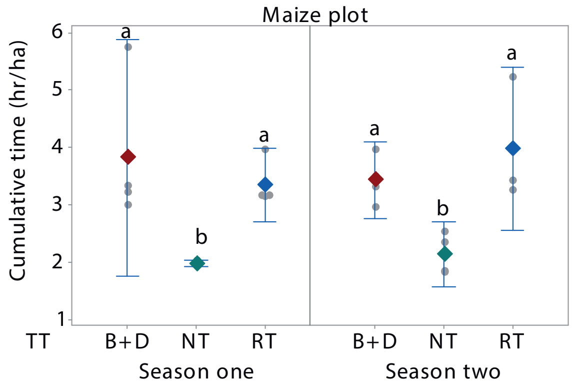
Table 1: Maize and soyabean plant densities, grain yield ($kgha^{-1}$) and rainfall-use efficiency ($kgmm^{-1}$) comparison between tillage treatments.

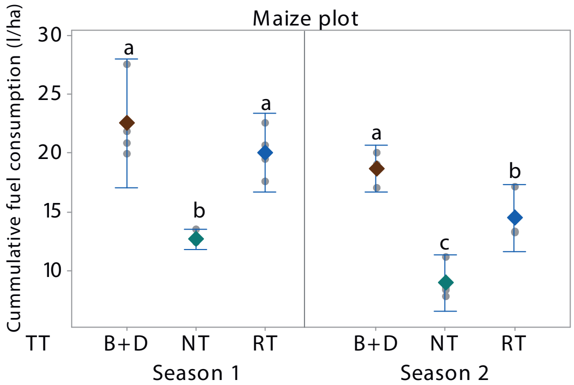
Crop	Tillage type	Plant population (ha-1)		Crop yield (kg/ha)*	Rainfall-use efficiency (kgmm-1)*
		2019/2020 Season	2020/2021 season		
Maize	Disc-harrowed	51,867a	54,289a	7,792a	10.91
	Ripped	49,579a	54,778a	7,873a	11.03
	No-till	52,033a	54,378a	7,802a	10.93
	p-value	0.463	0.915	0.969	
	SED(n)	2118(120)	1231(120)	348(40)	
Soyabean	Disc-harrowed	18,1741b	23,8059a	2,843b	3.98
	Ripped	22,8825a	28,0025b	2,997b	4.20
	No-till	21,6252a,b	28,5753b	3,120b	4.37
	p-value	0.024	0.010	0.499	
	SED(n)	14338(60)	12978(60)	0.222(20)	

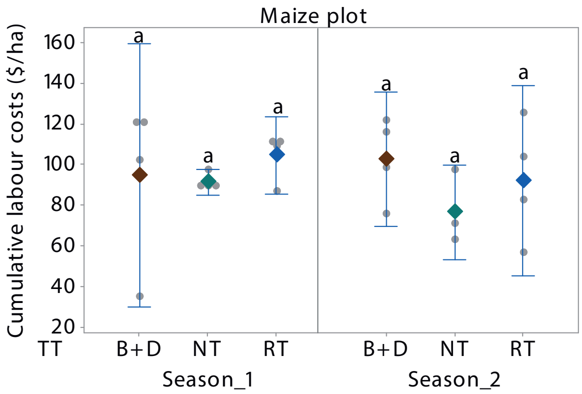
[a]Means that are not labelled with the letter 'a' are significantly different from the other means at $p \leq 0.05$ probability level, LSD-test, SED – standard error of difference. Note: * Crop yield and rainfall-use efficiency values are only for the 2019/2020 season.

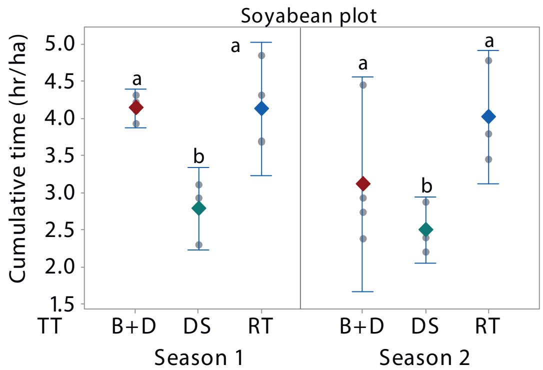
The conservation tillage practices (ripping and no-till) recorded higher yields for both maize and soya beans compared to the conventional burning and disc-harrowing tillage (Table 1). The highest maize yields were recorded in ripped plots (7873 kg/ha) while for soyabean in the no-till plots (3120 ton/ha). However, there was no significant difference in yield among the three tillage treatments for both maize (p=0.969) and soyabean (p=0.499) in the first season. Similarly, higher rainfall use efficiency was recorded in conservation tillage practices than in conventional disc-harrowed treatment for both maize and soyabean (Table 1).

3.3 Operation time, fuel and labour costs









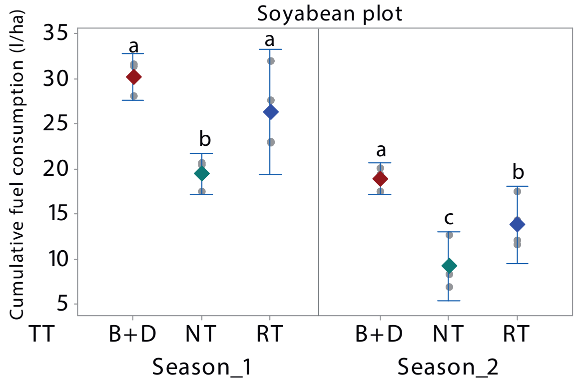
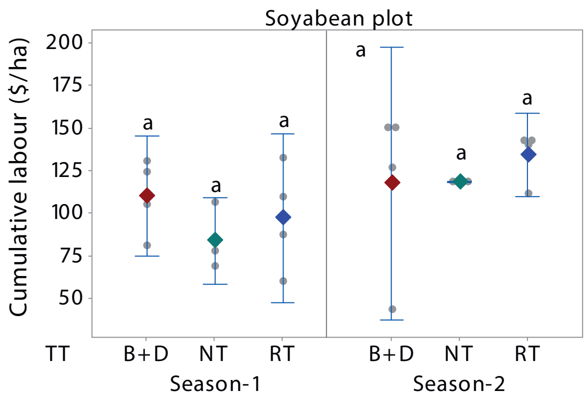


Fig. 3: Mean individual plots of maize and soybean's cumulative time, fuel consumption and labour costs for the three tillage treatments. aMeans that are not labelled with the letter 'a' are significantly different from the other means at p≤0.05 probability level, LSD-test. Note: B+D (residue burning plus disc-harrowing), RT (ripping tillage) and NT (No-till).



The individual plots (Fig. 3) show the mean of the cumulative operation time, fuel consumption and labour costs for all processes of land preparation, planting, fertilizer application, weeds, pests and fungi control for both maize and soyabean across the two seasons. Cumulative time (hr) per unit hectare taken to produce maize under disc-harrowed tillage (3.819 hr/ha) was almost twice the time need for no-till treatment (1.976 hr/ha). Time to produce soyabean per unit hectare under ripping tillage and disc-harrowed treatments were significantly higher compared to no-till treatment for the two seasons. There was no significant difference in operation time between ripped and disc-harrowed plots for the two seasons. Fuel consumption for ripped and disc-harrowed plots was significantly higher than the no-till plots for both maize (p=0.01) and soyabean (p=0.001) in the first season while in the second season fuel consumption in conservation ripped and no-till plots were significantly lower than the conventional disc-harrowed plot. Further, the cost of labour for maize production was higher in disc-harrowed and ripped plots than no-till plots even though not significantly different (*p*=0.684, *p*=0.343). On the other hand, there was no significant difference between the labour cost for soyabean production in three treatments (*p*=0.304, *p*=0.694). However, labour costs were higher in disc-harrowed and ripped plots than the no-till treatments for the two seasons.

DISCUSSIONS

4.1 Soil moisture and temperature conservation under MCA

Minimal soil disturbance and soil cover are very important principles of CA since they impact the soil structure, water infiltration, water retention and soil biological activities while limiting excessive erosion, evaporation and run-off (Palm et al., 2014). In this study, the soil moisture and temperature differences between no-till and disc-harrowed plots on the sandy loam experimental plot were evaluated. Contrary to the reported delayed CA differences, this research showed a positive difference right from the first season. Soil moisture availability in the no-till plot was uniformly distributed across the soil profile (10-60 cm) compared to the burned and disc-harrowed plots. Similarly, soil temperature was high in disc-harrowed compared to no-till plots. The availability of residues on no-till plots and the lack of residues on the disc-harrowed plots potentially impacted the water infiltration, evaporation rates from the soil and evapotranspiration from crops causing the moisture and temperature differences. These findings conform to previous studies which showed that the continuous pores system available in no-till plots enhances water infiltration while the soil mulches improve moisture retention (Thierfelder & Wall, 2009). Soil moisture retention is specifically important in drought-prone areas like Zambia that receive sporadic dry spell within the season (Mupangwa et al., 2016). The presence of high soil moisture at the top 10 cm and deep 60 cm on the no-till plots depict water availability to plant root hairs both at the early stages of crops development and through to maturity. Soyabean and maize have different root structures: taproots and fibrous roots, respectively. While maize fibrous roots can grow to the maximum depths of 180-300 cm, soyabeans taproots can reach up to 150-200 cm at the maturity stage (Ordóñez et al., 2018). But, during the early crop development stages, access to water at 20-30 cm and below are crucial for growth (Thierfelder & Wall, 2009).

There was a strong correlation between soil moisture content, crop yield and rainfall use efficiency across no-till, ripped and disc-harrowed plots for the two crops. The high moisture content at 60 cm on the no-till plots and the residue cover were both strong indicators against crop failure due to water stress thus potentially good yield. The higher yield and rainfall-use efficiency recorded on no-till and ripped plots than the disc-harrowed plots for both maize and soyabean crops contradicts some reported discourses of CA yield penalties especially in the initial years of its adoption (Tittonell & Giller, 2013). Further, these results show that MCA utilizing residue cover and minimal soil disturbance can aid risk-averse small and medium-scale farmers from crop failure while reaping from increased yield as early as the first season of adoption (Lalani et al., 2016).

4.2. Agronomic benefits of MCA over conventional practices

The plant population for both the maize and soyabean depicted high emergence percentage for the two seasons. However, the low soyabean plant population recorded in disc-harrowed plots was an indication of germination hindrance either due to hardpan or large clods on disced plots. Even though the plant densities in no-till and ripped plots were not significantly different from the disc-harrowed plot, the harvested moisture on the ripped or no-till lines impacted seed germination on the conservation plots.

From the onset, conservation tillage practices recorded relatively higher yields compared to the conventional disc-harrowing considering the medium rainfall amounts (714 mm) recorded in the first season (Grabowski et al., 2014). The fact that no-till and ripped plots yields were both higher for maize and soyabean highlights the potential short-term benefits of MCA practice. These findings concur with related work at Monze, Zambia with recorded a maximum yield of 4877 kg/ha, 5141 kg/ha, 5240 kg/ha and 6220 kg/ha for conventional ploughing, direct seeding, basin planting and direct-seeded rotation respectively (Thierfelder & Wall, 2009). The yields recorded in all the tillage treatments were above the national average maize (1900 $kgha^{-1}$) and soyabean (900 $kgha^{-1}$) yield. These results further reveal a significant impact of tillage treatment on the yield potential of both maize and soyabean even when all agronomic managements are held constant. These findings deviate from previous results that yield differences in CA is dependent on nutrient management and not on tillage treatment especially among smallholder farmers (Thierfelder et al, 2013). This implies that with adequate nutrient application and residue retention, mechanized conservation tillage practices perform better than conventional practice right from the first year of adoption.

4.3 Socio-economic differences of MCA

Socio-economic facets such as labour and time constraints have been cited as the leading stumbling blocks to CA adoption among smallholder farmers in Zambia (Mupangwa et al., 2017). Even though time, fuel consumption and labour aspects considered were in the context of mechanized CA, these results are useful, particularly when dealing with small and medium-scale farming using or intending to employ mechanized CA. These results show that a significant amount of time is saved during land preparation and planting operations in no-till plots compared to disc-harrowed and ripped plots. Tractor ripping tends to take more time because of the depth and low speed required to maintain ripping depth, thus, even with minimal soil disturbance, the operation time is not significantly different from the disc-harrowing. This suggests that no-till can improve work efficiency and reduce the CA drudgery experienced while using hand-held tools common among small and medium-scale farmers. Efficient energy use is critical in all farming operations. This research revealed that no-till and ripped operations could save close to half the fuel used in disc-harrowed plots. A reduction in fuel costs will have a direct impact on the net benefit of CA over conventional practices and incentivize service-providing emergent farmers keen on maximizing profit. Yet, the cumulative cost of labour for all the mechanized operations from land preparation to harvesting was not significantly different across the three treatments. Nevertheless, high labour charges were incurred in disc harrowing and ripping than on no-till plots for the two seasons. Mechanized CA in cooperating maize and soyabean rotations is cited to attract higher economic benefits while minimizing the risks of crop failure commonly experienced by conventional practices (Mupangwa et al., 2017).

CONCLUSIONS

This study examined the potential of mechanized CA tillage practices compared to the conventional disc-harrowing after burning the residues. On-farm experiment with plots reproducible and comparable to the small and medium-scale farmers farm sizes was planted with maize and soyabean under three tillage treatments while all the agronomic operations kept similar. Results showed that with adequate agronomic management, benefits of MCA in terms of soil water conservation, reduced soil temperature, socio-economic savings and better crop yields are attainable on a short-term basis. These accrued benefits of MCA can incentivize the medium-scale emergent farmers seeking to mechanized their farm operations through tractor hire services or acquisition of tractors and implements. Furthermore, considering emergent farmers as potential multipliers, their adoption of MCA harbours an inferred impact on the majority of smallholder farmers who might easily access tractors and CA implements.

This work also reveals that MCA can impact farmers' overall crop yield, soil and water conservation and economic gains both over a short- and long-term practice. This insight is of particular interest especially in informing policymakers, government stakeholders and international CA promoting agencies for strategic efforts concerted in ensuring the availability of both locally and international acquired machinery and equipment fit for both the small and medium-scale CA farming in Zambia. Based on demonstrated agronomic and socio-economic benefits, MCA practice can potentially spur CA adoption across all classes of farmers and impact the overall agricultural performance of many SSA countries.

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Conservation Agriculture (CA) has to move on

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After nearly five decades, zero tillage (no-till), the bedrock of CA, is *dejá vu* in Brazil. But CA is not just leaving the soil protected with residues or cover crops and planting/drilling crops through them, quality CA also requires a pluriannual rotation, frequently absent. It is also evolving by incorporating new compatible and sustainable technologies. Farmers, including organic farmers, are learning how to incorporate innovative biological and mechanical methods for disease, pest and weed controls, reducing pesticide and fertilizer use; the Farmer Responsibility Index underlines significant recent reductions in chemical hazards. As consumers demand greater food traceability, certification and benchmarking will continue to expand, while increasing complexities in soil, water, crop and livestock management are demanding higher skill levels and widespread use of specialized consultants. The success and longevity of the CA movement will depend on incorporating and promoting new compatible and sustainable technologies, such as biological controls, precision agriculture, controlled traffic farming, and drones for scouting and spot spraying. CA then provides land use intensification to reduce horizontal expansion, improved aquifer recharge, erosion control and other important environmental benefits, plus increased profit and lower food prices, with less negative environmental impacts. Historically, the environment has suffered, therefore, the above urgently requires more promulgation, backed by research. To expand the scope, and hence the definition, of CA, the following questions need to be addressed: (i) can CA become the umbrella definition for all these technologies; and, (ii) how do we adjust the concept to achieve this? One approach would be a CA base definition, with clarifying adjustments, and a list of approved compatible technologies. A challenge that needs to be addressed is from the novel label "Regenerative Agriculture" (RA), not yet scientifically defined but clearly based on CA principles. One approach would be to recognize CA as a *sine qua non* of agricultural sustainability, especially in the tropics, and the need to define additional science-based technologies that differentiate new labels from CA.

***Keywords**: Innovative technologies, agricultural sustainability, organic agriculture, Farmer Responsibility Index, Land Use Intensification, environmental impacts*

INTRODUCTION

In Brazil today, 50 years after its introduction, Zero Tillage (No-Till management system), the bedrock of Conservation Agriculture (ZT/CA), as defined by Freitas and Landers (2014), is d*ejá vu*. ZT/CA is not just leaving crop residues on the soil surface and planting/drilling crops through them, it is also evolving towards an overall combination of technologies to improve profit and ensure sustainability, through conservation.

Farmers, including the organic ones, are learning how to incorporate un-conventional weed, disease and pest controls with mechanical and biological methods (Parra et al., 2010; Landers and Challiol, 2013); precision agriculture (PA) with GPS permits variable rate input application, while eliminating overlaps and variable row widths between passes; controlled traffic farming (CTF) leaves uncompacted soil between fixed traffic lanes, reducing trafficking by 50-80% (Tullberg, et al., 2007, Chamen, et al., 2003) and fuel use by some 30-40% (Tullberg et al., 2007). Biological controls reduce the need for agricultural chemicals in non-organic agriculture. In addition, chemical hazards per ton produced can be minimized through six main factors; (I) increased yields, (ii) less toxic chemicals, (iii) adoption of biological controls, (iv) pluri-annual rotations, (v) integrated pest management (IPM) and (vi) more efficient application methods. As consumers demand greater food traceability, ZT/CA, precision farming, agricultural benchmarking and crop certification will continue to expand, while more and more complexities in soil, water, machinery and crop management are demanding higher skill levels, leading to widespread use of specialized consultants.

The ZT/CA revolution in Brazil (Landers, 1999) opened up a new era of sustainable farming, as it has done in many countries, the latest being countries in Eastern Europe and China (Kassam, Friedrich, Derpsch (2018). The success and longevity of the wider concept of ZT/CA will depend on evolving to incorporate and promote new compatible and sustainable technologies and also on the implementation of direct payments for farmers' environmental services (Prado et al., 2016; Landers et al. 2021). Policy-makers need to consider this by creating a level playing field for these payments; farmers are extremely under-represented in the worldwide allocation of incentives for biosphere-conserving technologies. Off-farm and on-farm benefits under CA practices need to be identified, quantified and valued at local and national level (Pearce and Turner,1990, Landers et al. 2001). Without this, farmers cannot receive payment for their environmental services, such as reduced GHG emissions (Lal, 2016, Sá et al., 2000), improved water and air quality, lower levels of silting and pollutant nutrients in water bodies, aquifer recharge and winter feed for wildlife, enhancing these populations (Landers et al., 2001), plus the more abstract existence and scenic values (Pearce and Turner, 1990). As an example of the latter, the prefecture of Heidelberg in 2006 paid a subsidy to farmers that planted oilseed rape in winter, whose bright yellow flowers relieved the monotony of a drab winter countryside and appealed to tourists.

The combination of new technologies and ZT/CA incentives will improve profit and ensure sustainability in a climate of downward pressures on agricultural prices, with concomitant demands to reduce negative environmental impacts (Polidoro et al., 2021).

Cognizance needs to be taken of the wider positive implications of ZT/CA for the sustainability of the biosphere (UK Treasury, 2019) and ZT/CA promoted as the best present agricultural solution towards the achievement of the Sustainable Development Goals (SDGs). Consequently, world policymakers need to recognize and remunerate the positive impacts of ZT/CA on the biosphere, or take responsibility for the ensuing biosphere degradation, qualified by the DasGupta review (UK Treasury, 2019). These financial incentives need to reward famers' environmental services in terms commensurate with measurable improvements in environmental quality *in-loco* and *ex-loco*, for instance using the proven Brazilian "Index of the Quality of Planting - IQP" (Martins et al., 2018; Telles et al., 2020) and measures of external impacts (Pearce and Turner, 1990; Landers et al., 2001).

The need to expand the number of technologies included in the concept of CA is evident from the preliminary list below of innovative technologies compatible with ZT/CA:

1. Biological control of pests and diseases (Parra et al., 2010);
2. Mixed cover crops (up to 30 or more, with different functions (Calegari, Ralish and Guimarães, 2006);
3. Innovative inoculants for improving soil biological activity and nutrient availability (Mendes et al., 2018);
4. Field scouting with drones for regular or spot input applications of chemicals and biological agents (FAO, 2018; Sylvester, 2018);
5. Controlled traffic farming to reduce soil compaction, especially in deeper layers (Tullberg et al., 2007; Chamen et al., 2003);
6. Laser robotics for weed control (Mathiassen et al., 2002);
7. Benchmarking of indicators to monitor improvements in operating and input efficiency;

8. Stone meal as soil conditioners and as a substitute of chemical fertilizers only in very stable ZT/CA areas (Landers et al., 2021);
9. Optimization of the direction of planting to minimize erosion.

2. DISCUSSION

To expand the definition of CA, the following questions need to be addressed:

Can ZT/CA become the umbrella definition for all sustainable agronomic technologies?

The answer is, not quite: all technologies with a direct impact on field performance must be included, except compatible technology (IT) because it is applied across-the-board to enhance other technologies and, although completely compatible with CA, should not be considered here to avoid double counting of impacts (IT impacts will be measured within the results of ZT/CA-compatible technologies). Thus, IT is in a special umbrella category of its own but should be accommodated under CA as a general contribution to sustainability via more efficient use of resources. Broadening the ZT/CA umbrella will appeal to farmers, who currently use many or all these technologies individually; a single uniform source for information will facilitate their assimilation of innovations. This falls within the remit of and national ZT/CA organizations.

How do we adjust the concept to achieve this?

One approach would be a CA base definition, modified to include "... minimum soil and crop residue disturbance of maximum width of 10 cm in the line of planting, restricted to this operation", with the incorporation of compatible sustainable technologies. Designation of ZT/CA-approved add-ons would be through an approved list similar to that on FAO's website for organic agriculture and would be indicated by a plus sign for each one, or a code number, viz:

$$CA^{++++} \text{ or } CA^{1,3,4,7} \quad (1)$$

In equation 1, the code number would have a key to identify the technologies. Heading these would be the three ZT/CA principles. However, the vast majority of farmers who say they practice No-Till, Zero Tillage or Conservation Agriculture do not comply with all three; commonly there is no pluri-annual rotation and soil cover may be less than the ideal minimum of 70%.

This paper uses ZT/CA to define this umbrella because it is necessary to emphasize that, without ZT, the long term sustainability of CA per se is jeopardized. It is widely recognized that cultivating soil oxidises soil organic matter (SOM), compromising sustainability (Sá et al., 2000). Also, the above modification to the ZT/CA base definition is necessary because over-generous interpretation of "minimum soil disturbance" in the FAO definitions leads to strip till and min-till being claimed as ZT/CA, in spite of cultivating the soil, in whole or in part when there is little or no residue in the planted area.

Do we need to create a new concept?

Probably not, because all new sustainable agronomic technologies employing ZT/CA fit under the new umbrella, with the exception of IT as explained above.

Another concept which would enhance the value and recognition of ZT/CA would be the Farmer Responsibility Index (FRI) that calculates the hazard risk of agricultural chemicals for the farm cropping pattern, using aggregate quantities of active ingredients quantities applies. A lower FRI rating indicates less hazard and improvements accrue from either: (i) lower hazard ratings in modern pesticides; (ii) biological controls substituting chemicals; (iii) lower application rates in precision agriculture; (iv) substitution of chemical fertilizers by rock meal and animal manure in some special conditions where ZT/CA is very well established; and, (v) substitution of herbicides by cover crops and/or mechanical operations to suppress weeds. A survey of top ZT/CA farmers in Brazil (Landers, 2018) gave the following results:

Table 1. Farmer Responsibility Index (FRI) for 20 farmers in Rio Verde-Goiás State, Brazil for a soybean/maize succession

Farmer Rating	FRI Index*
Top Farmer	19.47
Average Farmer	27.63
Worst Farmer	38.96
Difference Top/Worst	19.4 (-50%)

*Active ingredient/ha weighted by hazard class.

In Table 1, the FRI gets smaller as less hazard is generated and it is obvious that there is much room for improvement on the already quite low hazard levels. In addition, this data was for 2014, when there was negligible uptake of biological controls. Applying this index in 2021 would considerably reduce and enhance the value of the FRI. It is imperative to communicate to consumers the constant progress in food quality and sustainability achieved by farmers practising ZT/CA. This requires a conscious and co-ordinated effort by all farmer organizations on a country basis, in order to create a platform of public opinion in favour of environmental services payments. Only then will politicians enact them.

ZT/CA farmers are rapidly adopting biological controls (70% increase in 2018 for Brazil, 7% in the world), reducing their dependence on chemicals. They are also beginning to appreciate the merits of soil biology in creating soil health with the use of non-legume inoculants to increase positive microbial populations. Organic farmers are learning how to incorporate the multiple benefits of ZT/CA residue cover by combatting weeds without herbicides (using smother crops, knife rollers, crimpers, self-cleansing inter-row weeds, electric shock, laser treatments, or harnessing natural allelopathy in crop rotations). The chasm between the two sides is narrowing, with benefits to both.

Long-term economic analyses are needed to demonstrate to farmers that cover crops generate income; to date, they are generally regarded as loss leaders and the benefits to succeeding crops are not imputed against the cost of the cover crop; thus, only a few advanced farmers, with a positive cash flow, are adopting them. This will require sophisticated statistical analyses to discriminate the cover crop impacts from other variables over several succeeding years. Nicholson et al. (2018) skirted around this in the results of a long-term rotation experiment of the Mato Grosso Foundation, which unfortunately did not generate cost data.

Will root exudate stimulation, inoculation or gene transfer for specific exudates be the next technological breakthroughs? According to Gargallo-Garriga et al. (2018) "Some plants in phosphorus (P) poor soils can exude higher amounts of organic acids and phosphatase that help to mobilise recalcitrant P, e.g., *Lupinus albus*, *Medicago sativa* and *Brassica napus*. Mendes et al. (2018) describe assay techniques for phosphatase, beta-glucosidase, aryl sulphatase and other exudates and these authors show higher biological activity in ZT/CA soils. Such technologies must come under the ZT/CA umbrella.

3. CONCLUSIONS

As shown above, several categories of compatible and sustainable technologies can be included under the ZT/CA umbrella without diluting its principles. Fortunately, the wide application of the term CA can now be utilized as an umbrella for add-on practices beyond pure Zero Tillage or No-tillage, towards compliance with the SDGs. A suggested scheme of nomenclature is enunciated as a contribution to the debate necessary to obtain general approval of the same or to elect an alternative terminology.

The 8th WCCA could enshrine this concept, well-encompassed by the term CA. A plenary debate on the above could be included as an item in the final declaration on the event's recommendations. In addition, there is a pressing need to make ZT/CA benefits known to world policy-makers in order to optimize all categories of incentives for uptake. If FAO and national CA, ZT or NT organizations embrace this concept, it will facilitate their work towards effective agricultural sustainability. There is a need for tightening and making uniform the principles of CA.

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Effects of multifunctional margins implementation in annual crops on biodiversity

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Multifunctional margins implementation in annual crops is considered an important tool for increasing biodiversity in agricultural land. Increase biodiversity, in addition to its intrinsic value, provides ecosystem benefits, such as improvement in crop pollination, fight against pests and regulation of nutrients' cycle.
In order to know the effect of multifunctional margins implementation on biodiversity, the planting of 3 types of multifunctional margins, with different herbaceous composition for each of them was performed during the 2018-2019 agricultural campaign. With the purpose, not only to assess what floristic composition contributes to greater biodiversity, but also, what results it throws on a control margin of spontaneous flora. For this, the experience has been replicated in 4 farms located in the province of Seville (Spain).
In each farm, two plots have been established for each of the types of margins studied, with the intention of obtaining statistically significant data. For each plot, the Shannon biodiversity index, on the flora, on the arthropods that inhabit the plant species (aerial fauna) and on the arthropods that live on the soil (epigeal fauna), has been calculated.

For the evaluation of the results, various aspects have been taken into account to weigh the Shannon biodiversity index. As for the flora, the biodiversity of species that can serve as food for pollinating insects has been positively valued. While a negative value has been given to the presence of those that are potentially susceptible to invade the crop. Likewise, the biodiversity of pollinating insects within the aerial fauna has been valued to a greater degree than that of those who do not have this quality.

Taking into account these premises, a biodiversity value relative to each of the variables (flora, aerial fauna and epigeal fauna) has been obtained for each type of margin for all four farms, on a scale of 0 to 10. Subsequently, the average value of the three variables has been calculated, to obtain a global result that defines the qualities of the margin in terms of biodiversity.

The results reflect that the seeded multifunctional margins have a greater interest for their implantation, than those grown spontaneously. Specifically, the overall assessment of the four margins has been: Type 1 margin (7.16), Type 3 margin (7.04), Type 2 margin (6.85) and Control margin (6.24).

A particular study has also been carried out, taking into account only the Shannon biodiversity index for epigeal fauna in spring, with data on cultivated margins, control margin and crop. The results obtained for the four farms as a whole show a greater biodiversity of epigeal fauna in seeded margins (3.14) with respect to the control margin (2.99) and the one that owns the crop (2.73).

Keywords: *arthropods, auxiliary fauna, pollinators, biodiversity index, agri-environmental measures*

1. INTRODUCTION

Sustainability of rural world require makes a change from agricultural intensification to ecological intensification (Bommarco et al., 2013). This process reduces the use of agricultural inputs and increasing biodiversity in the orchards, helping the farms sustainability (Nabhan and Buchmann, 1997; Tittonell, 2014). Ecological intensification seeks to go wild again agriculture, retrieving the elements that agricultural intensification has subtracted agri-ecosystems in recent decades.

Ecological intensification in cultivated land promotes the use of Multifunctional Margins (Gaba et al. 2015). Their implementation in annual crops is considered an important tool for increasing biodiversity in agricultural land. Increase biodiversity, in addition to its intrinsic value, provides ecosystem benefits, such as improvement in crop pollination, fight against pests and regulation of nutrients cycle. In addition to connect natural areas, creating ecological corridors (Haaland et al. 2011).

Multifunctional Margins establishment can be done by letting adventitious vegetation grow, or by using sown species. Often, only seeds that have survived years of tillage and herbicide treatments remain in the soil (Neve et al. 2009) and tend to pose a high risk of infestation to the crop (Oerke 2006). The implantation of seeded Multifunctional Margins establishes a process of competition between with weeds, limiting their presence (Gaba et al. 2015).

2. MATERIAL AND METHODS

In order to know the effect of Multifunctional Margins implementation on biodiversity, the planting of 3 types of Multifunctional Margins (Table 1), with different herbaceous composition for each of them was performed during the 2018-2019 agricultural campaign. With the purpose, not only to assess what floristic composition contributes to greater biodiversity, but also, what results it throws on a control margin of spontaneous flora. For this, the experience has been replicated in 4 farms located in the province of Seville (Spain).

Table 1. Sowing percentages in sown Multifunctional margins.

MARGIN 1	MARGIN 2	MARGIN 3
Brassica napus (20%)	*Sinapis alba* (20%)	*Sinapis alba* (20%)
Coriandrum sativum (30%)	*Coriandrum sativum* (30%)	*Coriandrum sativum* (25%)
Lupinus luteus (5%)	*Salvia verbenaca* (5%)	*Salvia verbenaca* (5%)
Onobrichis viciifolia (5%)	*Medicago sativa* (10%)	*Medicago sativa* (10%)
Trifolium resupinatum (10%)	*Chrysanthemum coronarium* (5%)	*Trifolium resupinatum* (15%)
Trifolium suaveolens (10%)	*Borago officianlis* (15%)	*Borago officianlis* (30%)
Vicia sativa (20%)	*Vicia sativa* (30%)	*Ononis natrix* (5%)

In each farm, two plots have been established for each of the types of margins studied, with the intention of obtaining statistically significant data (Fig. 1). For each plot, the Shannon Biodiversity Index (Shannon and Weaver, 1949) on the flora, on the arthropods that inhabit the plant species (aerial fauna) and on the arthropods that live on the soil (epigeal fauna), has been calculated.

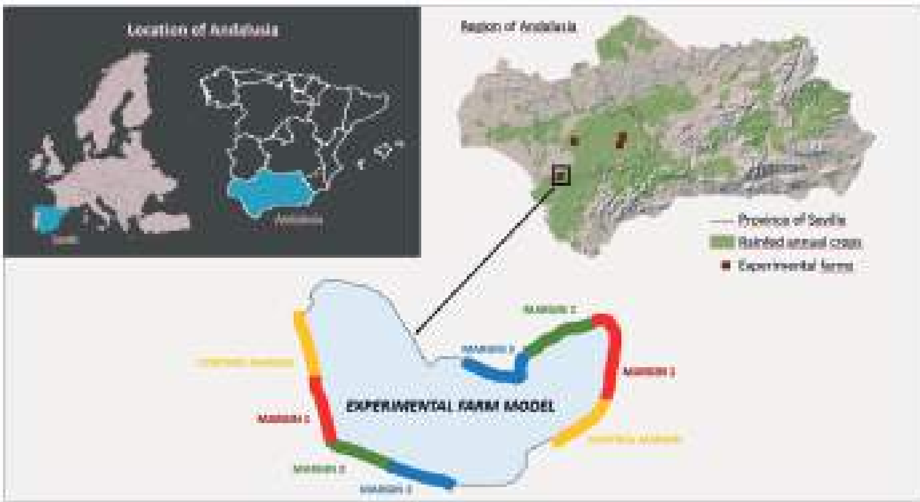

Fig. 1. Locations and experimental model.

For the evaluation of the results, various aspects have been taken into account to weigh the Shannon biodiversity index. As for the flora, the biodiversity of species that can serve as food for pollinating insects has been positively valued. While a negative value has been given to the presence of those that are potentially susceptible to invade the crop. Likewise, the biodiversity of pollinating insects within the aerial fauna has been valued to a greater degree than that of those who do not have this quality. In total, there have been 8 replications of each type of margin, 2 for each farm.

Taking into account these premises, a biodiversity value relative to each of the variables (flora, aerial fauna and epigeal fauna) has been obtained for each type of margin for all four farms, on a scale of 0 to 10.

3. RESULTS AND DISCUSSION

Flora biodiversity results (Fig. 2) show the existence of a greater heterogeneity of plant species in the planted margins. This may be due to the powerful colonization of weeds that occurs in the control margins. Within the planted margins, the greatest plant biodiversity falls on margins 1 and 3. While margin 2 has somewhat lower levels of flora biodiversity.

Fig. 2. Flora biodiversity results. Shannon index on a 0-10 scale. The letters represent significant differences in LSD test.

Margin 1 has shown a better disposition to host a greater biodiversity of aerial fauna with respect to the rest (Fig. 3). On the other hand, margin 2 showed lower values in this regard.

Fig. 3. Aerial fauna biodiversity results. Shannon index on a 0-10 scale. The letters represent significant differences in LSD test.

On the other hand, margin 2 is the one that has shown the best results in biodiversity in terms of the presence of epigeal fauna (Fig. 4). While for this aspect, margin 1 is the one that has shown the worst values.

In these results, the initial usefulness of the regulations from which they originated has been corroborated. Since type 1 originates from a regulation whose purpose is to benefit pollinators. While type 2, designed for the study, has had a good result for the conservation of soil fauna species.

Fig. 4. Epigeal fauna biodiversity results. Shannon index on a 0-10 scale. The letters represent significant differences in LSD test.

Subsequently, the average value of the three variables has been calculated, to obtain a global result that defines the qualities of the margin in terms of biodiversity

(Fig. 5). The results reflect that the seeded Multifunctional Margins have a greater interest for their implantation, than those grown spontaneously. Specifically, the overall assessment of the four margins has been: Type 1 margin (7.16), Type 3 margin (7.04), Type 2 margin (6.85) and Control margin (6.24).

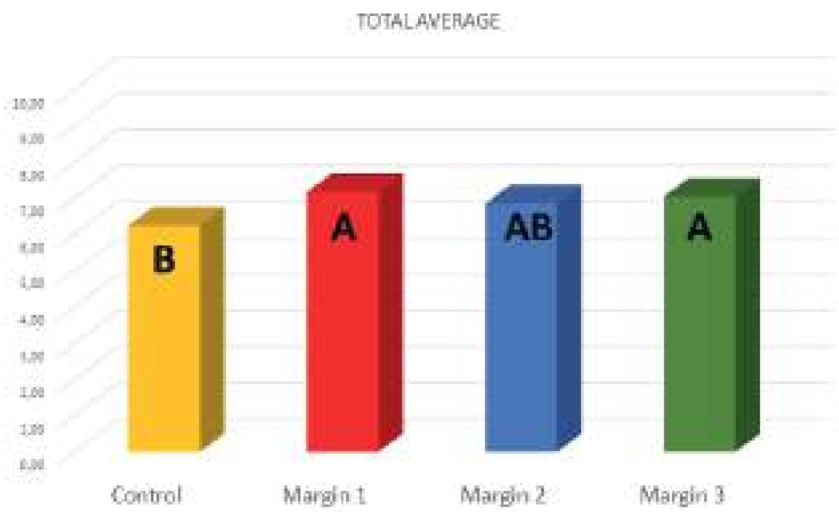

Fig. 5. Total average in biodiversity. The letters represent significant differences in LSD test.

A particular study has also been carried out, taking into account only the Shannon biodiversity index for epigeal fauna in spring, with data on cultivated margins, control margin and crop. The results obtained for the four farms as a whole show a greater biodiversity of epigeal fauna in seeded margins (3.14) with respect to the control margin (2.99) and the one that owns the crop (2.73). These results are similar to the studies carried out by Pfiffner and Luka (2000) and Aviron et al. (2007), in which studies about soil arthropods were performed in sown and spontaneous margins.

4. CONCLUSIONS

Multifunctional Margins significantly contribute to the increase in biodiversity of agricultural soils. Biodiversity of the epiedaphic fauna, the presence of a spontaneous flora multifunctional margin has meant increases of 15% on the biodiversity observed in the crops. While in the sown multifunctional margin, the average increase in biodiversity over the crop has been 32%.

The monitoring of different aspects of multifunctional margin implementation and its implication in improving biodiversity, as well as the ecosystem services that the mentioned biodiversity generates made it possible to demonstrate the important qualities that the FM provide in order to be considered as one of the eco-schemes that will govern future agri-environmental aid in Europe.

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LIFE+ Climagri: best agricultural practices for climate change: integrating strategies for mitigation and adaptation (Conservation Agriculture case study)

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If there is any sector that will strongly be affected by climate change, it is the agricultural sector, which is a consequence of the close relationship between agricultural activities and the climate. On the other hand, the agricultural sector is not only affected by climate change, but it is also a source of greenhouse gas emissions. Agriculture is responsible for 10% of the total Greenhouse Gases' emissions in Europe. As a result, agriculture faces both the challenge of mitigating climate change and the need to adapt to the new scenarios that result from global warming, proposing solutions that contribute to this dual objective. On this basis, The LIFE+ Climagri project proposes a holistic approach to the problem of climate change in the agricultural sector, and more specifically in irrigated crops located in the Mediterranean Basin. The general objective pursued by the project is the establishment of agronomic management strategies for extensive crops that contribute jointly to the mitigation of climate change and the adaptation of crops to both present and future climatic conditions, and that serve to boost and develop environmental policies and laws in the EU and its Member States regarding climate change. To do so, ten Best Management Practices (BMPs) have been defined in the framework of the project, including Conservation Agriculture, among others. These BMPs have been implemented on a pilot scale in two farms located in the Guadalquivir Valley (Andalusia-Spain) and on a transnational scale in 13 farms located in Mediterranean countries (Portugal, Spain, Italy and Greece). On this pilot scale, two scenarios have been established, one with the current climatic conditions to test the BMPs in the present, and another reproducing the expected climatic conditions in the future, in order to study the impacts of climate change on the crop and anticipate the best adaptation strategies. To reproduce expected future climate conditions, a greenhouse was used to create areas with high temperature conditions and high CO_2 concentrations (450 ppm and 700 ppm).

After more than four years of project execution, results show that the plots with a greater number of implanted BMPs reduced CO_2 and N_2O emissions by 48% and 2 to 10% respectively, increased soil carbon sequestration by about 8% compared to conventionally managed plots, and saved 32% of energy consumption. In addition, on average, total costs of plots managed with BMPs, were reduced by 12.4% (€ 142 /ha) compared to plots using conventional management techniques without any BMP.

Based on the results obtained, the project has demonstrated the effectiveness of Conservation Agriculture practices in mitigating climate change and promoting the adaptation of crops to its effects at farm level. Therefore, these practices are very useful for their inclusion in those policies aiming at combating climate change that may arise under the Paris Agreement, the Sustainable Development Goals or the 4 per 1000 initiative, among others.

Keywords: *Best Management Practices, No-till, Carbon sequestration,Grennhouse gasses.*

Aknowledgements: *This paper has been possible thanks to the contribution of the LIFE financial instrument of the European Community*

INTRODUCTION

If there is any sector that may be affected by climate change, that is the agricultural sector, which a consequence of the relationship between agricultural activities and the climate. The conclusions reached by a wide variety of studies covering a wide range of regions and crops show that the negative effects of climate change on crop yields have been more common than the positive effects. Therefore, in Europe, the agricultural areas mostly exposed to these impacts are located in countries with Mediterranean climate. Thus, in these regions it is expected that rainfall and river flows will be reduced, the risk of droughts and heatwave periods increased, therefore affecting crops negatively.

On the other hand, the agricultural sector is not only affected by climate change, but it is also a source of greenhouse gas emissions. Agriculture is responsible for 10% of the total Greenhouse Gases emissions in Europe. As a result, agriculture is faced with the challenge of mitigating climate change and adapting to the new scenarios that result from global warming, proposing solutions that contribute to this dual objective. The agreements reached at the international level urge countries to take actions that limit the rise in temperatures below 2°C (Paris Agreement - COP 21) and reduce GHG emissions by 2030 by 40% compared to 1990 emissions (The 2030 climate and energy framework - COM (2013) 169 final).

The LIFE+ Climagri project endorses these challenges and proposes a holistic approach to the problem of climate change in the agricultural sector, and more specifically in irrigated crops located in the Mediterranean Basin.

The general objective pursued by the project is the establishment of agronomic management strategies for extensive crops that contribute jointly to the mitigation of climate change and the adaptation of crops to both present and future climatic conditions, and that serve to boost and develop environmental policies and laws in the EU and its Member States regarding climate change. To achieve this goal, the project has established the following specific objectives:

Demonstrate the viability of soil management systems based on the integration of mitigation measures and adaptation to climate change in irrigated crops in the Mediterranean Basin.

Globally verify the impact of joint mitigation-adaptation strategies adopted through the creation of a European Network of Demonstration Farms (ENDF).

Establish an action protocol that, based on the identified mitigation-adaptation strategies, allows technical recommendations for adoption and follow-up of its implementation, also serving to verify the application of agro-environmental measures and other programs related to climate change.

Disseminate and transfer the gained experience and the management philosophy to other areas with similar circumstances, strengthening communication channels between research, administration, farmers and technicians.

MATERIALS AND METHODS

Best Management Practices used to mitigate climate change and adapt to its effects.

In order to mitigate climate change and make crops adapt better to its effects, a series of Best Management Practices (BMPs) have been established. They have been grouped into the following decalogue (Table 1).

Table 1. Best Management Practices decalogue of LIFE + Climagri.

Best Management Practices		Agricultural practice/equipment/strategy used
1	Use of permanent soil cover.	No tillage. Groundcovers in woody crops.
2	Use of minimum soil disturbance practices.	No tillage.
3	Perform suitable crop rotation/ diversification	Successive planting of different crops on the same land, following a defined order.
4	Optimisation in the use of agrochemicals.	Soil analysis. Plant analysis. Agrochemical application strategies based on prescription maps. Use of equipment with variable dosing systems. Use of site-specific application equipment.
5	Appropriate management of agrochemical products.	Follow the basic rules for the use of plant protection products. Calibration and maintenance of agrochemical application equipment. Management of containers.
6	Use of advanced technology (decision-making aid systems, precision agriculture, fleet management, etc.).	Automatic guidance systems. Use of decision support systems through the use of computers. Monitoring of operations through sensors. Use of equipment with variable dosing systems. Use of site-specific application equipment.
7	Implementation of regulated deficit irrigation strategies.	Use of simulation models for the generation of optimal and deficit irrigation schedules.
8	Joint consideration of optimised agricultural, technical and financial practices to improve irrigation water management	Use of simulation models for the generation of irrigation schedules considering not only water balance but also other management practices such as fertilizer application, phytosanitary, harvesting, optimal or deficit irrigation, etc.
9	Implementation of multifunctional margins and retention structures	Multifunctional margins (vegetation strips).
10	Measures for the promotion of biodiversity	Maintenance and implementation of edges between plots with various plant species in order to improve/provide habitats for auxiliary fauna (mainly invertebrates). Maintenance of walls, heaps or structures made of stones without mortar that provide shelter for small vertebrates (reptiles and small mammals). Maintenance and vegetal restoration of slopes and gullies. Creating copses-island in unproductive or very steep areas.

Implantation area

LIFE+ Climagri has focused its action on irrigated crops in countries of the Mediterranean basin, since these are the ones that will suffer the most from the effects of climate change. Therefore, two study scales have been established, a pilot scale in the Guadalquivir Valley and a transnational scale in countries of the European Mediterranean basin (Portugal, Spain, Italy and Greece).

Pilot scale

A series of pilot trials have been established in the Guadalquivir Valley (Spain), to verify the mitigating and adaptive capacity of the BMPs defined in the framework of the project, in demonstration plots, both in the present climatic conditions ('Rabanales' Farm and 'Alameda del Obispo' farm), and in expected future conditions affected by climate change, such as high temperatures and high concentrations of CO_2 ('Alameda del Obispo' farm) (Fig.1).

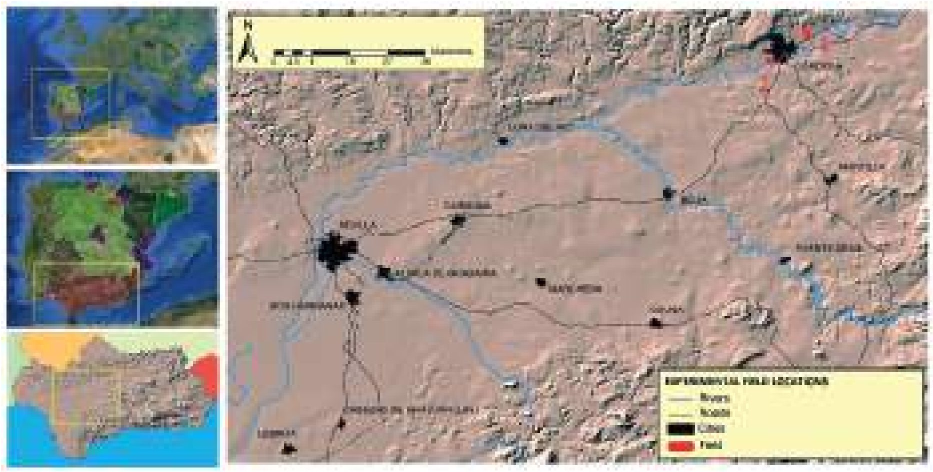

Fig. 1 Location of Rabanales farm (1) and Alameda del Obispo farm (2).

The 'Rabanales' farm has 150 ha, of which 10ha area has been selected, used for testing during this project. This area has been divided into two plots. In one of them conventional management has been carried out, based on the irrigation strategies and common and typical agronomic practices of the area, while in the other plot, some of the BMPs defined within the project have been implemented, whose goal is to mitigate climate change and adapt crops to it (Table 2).

In the "Alameda del Obispo" farm, a division has been made based on the soil management system, with a sub-plot in which conventional tillage techniques have been implemented and another one where a strategy based on no-tillage has been developed (BMP 1 AND 2). Both subplots have been subdivided into two different irrigation zones, an area where a BMP has been implemented, irrigating at 60% (BMP 8), and another one with irrigation on demand. Finally, in each irrigation zone, three different fertilization strategies (BMP 4) have been established (Fig. 2).

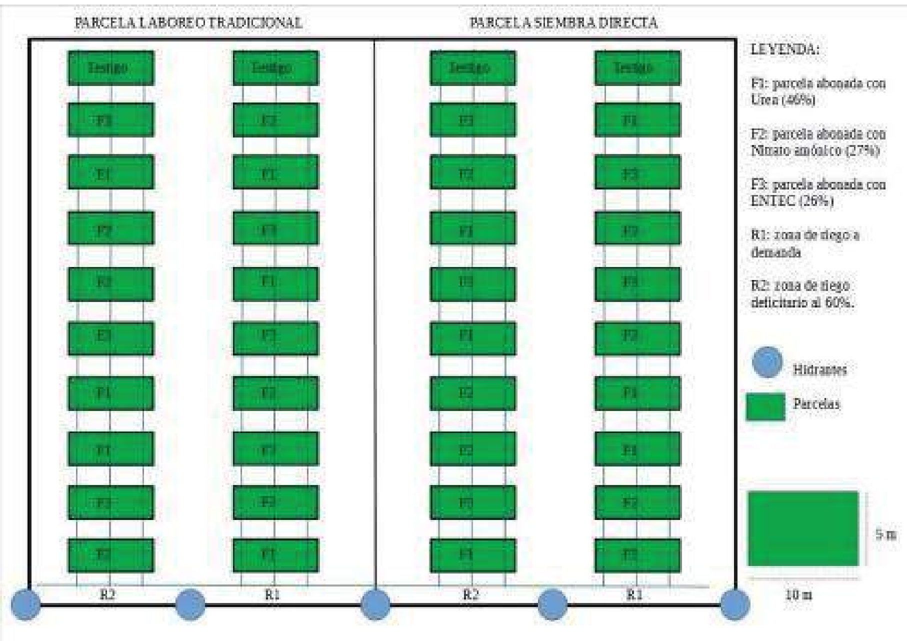

Fig. 2 Experimental design in 'Alameda del Obispo' farm.

In order to study the impacts of climate change effects on the crop expected in future scenarios, a greenhouse has been installed on the 'Alameda del Obispo' farm to be able to reproduce the climatic conditions derived from a high concentration of CO_2 and high temperatures. The greenhouse, 22 m long and 6.5 m wide, is divided into two watertight compartments that will allow the reproduction of two different climatic conditions. Thus, in the first, high concentrations of CO_2 are established (700 ppm) while the second one has climatic conditions similar to the current ones (400 ppm) (Fig. 6).

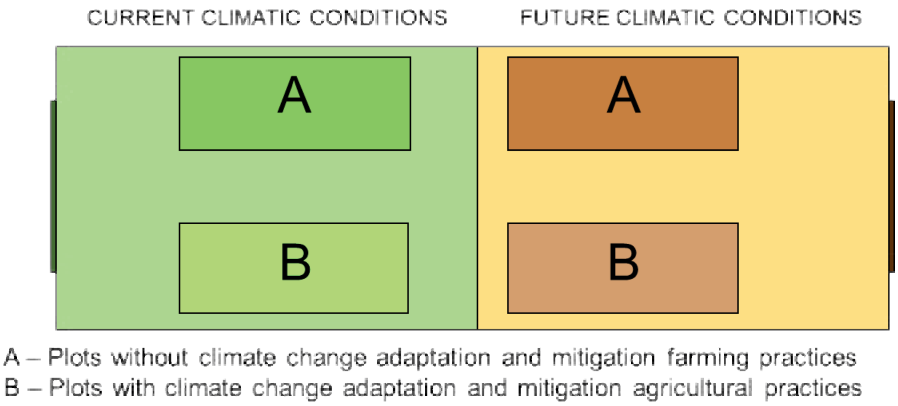

Fig. 3. Design of the demonstrative model in the demonstrative studies in future climatic conditions.

For each location contemplated on a pilot scale, different combinations of BMPs defined in the project have been established in order to see their behavior regarding climate change mitigation and adaptation (Table 2).

Table 2. Combinations of BMPs implanted on a pilot scale.

	Current weather conditions		Future weather conditions
	"Rabanales" farm	"Alameda del Obispo" farm	Demonstration tests in controlled atmosphere (greenhouse)
BMPs related to climate change mitigation	No-tillage (BMP 1, BMP 2, BMP 3). Variable and site-specific application of inputs (BMP 4 and BMP 6). Application equipment reviewed by ITEAF (Inspection scheme for plant protection product application equipment.) (BMP 5). Tractors with automatic guidance (BMP 6).	No-tillage (BMP 1, BMP 2, BMP 3). Use of fertilizers located in the sowing line (BMP 4).	
BMPs related to adaptation to climate change	Irrigation amount applied according to the needs of the crop (BMP 7). Multifunctional margins (BMP 9).	Irrigation amount applied according to the needs of the crop (BMP 7). Advancing the sowing time (BMP 8). Use of short growing cycles (BMP 8).	Irrigation amount applied according to the needs of the crop (BMP 7). Advancing the sowing time (BMP 8). Use of short growing cycles (BMP 8).

Transnational scale

In order to apply the BMPs on a large scale, a European Network of 13 Demonstration Farms managed by farmers in Portugal, Spain, Italy and Greece was established (Fig. 4).

Fig. 4. European Network of Demos Farms.

In this network, combinations of different BMPs included in the project have been evaluated in 10 different crops, evaluating the degree of implementation from 0 (not implemented) to 10 (very well implemented) for each agricultural season, depending on the score given by a monitoring protocol designed for this purpose. In addition, the sustainability of the management system used in the plots, in which the monitoring has been carried out, has been evaluated through the 25 indicators defined in the project (Table 3).

Table 3. Sustainability indicators.

Indicator	BMP evaluated
Net income per ha	2 to 8
Net income per annual work unit	2 to 8
Production costs	2 to 8
Yield/ha	2 to 8
Full-time equivalent working hours	2, 3, 6
SI – Satisfaction Index	1 a 10
Soil Tillage Index	1, 2
Annual soil cover rate	1 a 3
Organic matter level	1 to 3, 7, 8
Crop rotation	2
N efficiency rate	2 to 8
N productivity rate	2 to 8
Energy balance	2 to 8
Energy productivity	2 to 8
Surface for energy production	3
Biodiversity surface area	9, 10
Ratio between natural vegetation surface and total surface of the farm	9
Farm's connection with environmental networks and schemes	10
Biodiversity structures (nests, hives, spider-nets, etc.)- habitats	9, 10
Use of PPPs in some farms close to the water streams	9
GHG level	2 to 8

Measured parameters

On a pilot scale, in order to verify the mitigating and adaptive potential of the BMPs against climate change, direct measurements of various parameters related to the soil carbon content, energy consumption, N2O emissions, harvest, productivity and irrigation water efficiency and soil moisture, have been performed (Table 4).

Table 4. Type of monitoring carried out in each location on a pilot scale.

	Current weather conditions		Future weather conditions
	"Rabanales" farm	"Alameda del Obispo" farm	Demonstration tests in controlled atmosphere (greenhouse)
Measures related to the monitoring of climate change mitigation	Sink effect (measurement of C in the soil). CO_2 emissions from the ground. CO_2 emissions related to energy consumption.	Sink effect (measurement of C in the soil). CO_2 emissions from the ground. N_2O emissions from the ground.	
Measures related to the monitoring of adaptation to climate change	Amount of applied irrigation. Determination of final harvest.	Estimated water content in the soil. Amount of applied irrigation. Measuring crop coverage and studying its evolution. Studying irrigation water productivity and efficiency in the use of irrigation at the plot level.	Quantification of the adaptation measures effect by analyzing the parameters measured in relation to climate information (temperature, radiation and CO_2).

On a transnational scale, the verification of the mitigating and adaptive potential of BMPs to climate change has been carried out calculating the indicators defined in the project.

In all cases, the measurements began in autumn 2014 and ended in June 2018.

RESULTS AND DISCUSSION

Pilot scale

Climate Change Mitigation

Reduction of GHG emissions from the ground: Plots with a greater number of implanted BMPs have reduced CO_2 emissions by 48% and N_2O emissions by 2 to 10% compared to plots without BMPs.

Increase in carbon sequestration: Soils in plots with a greater number of implanted BMPs (Best Management Practices) have increased their carbon content by 8% compared to conventionally managed plots (1.16 t ha^{-1} of C). This is equivalent to a 5-ha big farm to offset the amount of CO_2 emissions equal to that one produced by a car which would make 10 round trips between Madrid to Moscow.

Reduction of CO_2 emissions linked to energy consumption: The plots in which a greater number of BMPs have been implemented have achieved annual reductions of up to 35% compared to the plots in which no BMP has been carried out, so the average annual reduction in this case was 32%, after 4 analysis campaigns. This means that, after four agricultural campaigns, in the plots with a greater number of BMPs, 15.11 t CO_2 ha^{-1} less have been emitted than in the plots with a conventional management system. Comparing this amount to the previous example related to the carbon sequestration, it would compensate the emissions of a vehicle that made the round trip between Madrid and Moscow 7 times.

Climate change adaptation

Impacts of climate change: Demonstrative trials in which future climatic conditions have been reproduced have served to detect that, with high temperatures, there is a phenomenon of asynchrony in flowering, complicating pollination and grain formation, which leads to a drastic reduction in the number of crops.

Effectiveness of adaptation measures:

Advancing the sowing date will allow the crop to avoid high temperatures while flowering and grain filling, which are the most critical periods of the crop, ensuring the correct development of the grain and therefore higher yields for the farmers.

The use of short-cycle crops, what means, crops with a shorter development period than conventional varieties, makes it possible to avoid high temperatures and high evapotranspiratory demand, especially in the most critical crop phases.

Measures based on the decrease in irrigation, if applied, should be very controlled, since it can cause crop reduction if special attention is not paid to the critical phases of the crop, such as flowering or grain filling.

Trasnational scale

After four seasons, all farms have increased the average degree of implementation of BMPs except for the “Il Racolto” farm located in Italy, because in the last season they received a public subsidy for the renovation of irrigation infrastructure and had to till the plot (Table 5).

Table 5. Average degree of implementation of BMPs in the DFN (Demonstration Farm Network) farms. (0: BMPs not implanted, 10: BMPs fully implanted)

Country	Farm	Initial Average Grade	Final Average Grade
Spain	La Vega de Coria	4,10	4,58
	La Parrilla	6,34	6,88
	El Lirón	3,63	5,67
	La Jurada	4,10	5,28
Italy	Palazetto	7,06	7,45
	Il Racolto	8,46	7,24
	Cascina Casoni	7,08	7,35
Greece	Marinoudis	1,63	4,05
	Evaggelopoulos	1,39	6,23
	Bartzialis	2,62	6,54
Portugal	Herdade Do Tojal	3,48	6,36
	Herdade Do Melinho	7,16	7,65
	Herdade Da Godinha	5,37	5,70

Regarding the grade of the indicators, most of the DFN (Demonstration Farm Network) farms have experienced an increase in the value of the indicators, which indicates that the greater degree of implementation of the BMPs has had a positive impact on the sustainability of the farm. These increases have ranged from 6% in the case of the 'Herdade do Melinho' farm to 71% as is the case of 'Evaggelopoulos farm' (Table 6). The only case in which the indicator grade has dropped, has been the so-called "Il Racolto", in which the average degree of implementation of BMPs has dropped.

Table 19. Average grades of the indicators in the DFN (Demonstration Farm Network) farms (0-100).

Country	Farm	Initial Average Grade	Final Average Grade
Spain	La Vega de Coria	43,6	56,6
	La Parrilla	69,5	81,3
	El Lirón	55,4	67,5
	La Jurada	53,2	70,6
Italy	Palazetto	62,3	72,4
	Il Racolto	58,7	53,8
	Cascina Casoni	57,0	66,5
Greece	Marinoudis	44,8	50,9
	Evaggelopoulos	50,7	76,4
	Bartzialis	65,1	63,6
Portugal	Herdade Do Tojal	59,3	74,6
	Herdade Do Melinho	70,1	74,2
	Herdade Da Godinha	58,4	70,1

Although the increase in the implementation of BMPs has been greater in some farms than in others, mainly in farms located in Greece, the increase in the average value of the indicators has been more homogeneous, suggesting that besides BMPs, other factors influence the final result, such as the edaphoclimatic conditions of the plots as in the case of environmental indicators, or specific market conditions of each country as in the case of economic indicators.

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Effect of Conservation Agriculture practices on soil biological and physico-chemical properties of light black soil under peanut-wheat cropping system

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A field experiment was conducted at Research Farm of ICAR - Directorate of Groundnut Research, Junagadh in India, for four years during 2012-13 to 2016-17 to evaluate the effects of different tillage and residue management practices on soil biological, physical and chemical properties in peanut-wheat cropping system. The soil at the experimental site was clayey (55.7% clay), moderately calcareous (30.9 % $CaCO_3$), slightly alkaline (pH 8.2) with EC of 0.7dS/m, low in organic carbon (4 g kg^{-1}), available N (97.3 kg ha^{-1}), and available P_2O_5 (9.2 kg ha^{-1}) and medium in available K_2O (269 kg ha^{-1}). The treatments were three tillage practices: conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) in the main plots, and each soil tillage management had three residue management practices: no residue (NR), wheat residue (WR) and wheat residue + *Cassia tora* mulch in wheat (WC) in three subplots of each, and replicated thrice totaling 27 plots. The soil biological (enzymatic activities and soil microbial biomass carbon [SMBC]), physical (total aggregate percent, mean weight diameter [MWD], geometric mean diameter [GMD], porosity and infiltration), and chemical (soil organic carbon [SOC], cation exchange capacity [CEC], available N, P_2O_5, K_2O) parameters were studied following the standard procedures. Soil samples were taken after harvest of wheat in 2017 to measure physical and chemical parameters while moist samples were taken 30 days after sowing of peanut in each year to study enzymatic activities and SMBC. Porosity and infiltration rate were measured during wheat season in 2017. Data were statistically analyzed in split plot design using F-test procedure given by Gomez and Gomez (1984) and Tukey's test ($p \leq 0.05$) was used to differentiate the treatment means. The results indicated that dehydrogenase, alkaline phosphatase, and urease activities were similar in MT and ZT but significantly higher over CT in 0-15 cm depth. β glucocisade activities and SMBC were in the order ZT>MT>CT ($p<0.05$) in 0-15 cm depth. However, activities of all the enzymes and SMBC were significantly high with CT over ZT in 15-30 cm depth. Enzymatic activities and SMBC was found significantly high with WC over NR in both the depths.
Total aggregate percent, MWD, GMD, porosity and infiltration rate was found to be significantly high in ZT over CT in both the depths. Total aggregate percent (0-15 and 15-30 cm), GMD (15-30 cm), MWD (15-30 cm) porosity and infiltration rate was found to be at par under MT and ZT. Total aggregate percent, GMD, MWD, porosity, and infiltration rate were found to be significantly higher under WC while least values were found with NR.

Available NPK and CEC were high under ZT as compared to CT in both the depths ($p<0.05$). SOC was found high with ZT in 0-15 cm depth over CT, but in 15-30 cm depth SOC was high with CT as compared to ZT ($p<0.05$). SOC, CEC, and available NPK were significantly high with WC as compared to NR. Thus, the results of four years study indicate that zero/minimum tillage and wheat stubble retention and *Cassia tora* mulch may potentially be used to improve soil biological and physico-chemical properties in light black soils under peanut-wheat cropping system in Saurashtra region, India.

***Keywords**: zero/minimum tillage, peanut-wheat system, stubble mulch, soil quality*

INTRODUCTION

Conservation tillage practices such as zero tillage (ZT) or minimum tillage (MT) with residue retention are popularly known to mitigate the adverse effects on soil properties caused by intensive conventional agricultural practices. Understanding the effects of Conservation Agriculture (CA) practices on soil properties is important for its implementation on the field. Soil enzymes are lifeline for the nutrient cycling and nutrient transformations and are major indicators of soil microbial activity and soil quality (Frankenberger and Dick, 1983; Visser and Parkinson, 1992). Quality, quantity and type of plant residues and soil management practices influence the soil microbial processes and enzymatic activities (Kandeler et al. 1999). Soil nutrient transformations brought by hydrolytic enzymes are considered as major factor involved in deciphering the soil microbial activity (Frankenberger and Dick, 1983) and soil quality (Visser and Parkinson, 1992). Alterations in tillage and residue management practices lead to changes in distribution and activities of soil microbial community and enzymes (Madejón et al., 2007; Melero et al., 2008).

Soil aggregation (macro and micro) and stability can have a large effect on soil organic carbon (SOC) dynamics and sequestration, and C availability. Soil macro-aggregates affect C storage by occluding organic residues, making them less accessible to degrading organisms and their enzymes (Six et al., 2000). CA improves soil cation exchange capacity (CEC) and long-term stability of micro aggregate (Herrich and Wander, 1997). Nutrient availability and concentrations could be affected by tillage practices (Shokati and Ahangar, 2014). Thus, efforts of conversion from plow-till to no-till practice could serve as the most effective factor in crop management for SOC sequestration and increased productivity (Lal, 1997). Ploughing messes up with earthworm soil habitats, especially deep burrowing (anecic) species, and exposes earthworms to predation and desiccation (Holland, 2004). As per Chan (2001) different types of factors viz., soil types; crop rotation; and the type, date and intensity of tillage affect the earthworm population. However, no studies have been done till now to investigate the effect of tillage and residue management practices on above soil biological and physico-chemical properties in peanut-based cropping systems in light black soils of Saurashtra peninsula of western India. Therefore, this study was initiated during rainy season of 2012 with the hypothesis that conservation tillage and residue/mulching practices will improve important characteristics of calcareous, low carbon, poorly fertile and shallow light black soils of the region.

MATERIALS AND METHODS

A field experiment was initiated at Research Farm of ICAR-Directorate of Groundnut Research, Junagadh during rainy season of 2012 to evaluate the effect of different tillage and residue management/mulching practices on soil biological and physico-chemical properties in peanut-wheat cropping system. The soil at the experimental site was clayey, moderately calcareous (30.9 % $CaCO_3$), slightly alkaline (pH 8.2) with electrical conductivity (EC) of 0.7 dS/m, low in organic carbon (4 gkg^{-1}) available N (197.3 $kgha^{-1}$), and available P_2O_5 (9.2 $kgha^{-1}$) and medium in available K_2O (269 $kgha^{-1}$). The treatments were three tillage practices *viz*., conventional tillage (CT); minimum tillage (MT), and zero tillage (ZT) in main plots, and three residue management/mulching practices *viz*., no residue (NR), wheat stubble retention (WS), and wheat stubble retention + *Cassia tora* mulching wheat (WC) in sub-plots, and replicated thrice. The data were analyzed using split plot design. The soil samples were taken at 30 days after sowing of peanut from 0-15 and 15-30 cm depth in 2013, 2014 and 2015 to study the soil enzymatic activities and soil microbial biomass carbon (SMBC). While, soil samples were taken from the two depths after the completion of cropping sequence i.e., after harvesting of wheat crop in 2016 to study physical and chemical properties of the soil. Porosity and infiltration rate were studied in 0-30 cm depth. Earthworm counts were recorded in 2013 and 2015 during peanut season in 0-15 and 15-30 cm depth and pooled values are presented. All the soil parameters were analyzed following standard procedures.

RESULTS AND DISCUSSION

3.1 Effect of tillage practices

3.1.1 Soil enzymatic activities, SMBC and earthworm counts

Dehydrogenase (DHA), alkaline phosphatase, β glucosidase, urease activities, SMBC were significantly affected by the tillage practices. The results indicated that DHA, alkaline phosphatase, and urease activities were similar in MT and ZT but significantly higher over CT in 0-15 cm depth. β glucocisadeactivities and SMBC were in the order ZT>MT>CT ($p<0.05$) in 0-15 cm depth. However, activities of all the enzymes and SMBC were significantly high with CT over ZT in 15-30 cm depth. Soils under conservation tillage have higher SMBC and enzymatic activity than those under CT systems due to population expansion of microorganisms through carbon source inputs from organic residues (Madejón et al., 2007; Melero et al., 2008). Higher β-glucosidase (De la Horra et al., 2003), DHA, urease, β-glucosidase and acid phosphatase (Roldán et al., 2003), and SMBC (Ghosh et al., 2010) under conservation tillage has been reported by several workers.

Earthworm population was significantly higher under ZT under the two depth profiles (0-15 cm and 15-30 cm). Under ZT, earthworms and their habitats remain undisturbed while under CT earthworms get exposed and subject to predation and desiccation (Holland, 2004; Chan, 2001).

3.1.2 Soil aggregation, porosity and infiltration rate

Total aggregate percent, mean weight diameter (MWD), geometric mean diameter (GMD), porosity and infiltration rate was found to be significantly high in ZT, while least values were observed under CT in both the depths.Total aggregate percent (0-15 and 15-30 cm), GMD (15-30 cm), MWD (15-30 cm), porosity and infiltration rate was found to be at par under ZT and MT. CT practices cause rapid loss of SOC and stable aggregation (Lal, 1997) and also affect the distribution and stability of soil aggregates (Six et al., 2000). Yuan Li et al. (2019) and Beare et al. (1994) also reported increase in water stable aggregate, MWD, GMD, and infiltration rate due to Conservation Agriculture practices over CT.

3.1.3 CEC, SOC, total aggregate associated carbon and available NPK

Available NPK (Fig. 1) and CEC were high under ZT as compared to CT in both the depths ($p<0.05$). SOC was found high with ZT in 0-15 cm depth over CT, but in 15-30 cm depth SOC was high with CT as compared to ZT ($p<0.05$). Higher soil aggregation under ZT improves SOC by occluding organic residues (Six et al., 2000). Our results are consistent to findings of Herrich and Wander (1997) and Shokati and Ahangar (2014) who reported higher CEC and available NPK, respectively under ZT over CT.

3.2 Effect of residue management/mulching practices

3.2.1 Soil enzymatic activities, SMBC and earthworm counts

Soil enzymatic activities and SMBC were significantly affected by residue management and mulching practices. Activities of DHA, alkali phosphatase, β glucosidase and urease, and SMBC (0-15 and 15-30 cm) were found to be higher under WC as compared to NR ($p<0.05$). Addition of organic matter in the form of crop residues and mulch ensures ready availability of carbon for rapid multiplication of microbes leading to higher soil enzymatic activities and SMBC (Madejon *et al.*, 2007).

Earthworm counts (0-15 and 15-30 cm) were observed significantly higher under WC over NR, which is attributed to higher organic matter availability under WC (Briones and Schmidt, 2017).

3.2.2 Soil aggregation, porosity and infiltration rate

Total aggregate percent, MWD, GMD, porosity and infiltration rate were found to be significantly higher under WC while least values were found under NR in both the depths ($p<0.05$). Total aggregate percent, GMD, MWD, porosity, and infiltration rate were found to be significantly higher under WC while least values were found with NR. Addition of organic matter through wheat stubbles and *Cassia tora* mulching improved the soil aggregation, porosity and consequently the infiltration rate under WC. The stability of aggregates is determined by the ability of the cohesive forces between the particles to withstand an applied force. Aggregation is maintained by the presence of organic matter in the soil (Lynch and Bragg, 1985). Increased porosity and infiltration rate due to residue application was also reported by Oliveira and Merwin (2001) and Thierfelder and Wall (2009), respectively.

3.2.3 CEC, SOC, total aggregate associated carbon and available NPK

CEC, SOC, total aggregate associated carbon, available N, P and K (Fig. 1) were found higher under WC as compared to NR at both the depths ($p<0.05$). Total aggregate associated carbon was found at par between MT and ZT. Least values of these parameters were recorded under NR. Crop residues are direct source of organic carbon and release nutrients upon decomposition as also reported by Kundu et al. (2007).

CONCLUSION

The results suggest that zero and minimum tillage and wheat stubble retention and *Cassia tora* mulching are effective in improving soil biological and physico-chemical properties of light black soils of Saurashtra region. This is important for sustainable production in these calcareous, low carbon, and poorly fertile shallow soils of the region.

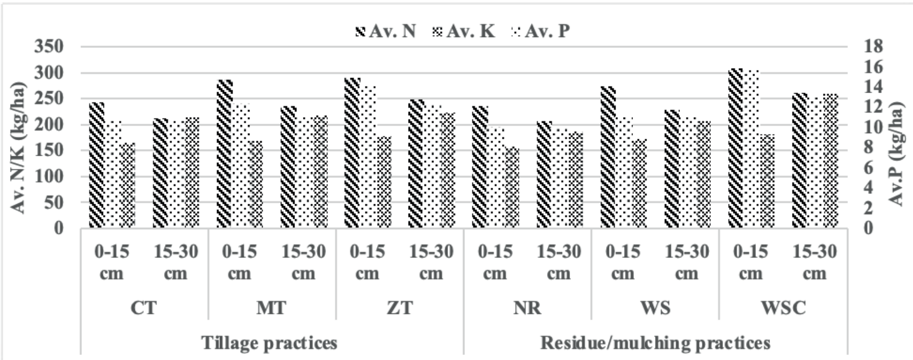

Figure 1. Effect of tillage and residue management/mulching practices on available NPK in soil after four years of the experimentation. CT, conventional tillage; MT, minimum tillage; ZT, zero tillage; NR, no residue; WS, wheat residue retention; WSC, wheat residue retention + *Cassia tora* mulch in wheat.

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Carbon sequestration potential in the soil under two cropping systems and different irrigation systems

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Approximately more than 40% of the earth's surface is currently threatened by soil degradation, a process in which the loss of soil organic carbon (SOC) has a relevant role, and which is accelerated by climate change. It is generating strong impacts on food security and small farmers.

In soils dedicated to agricultural activities, quality and productivity can be improved by increasing the SOC changing the management practices that are used. Intensive agriculture has led to the loss of carbon in agricultural soils, between 30 and 50% in the last two decades. Developing models which simulate the carbon cycle have shown that the changes in soil management have provoked greater impact on this element than those caused by climate change. The problem of SOC decrease especially affects the Mediterranean basin, where cold and humidity in winter together with hot and dry summers with high temperatures accelerate the decomposition processes. These SOC losses are influenced by traditional, non-conservative agronomic practices that favour the decomposition of organic remains and erosive processes.

A 4-year study has been conducted in order to determine the mitigating capacity of agriculture against climate change. The capacity of the soil to sequester atmospheric carbon has been evaluated by increasing its SOC through the implementation of conservation management systems.

Several studies state that the carbon gain through Conservation Agriculture practises is related exclusively to the stratification of organic carbon in the soil profile. However, other works point out that the evolution of stratification ratio is a significant indicator of carbon sequestration in soils under Conservation Agriculture. On this basis, stratification ratios of 0-5/5-10, 0-5/10-20 and 0-5/20-40 cm in depth were calculated.

The obtained ratios were 1.22, 1.55 and 2.3 in the soil under conservationist practices, and 1.15, 1.39 and 2.2 in the traditional system. It must be highlighted that stratification was higher in Conservation Agriculture for each sampled depth.

Analysing organic carbon content at the end of the experiment, on average, soils managed with Conservation Agriculture techniques showed 13%, 7.8%, 3.2 % and 9% more SOC than soils under traditional management at depths of 0-5, 5-10, 10-20 and 20-40 cm respectively.

The coefficients of determination obtained between SOC and stratification ratios were R^2= 0.59; R^2=0.62 and R^2= 0.78 for the studied depths.

Keywords: *carbon sequestration, stratification ratio, Conservation Agriculture, climate change, no-till*

INTRODUCTION

In soils dedicated to agricultural activities, quality and productivity can be improved by increasing the SOC changing the management practices that are used. Agricultural management practices alter soils and the functioning of ecosystems, what usually decreases SOC reserves, particularly in intensive tillage systems. For example, in Spain it has been estimated that SOC levels on farms declined by 17% between 1933 and 2008, partly due to climate change and partly due to changes in agricultural management (Aguilera et al., 2018).

The problem of SOC decrease especially affects the Mediterranean basin, where cold and humidity in winter together with hot and dry summers with high temperatures accelerate the decomposition processes (De Brogniez et al., 2015), These SOC losses are influenced by traditional, non-conservative agronomic practices that favour the decomposition of organic remains and erosive processes.

Regarding irrigation, this practice increases soil productivity, which is associated with more soil C, due to the greater amount of generated biomass. On the other hand, irrigation also reduces the amount of C available for the roots and affects the dynamics of SOC by improving growth conditions and microbial activity, thus promoting soil respiration and therefore loss of SOC due to CO2 emissions. The balance will mainly depend on the relative dominance of one or the other process (higher C inputs versus higher mineralization). It could potentially be improved if we opt for the implementation of Conservation Agriculture soil management systems that leave plant remains on the soil surface, favoring its protection and the recycling of nutrients and releasing carbon during their decomposition, compared to conventional systems that remove the most of these remains for other uses and bury the rest, what accelerates its decomposition and favors a greater production of CO2 emissions to the atmosphere (Carbonell et al., 2019). Also, deficit irrigation is an important strategy to manage water, but its impacts on soil C sequestration and physical properties have not been well documented, Blanco Canqui et al. (2009) indicated that these practices affected SOC concentration and soil structural development near the soil surface, but the magnitude of impacts was site specific. Experimental studies have found both higher SOC reserves (Wu et al., 2008) and lower SOC reserves (Nunes et al., 2007, Martiniello, 2011) on irrigated plots.

Different studies, carried out in Mediterranean environment, about the impact that conventional practices and soil conservation have on carbon sequestration, show more favorable results in Conservation Agriculture systems, since these practices improve the C balance in the soil due to the continuous presence of plant remains on its surface, also minimizing soil disturbance and effectively protecting it against erosion, a process that involves a significant amount of SOC loss (González-Sánchez et al., 2012, Aguilera et al., 2013, Vicente- Vicente et al., 2016).

MATERIAL AND METHODS

EXPERIMENTAL SITES

The experiment was conducted in a Mediterranean area with a Xeric regime, according to the standards set by Soil Survey Staff (1999).

The climatic conditions of the study area follow the pattern of the Mediterranean climate which is characterized by a temperate climate with a cold and rainy season in autumn and winter which accounts for 80% of the total annual precipitation and very dry and hot summers.

The selected farm is located in Córdoba in the Southern Spanish region of Andalusia: 37º 51′ 48″ N; 4º 47′ 29¨W and the studies were conducted in three agricultural seasons 2016, 2017 and 2018. The corn (*Zea mays* L.) under irrigation was the crop implanted during the whole study.

The factors considered in the study have been soil management system (No Till (NT) and Tillage (T)) and irrigation dose (full dose on crop demand: 100 % and deficient dose, up to 75 %).

At the beginning of the study, a soil sample was taken in order to define the physical and chemical characteristics of the study sites (Table 1).

Table 1. The physical and chemical characteristics of different soil layers at the study sites.

Soil system	Depth	pH H_2O	pH $CaCl_2$	P	K	OC	OM	CO_3^{-2}	CEC	Sand	Lime	Clay	Texture
	cm			mg kg^{-1}			%		meq 100gr^{-1}		%		
Tillage	0-5	8.60	7.77	12.23	252.12	0.41	0.69	18.63	11.92	47.49	34.99	17.52	Loamy
	5-10	8.58	7.73	9.86	202.12	0.40	0.68	17.93	12.09	46.39	36.41	17.20	Loamy
	10-20	8.63	7.78	9.36	123.54	0.40	0.68	18.21	12.69	47.29	36.68	16.03	Loamy
	20-40	8.76	7.85	6.21	99.36	0.28	0.48	20.59	11.40	49.42	34.59	15.99	Loamy
	40-60	8.66	7.88	6.01	103.76	0.22	0.37	19.99	11.85	51.38	33.71	14.91	Loamy
No Till	0-5	8.55	7.75	6.52	235.88	0.44	0.75	19.98	10.95	52.53	32.31	15.16	San-dy-Loam
	5-10	8.65	7.77	4.43	126.16	0.40	0.68	20.04	11.88	53.44	32.34	14.22	San-dy-Loam
	10-20	8.58	7.66	5.01	179.88	0.44	0.74	20.28	10.84	47.1	36.63	16.27	Loamy
	20-40	8.64	7.84	2.90	95.21	0.30	0.51	21.56	11.35	49.35	34.71	15.94	Loamy
	40-60	8.67	7.78	2.21	102.64	0.27	0.46	20.27	9.73	51.73	34.75	13.52	Loamy

P: available phosphorus; K: Exchangeable potassium; OC: organic carbon; OM: organic matter; CEC: Cation Exchange Capacity.

2.2. EXPERIMENTAL DESIGN

As experimental design a split-plot was chosen with three replicates, being the main factors the soil management system (NT, T), and the sub-subplot factor the irrigation (100, 75%). Each experimental unit (subplot) has a dimension of 5×10 m^2 and nine subplots were established per irrigation dose and soil management system.

2.3. SOIL SAMPLES

Soil sampling was carried out monthly. Samples were taken at three depth, 0-5, 5-10, 10-20 and 20-40 cm.

The first depth was taken because many studies have reported that most of the organic carbon are concentrated there.

The samples were extracted with a Veihmeyer tube and transported to the laboratory in a plastic bag.

In laboratory, the samples were dried, put through a 2 mm sieve and their OC content was analysed using the Walkley-Black method (Nelson and Sommer, 1982).

3. RESULTS

The monthly sampling of the experimental plots allowed us to study the temporal evolution of the soil organic carbon content in both management systems and the influence that the applied irrigation dose may have had on the carbon sequestration capacity.

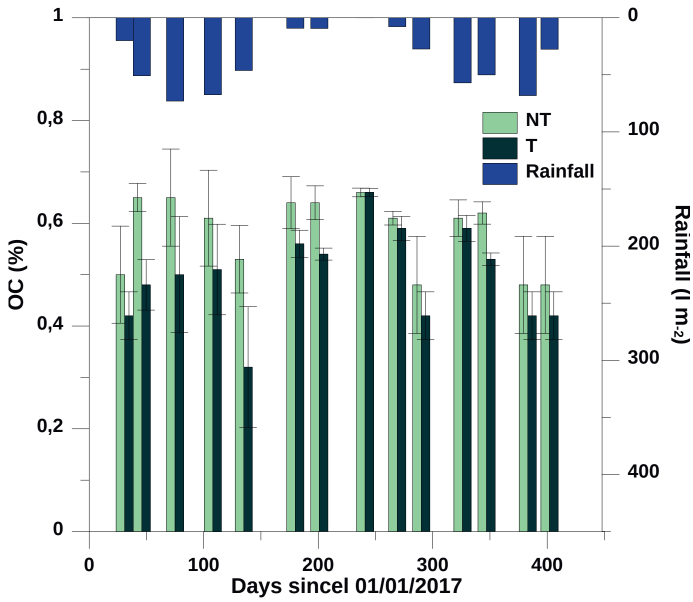

Figure 1. Evolution of the OC contents in the two management systems contemplated in the project (NT and T). Each point represents the average of all the points sampled on each date. The black vertical bars represent the variance value of each represented group of values.

As can be seen in figure 1, the temporal evolution of the soil OC content represents a series of maximums and minimums caused by the activity of microorganisms that attack the organic remains, and that is all influenced by soil humidity and temperature.

Regardless of the sampling date, soil OC contents in no-till are higher than those of the tilled soils. The non-alteration of the soil, which favors the decomposition of the plant remains, and the maintenance of the stubble on the soil surface may be some of the reasons of those differences.

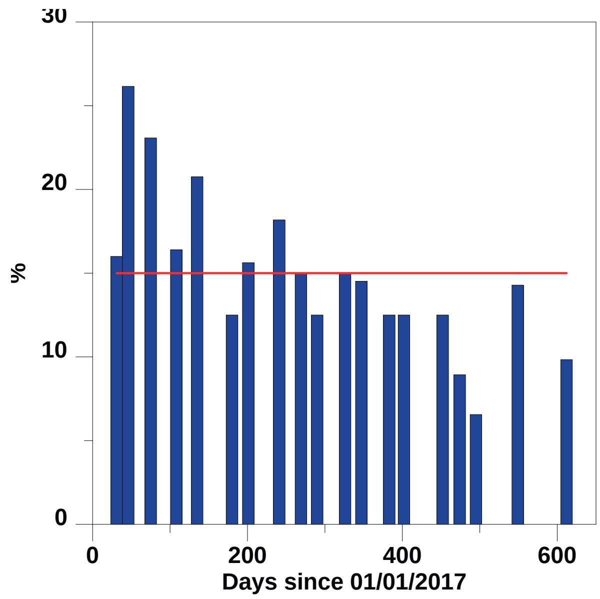

Figure 2. OC contents gained in soils managed under No-till compared to traditionally tilled soils throughout the entire study.

In the represented period, the soil managed by NT has presented, for the first 0.05 m of depth, an average of 15% more OC than the soil managed by traditional tillage techniques.

There are studies that ensure that the carbon gain generated by applying Conservation Agriculture techniques is exclusively caused by organic carbon stratification. However, other studies show that monitoring the evolution of the stratification ratio is an important indicator of carbon sequestration in soils managed by Conservation Agriculture techniques. The organic carbon stratification relationship is a natural process in natural ecosystems (Franzluebbers, 2002). It is normally calculated by dividing the OC content in the surface layer (0-5 cm) and the following subsurface layers, reaching the depth that the tillage tools reach. In our case, the data up to 40 cm depth have been presented because greater depth than that one is not altered by tools in our case.

- According to this premise, the stratification ratio has been calculated at depths 0-5 / 5-10, 0-5 / 10-20 and 0-5 / 20-40.

Depth	0-5 cm/ 5-10 cm	0-5 cm/ 10-20 cm	0-5 cm/ 20-40 cm
Stratification ratio in Till	1,15	1,39	2,2
Stratification ratio in No Till	1,22	1,55	2,3

- As can be seen at all depths, this relationship has been stronger in soils under Conservation Agriculture.

- Below, the influence that the irrigation variable may have had on the soil OC contents is going to be analyzed.

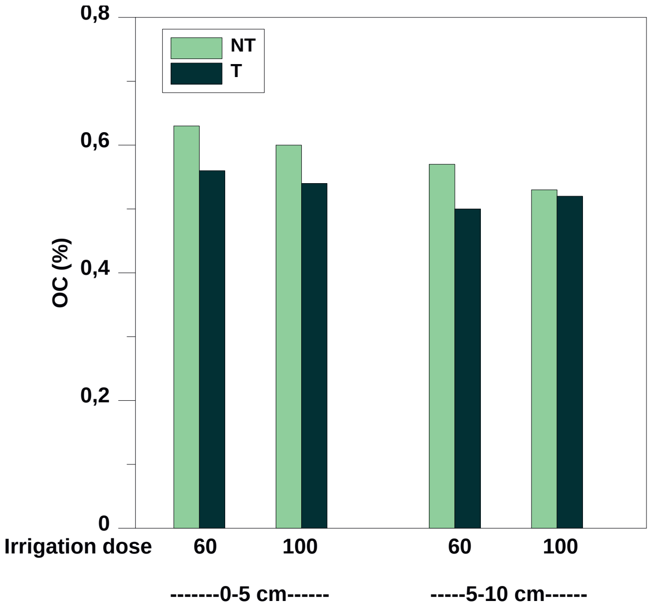

Figure 3. Average soil OC contents (%) for the studied depths, depending on the irrigation dose.

Figure 11 shows the average SOC content in the plots managed by both systems, no-tillage and traditional tillage differentiated according to the irrigation regime, deficit irrigation at 60% (R 60) and irrigation on demand 100% (R 100), for different depths.

It can be seen that irrigation, regardless of the used management system, has had an influence on the soil carbon content.

Comparing the irrigation volumes it can be observed that at 0-5 cm depth, the 60% irrigated soil has fixed 1.7% more OC than the one 100% irrigated while the amount of fixed OC at 5-10 cm depth has been exactly the same.

Within the same management system, interesting differences have been observed when comparing the two irrigations used. Thus, it can be noticed that in the first layers of NT soils 5% more OC has been fixed in those 60% irrigated. That has not been observed in traditionally tilled soils in which the OC content has been maintained in both irrigation systems.

4. DISCUSSION

Comparing the two variables analyzed in these tests, soil management and irrigation, it has been noticed that the first one has most influenced the dynamics of carbon sequestration. On average, soils managed by Conservation Agriculture techniques have shown 13% and 7.8% more OC than traditionally managed soils at 0-5 and 5-10 cm depths, respectively.

The Conservation Agriculture techniques are more efficient in sequestering soil carbon in situations of water stress. Regarding deeper layers, the NT plot has sequestered 3% more OC in the soils 60% irrigated, while in the soils completely irrigated it has not increased and, what is more, the OC sequestration decreases by 6% in the case of deficit irrigation. In other words, to achieve an increase in carbon sequestration, greater water amount is necessary.

When analyzing the OC content at the end of the study, soils managed with Conservation Agriculture techniques have shown 13%,7.8%, 3.2 % and 9% more OC than soils under traditional management at depths of 0-5, 5-10, 10-20 and 20-40 cm respectively.

Authors such as Sá and Lal (2009) found a positive correlation between the stratification relationship, the soil OC content, and the soil carbon sequestration. In our case, the correlation obtained between the OC contents and the stratification ratios has been R^2= 0.59; R^2=0.62 and R^2= 0.78 at studied depths.

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Camelina: a promising cash cover crop in North Italy

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Camelina [*Camelina sativa* (L.) Crantz] is an oilseed crop belonging to the *Brassicaceae* family, native to Europe and well adapted to arid and semi-arid climates (<350 mm annually). Camelina oil (~40%) has an excellent profile with a unique fatty acid composition, with high amounts of oleic (C18:1, 14.9–18.8 %), linoleic (C 18:2, 16–22.4 %) and linolenic (C18:3, 28–50.3 %) acids, that make it highly interesting for several foods, feed and industrial applications, including biofuels. Camelina is characterized by a very short cycle, low-input requirements, and high cold and drought stress tolerance. Camelina can be introduced into Mediterranean cropping systems as a cash cover crop in substitution to fallow or as an alternative to putting in rotation with winter cereals, thus promoting biodiversity and crop diversification. It can be harvested very early thus allowing double cropping with the typical main summer crops such as maize, sunflower, soybean, and sorghum. Moreover, camelina is well suited to Conservation Agriculture, thus enabling to enhance soil and water conservation. Optimizing soil tillage and seeding strategy are strictly necessary for maximizing oil yield, particularly for a new species such as camelina. A field trial was set in Bologna (North Italy, 44° 33' 32 m a.s.l) in autumn 2020. Different tillage techniques (no-tillage vs. minimum tillage), sowing dates (SD1=early October vs. SD2=late October) and methods (broadcasted vs. row-seeding) were compared. The camelina variety, Alba (by Camelina Company, Spain) was used. To evaluate the capacity of camelina to effectively cover soil, the 'Canopeo' web application (Oklahoma State University) was used at an interval of 15 days. Emergence rate was significantly different between sowing methods. Broadcasted plots showed an emergence rate of 96%, while a 39% reduction was observed in row seeded plots. Referring to soil coverage, higher values (+67%) were observed in S1 compared with S2. Soil tillage did not affect any parameter, thus confirming the high suitability of camelina for sod-seeding. In the coming months crop growth, phenology, capacity to compete against weed, N uptake, soil water infiltration at deeper layers, and seed yield will be surveyed in order to identify the best agronomic technique for camelina as a cash cover crop in Northern Italy.

***Keywords**: Cash cover crop, oilseed crop, sod-seeding, crop rotations*

INTRODUCTION

Camelina [*Camelina sativa* (L.) Crantz] is an oilseed crop belonging to the *Brassicaceae* family and native of the European area. This species is a multipurpose crop that has been studied in the last years for biobased applications such as bioplastics and biolubricants, or as a feedstock for jet fuels. Camelina could also fit the needs of the feed and food sectors in relation to its peculiar seed composition: high seed oil (>30%) and protein (25-30%) contents, α-linolenic acid content (> 33%), and large amounts of antioxidant compounds such as tocopherols (Zubr, 2009). Moreover, thanks to its short growing cycle, low input requirement and high rusticity, this crop can quit its status of niche crop and become a cash cover crop in the Mediterranean area (Zanetti et al., 2021). Camelina has winter and spring biotypes, thus allowing both autumn and summer sowing in order to replace fallow period, especially in rainfed cereal-based rotations in the Mediterranean basin. In the framework of the 4CE-MED project (Camelina: a Cash Cover Crop Enhancing water and soil conservation in Mediterranean dry-farming systems), founded by the PRIMA research program (G.A. 1911), the optimal sowing date, seeding rate and tillage have been studied in a Mediterranean north climate (Metzger et al. 2005) in camelina in order to maximize soil coverage before winter and reduce soil erosion and nitrates leaching.

MATERIALS AND METHODS

A plot trial has been set up at the experimental farm of the University of Bologna at Cadriano (44° 33' N, 11° 23'E, 32 m a.s.l.) in autumn 2020. The experimental site is characterized by a mean annual cumulative precipitation of 712 mm, an annual mean temperature of 13.2 °C, and a silty-clay-loam soil texture. The camelina cultivar Alba, supplied by Camelina Company Spain, has been used. The experimental design is a strip-split-plot with four replicates: in the main strips there are the two tillage techniques: minimum tillage (MT) (disk harrowing without soil inversion) vs. no tillage (NT); in the main plots there are two sowing dates: S1 (8th October 2020) vs. S2 (28th October 2020), and in the subplots there are the two sowing techniques: row seeding vs. broadcasting. Sowing has been performed by a mechanical cereal seeder (Damax 17) adopting a seeding rate of 6 kg ha^{-1} in the row seeding (interrow distance 0.17 m) and of 8 kg ha^{-1} in the broadcasting. Emergence rate was surveyed 10 and 20 d after sowing and before winter. Plant counting has been performed in a 1-m-long row in the row-seeded plots, and in a 0.2 x0.2 m square area in the broadcasted ones. In order to monitor soil coverage, the "Canopeo" app (Oklahoma State University) has been used: three photos within every plot were taken at 0.6 m of height from soil. Canopeo surveys have been performed from emergence until the 14th of December 2020 (Table 1). ANOVA analysis was performed and if significant differences ($P \leq 0.05$) were observed LSD test was used to separate means.

Table 1. Days after sowing (DAS) and GDD (Growing Degree Days) when soil coverage surveys performed by means of the Canopeo app.

S1a		S2a	
DAS	GDDb	DAS	GDDb
20	186	15	129
35	308	26	181
46	360	47	207
67	386		

a=sowing date: S1 = 8/10/2020, S2 = 28/10/2020
b= growing degree days from sowing until the survey, base temperature for calculation 4°C (Gesh and Cermak, 2011)

Accumulated growing degree days (GDD, °C d) at each survey were calculated as:

GDD $=\Sigma[(T_{max}+T_{min})/2-T_{base}$ where T_{max} and T_{min} are daily maximum and minimum air temperature, respectively, and T_{base} is camelina base temperature for which a value of 4 °C was adopted (Gesh and Cermak, 2011).

3. RESULTS AND DISCUSSION

Soil rate was significantly influenced by sowing date. Figure 1 reports the relationship between soil coverage and growing degree days accumulation. In details, both sowing dates showed a growing trend in soil coverage: S1 reported a +84% increment between 20 and 67 days after sowing and an in increment of 61% was observed in S2 from 15 to 45 days after sowing. Moreover, plots sown at the earliest sowing date (S1) accumulated 186 GDD before the sowing of the S2 plots, resulting in an higher soil coverage and higher biomass accumulation. This growth gap between the two sowing dates was never filled before winter, in fact in the last survey before winter an average value of 82.1 % was observed in S1, compared with only 13.4% soil coverage in S2.

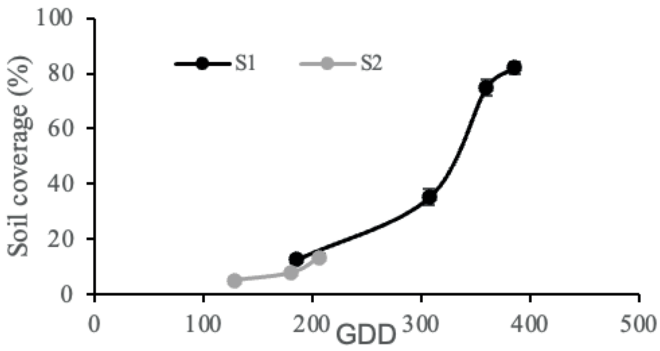

Fig.1 Soil coverage growth rate and GDD accumulation from emergence until the 14th of December 2020 in the two sowing dates (S1= 8/10/2020, S2 = 28/10/2020).

Soil coverage and emergence rate were significantly influenced by all the considered factors. In particular soil coverage was significantly influenced by sowing date and the interaction “sowing date x sowing method”. Soil coverage in S1 was significantly higher than in S2 (63.8% and 10.1% respectively, main effect sowing

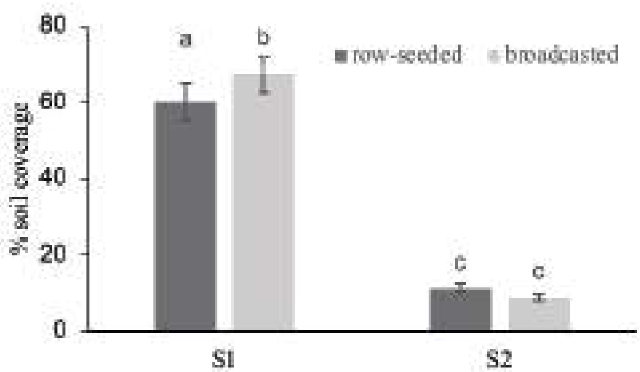

Fig. 2 Soil coverage in response to interaction between sowing date (S1= 8/10/2020, S2 = 28/10/2020) and sowing method (row-seeding vs broadcasting). Vertical bars: standard error. different letters: significant different means for $P\leq0.05$ (LSD’s test).

date). The interaction between sowing date and sowing method revealed higher values of soil coverage in the broadcasted plots compared with the row-seeded ones (67.3% and 60.1% respectively) in S1, while in the second sowing date there were not significant differences between sowing methods (Fig. 2).

Finally, the interaction between sowing date and date of the survey significantly influenced soil coverage: in S1 a significant linear increase in soil coverage was observed in time with an average value of 36% in the first survey and an increment of +52% and +61% in the second and last survey respectively. On the other hand, S2 reported no significant differences between the first and the second survey, while camelina significantly increased soil coverage in the last survey, demonstrating that camelina growth is not stopped by low temperature and this trait allowed camelina to be considered a good candidate as winter cover crop Emergence rate was significantly higher in no-till plots than in plots with minimum tillage (97% and 81% respectively). The interaction between sowing method and tillage system influenced emergence rate, in particular broadcasted plots showed significantly higher emergence under no tillage, while row-seeded plots did not report significant differences between tillage (Fig. 3). Emergence rate higher than 100% was surveyed in the broadcasted plots presumably in relation to the unprecise setting of the available seeding equipment which was ad hoc modified for broadcasting.

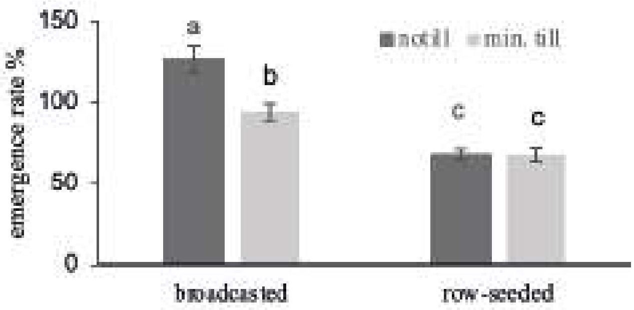

Fig. 3 Emergence rate (%) in response to interaction between sowing density and tillage method. Vertical bars: standard error. Different letters: significant different means for $P \leq 0.05$ (LSD's test).

4. CONCLUSIONS

The present study is still undergoing so the results are still preliminary. The opportunity to grow camelina as cash cover crop is new for Italy, and might open to an increase acceptance by farmers in the adoption of cover crops under Conservation Agriculture systems, Nevertheless, camelina plants seeded at the beginning of October, due to higher temperatures allowing higher biomass accumulation before winter, were able to much better cover soil than plants seeded at the end of October. The possible occurrence of some frost injuries during winter may on the other hand cause a reduction in soil coverage, but further investigation is needed in order to identify the real entity of the damage and the consequent effect on final crop yield. Moreover, broadcasting technique seems to promote soil coverage compared with row seeding, when sowing is performed early, at the beginning of October. Finally, sod seeding confirmed its high suitability for establishing camelina and was able to achieve equal or better emergence rates.

Acknowledgements

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Conservation tillage reduced soil erosion significantly – results from a long-term monitoring study in Switzerland

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The positive effects of conservation tillage have mostly been demonstrated using small test plots and experiments. The present study aims at confirming such observations on farmers' fields at catchment scale. In a 20-year monitoring programme between 1997 and 2017, accurate mapping of erosion damage was carried out in the Frienisberg region (Switzerland). The investigation area included 203 arable fields with a total area of 263 ha, i.e. the mean field size was 1.3 ha. Most of the farms were mixed farms, i.e. they grew crops and kept livestock. During 115 field inspections, 4060 plot years were examined and 2165 mapped erosion systems were recorded.

The Swiss agriculture policy system is based on a complex system of direct payments (subsidies). In addition, there are various cantonal and state subsidy programmes for conservation tillage. In the communities of the Frienisberg region, the share of reduced tillage with mulch from the previous crop rose from 1% of arable land in 1997 to 53% by 2015, and the share of no-till from 1% to 32%, so that a total of 85% of arable land was 2015 cultivated with conservation tillage. This high level of Conservation Agriculture application can be explained by the particularly high sensitivity of farmers to the topic of soil protection in the region; motivation through financial incentives, rising awareness among farmers, innovative farm contractors, knowledge transfer and good extension service of cantonal agencies.
The significant decrease of soil loss from an average of 0.74 t ha^{-1} yr^{-1} during the first ten years period to 0.20 t ha^{-1} yr^{-1} during the second ten years can directly be linked to the increased use of conservation tillage. The majority of soil erosion (88%) took place on plough tilled land (PT), 9% on non-ploughed land with less than 30% surface residue cover (RT), 1% on mulch-tilled land with more than 30% surface residue cover (MT), and 2% on non-tilled or strip-tilled land with >30% soil cover (NT). At 0.07 and 0.12 t ha^{-1} yr^{-1}, respectively, the mean soil loss in MT and NT fields was an order of magnitude lower than that under PT (1.24 t ha^{-1} yr^{-1}).

The field measurements show that soil erosion can be significantly decreased by changes in soil tillage practices. This finding also underpins that conservation tillage can be a successful production system in real-life agriculture in Switzerland. In this respect, the Frienisberg region should be considered a case example of successful erosion control.

Keywords: *soil erosion, soil loss, conservation tillage, field measurements, long-term monitoring*

INTRODUCTION

Conservation tillage practices such as mulch seeding or no-till are well known as effective mitigation measures for soil erosion (Seitz et al., 2020). However, the positive effects of conservation tillage have mostly been demonstrated on relatively small test plots or experiments. The present study aims at confirming such observations on farmers' fields at catchment scale. In a 20-year monitoring programme between 1997 and 2017, mapping of erosion damage was carried out in the Frienisberg region (Switzerland). In addition, data on crops and tillage practices were also collected and data on farmers' participation in conservation programmes were available; allowing evaluation on the impact of these measures on soil loss rates. This 20-year data series represents a unique data set.

METHODS

2.1. Study area

The study area is located about 20 km northwest of the city of Berne in the Swiss Plateau. The region falls within the moderate climate zone with an annual average temperature of 8.5 °C and annual precipitation ranging from 1035 to 1150 mm. The area is characterised by moderate hillslopes with a mean slope of 6.5% (range: 1–25%). Most soils are well drained Cambisols and Luvisols on ground moraine and tertiary molasses; they are mostly sandy loams, which have been rated as having moderate erodibility. The investigation area included 203 arable fields with a total area of 263 ha, i.e. the mean field size was 1.3 ha. Most of the farms were mixed farms, i.e. they grew crops and kept livestock. Crop rotations are versatile and mostly include a high share of temporary grassland.

2.2. Field assessments

From autumn 1997 to autumn 2017, field assessments were carried out on all 203 fields. During 115 field inspections, 4060 plot years were examined and 2165 mapped erosion systems were recorded by an experienced surveyor. For linear erosion features, the lengths and the cross-sectional areas on representative locations were measured. Sheet erosion was estimated semi-quantitatively. The methodological approach has been described in detail in Ledermann et al. (2010) and Prasuhn (2011). For most of the analyses, the results were separated into two periods: P1 from autumn 1997 to autumn 2007 and P2 from autumn 2007 to autumn 2017 (Prasuhn, 2020).

2.3. Conservation measures and programmes

In addition to the Swiss national system for direct payments, there are various regional subsidy programmes for conservation tillage. The Canton of Berne started to promote mulch seeding and no-tillage in 1996. From 2010 to 2015, the implementation of the Soil Support Programme of the Canton of Berne offered financial incentives for different conservation tillage methods (mulch seeding, strip-tillage or no-tillage). In 2014, financial incentives for conservation tillage were introduced throughout Switzerland.

We use two different datasets in this paper: On the one hand, data regarding the share of fields participating in the different programmes were available for the years 1997/98 to 2016/17 from the Soil Conservation Office Canton Berne. The information was not available on the level of the study area (265 ha), but only at the level of the three municipalities in the study region (around 1400 ha). On the other hand, interviews were conducted with all farmers on tillage practices of the 203 fields in the study area for the periods 1987-1989, 1997-1999, 1997-2006, 2003-2009 and 2010-2014. Four different tillage practices were considered: conventional mouldboard ploughing, reduced tillage without ploughing with <30% soil cover, mulch seeding with >30% soil cover, strip-till / no-till. In contrast to international literature where only mulch seeding and strip-till / no-till is defined as "conservation tillage" (Kassam et al., 2009), in this study all three non-plough cultivation techniques are summarised as conservation tillage.

RESULTS

In total, 2165 erosion systems were mapped and stored in a database of 907 fields affected by erosion in the 20 years and 4060 observed field years (Prasuhn, 2020). Of these, 1639 erosion systems originated from P1 (76%) and 526 from P2 (24%) (Table 1). The number of eroded fields decreased clearly from 653 in P1 to 254 in P2. The average soil loss per year was 0.74 t ha^{-1} yr^{-1} in P1, almost four times as much as in P2 with 0.20 t ha^{-1} yr^{-1}. In particular, the number of fields with high soil loss and non-tolerable soil loss according to Swiss legislation has decreased. In Switzerland, the Ordinance on Soil Pollution contains legally mandatory guideline values for tolerable soil loss. Accordingly, the long-term average soil loss for shallow soils with <70 cm soil depth is 2 t ha^{-1} yr^{-1} and for deep soils with >70cm soil depth it is 4 t ha^{-1} yr^{-1}. Fourteen fields exceeded this target in P1, only three fields in P2 (Table 1).

The annual variability of soil loss was very high (Fig. 1). The highest soil loss was measured in 1998/99 with 1.82 t ha^{-1} yr^{-1}, the lowest with no erosion in 2010/11. No relationship was observed with the annual amount of precipitation or with the annual rainfall erosivity (Fig. 2) (Prasuhn, 2020). However, the significant decrease of soil loss from an average of 0.74 t ha^{-1} yr^{-1} during P1 to 0.20 t ha^{-1} yr^{-1} during P2 can directly be linked to the increased use of conservation tillage (Fig. 1). In the region of the study area, the share of conservation tillage rose from 1% of arable land in 1997/98 to 53% by 2014/15, and the share of no-till from 1% to 32%, so that a total of 85% of arable land was 2015 cultivated with conservation tillage (Fig. 1). This high level of Conservation Agriculture application can be explained by the particularly high sensitivity of farmers to the topic of soil protection in the region; motivation through financial incentives, rising awareness among farmers, innovative farm contractors, knowledge transfer and good extension service of cantonal agencies. The slight decrease in conservation tillage since 2015/16 can be explained by a new programme in the Canton of Berne, aiming to reduce the use of plant protection products. The financial payments for herbicide abandonment are higher than the contributions for conservation tillage. Therefore, weed control today is done more frequently by ploughing.

Prasuhn (2012) already found in his in-depth analysis of the years 1997/98 to 2006/07 that 88% of soil erosion took place on plough tilled land, 9% on non-ploughed land with less than 30% surface residue cover, 1% on mulch-tilled land with more than 30% surface residue cover, and 2% in non-tilled or strip-tilled land with >30% soil cover. The mean soil loss in mulch seeding and no-till or strip-till fields was more than an order of magnitude lower than that under mouldboard ploughing.

Table 1: Annual soil loss for all fields (*n* = 203) and the two periods divided into five soil loss classes as well as number of mapped erosion systems and number of fields affected by erosion for the two periods 1997/98 to 2006/07 and 2007/08 to 2016/17. The class boundaries 2 and 4 t ha^{-1} yr^{-1} correspond to the reference values for soil erosion in the Swiss legislation.

Category	Number of fields		Soil loss (t yr^{-1})	
	1997/98-2006/07	2007/08-2016/17	1997/98-2006/07	2007/08-2016/17
Soil loss >4 t ha^{-1} yr^{-1}	5	1	61.3	7.1
Soil loss 2-4 t ha^{-1} yr^{-1}	9	2	45.3	7.0
Soil loss 1-2 t ha^{-1} yr^{-1}	15	7	35.7	11.6
Soil loss 0.1-1 t ha^{-1} yr^{-1}	150	108	54.6	27.2
No soil loss	24	85	0	0
Sum	203	203	196.9	52.8
Mean soil loss (t ha^{-1} yr^{-1})			0.74	0.20
Number of mapped erosion systems	1639	526		
Number of fields with erosion	653	254		

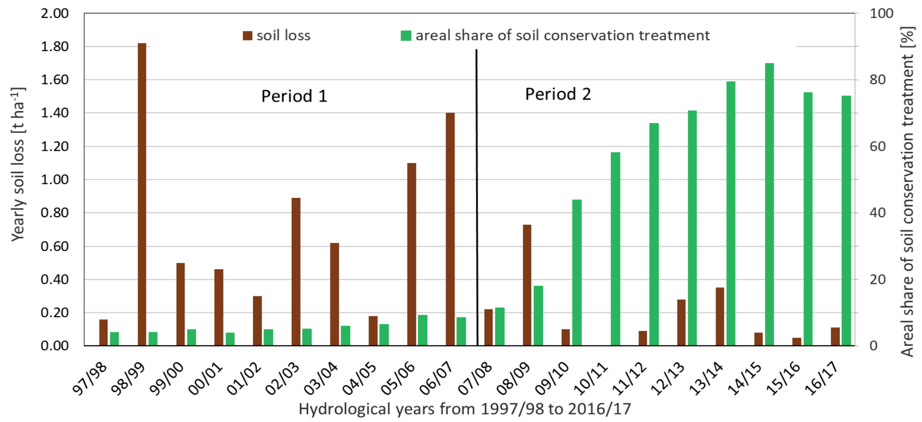

Fig. 1: Average yearly measured soil loss (t ha^{-1}) in the study area (265 ha) and area share of conservation tillage practices (%) in the region for hydrological years in period 1 (1997/98 to 2006/07) and period 2 (2007/08 to 2016/17).

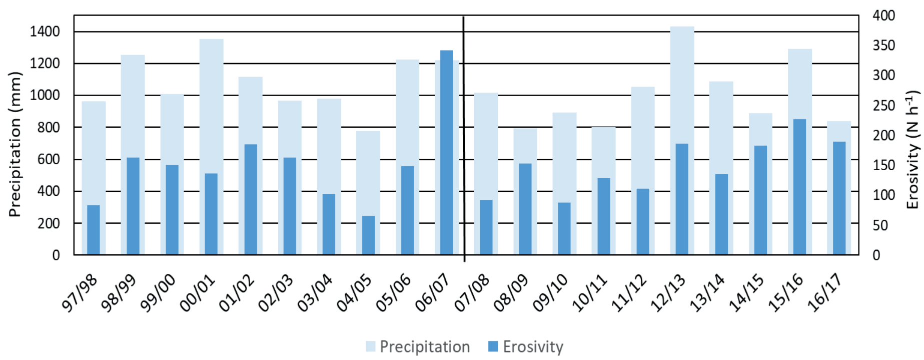

Fig. 2: Annual precipitation and annual erosivity values for the hydrological years 1997/98 to 2016/17 in the study area.

The analysis of the second data set on tillage practices confirms these trends. The tillage practices have changed significantly over the five periods (Fig. 3). Whereas almost all soils were ploughed in 1987-89, the share of tillage techniques without ploughing increased rapidly afterwards. In the period 2010-14, only 26% of the main crops were mouldboard ploughed, while 74% of the main crops were cultivated without ploughing. Of the main crops, 54% were grown with conservation tillage practices such as mulch seeding >30% soil cover, strip-till or no-till. The mapped soil loss 1987–89 was slightly lower with 0.71 t ha^{-1} yr^{-1} than the soil loss 1997–99 with 0.83 t ha^{-1} yr^{-1} (Fig. 4). However, the two time periods are very short and do not sufficiently reflect the high temporal variability of soil erosion (Prasuhn, 2020). From 1997–99 onwards, soil losses decreases continuously and amounts to 0.32 t ha^{-1} yr^{-1} in 2010-14, only 38.8% of the soil loss in 1997-99.

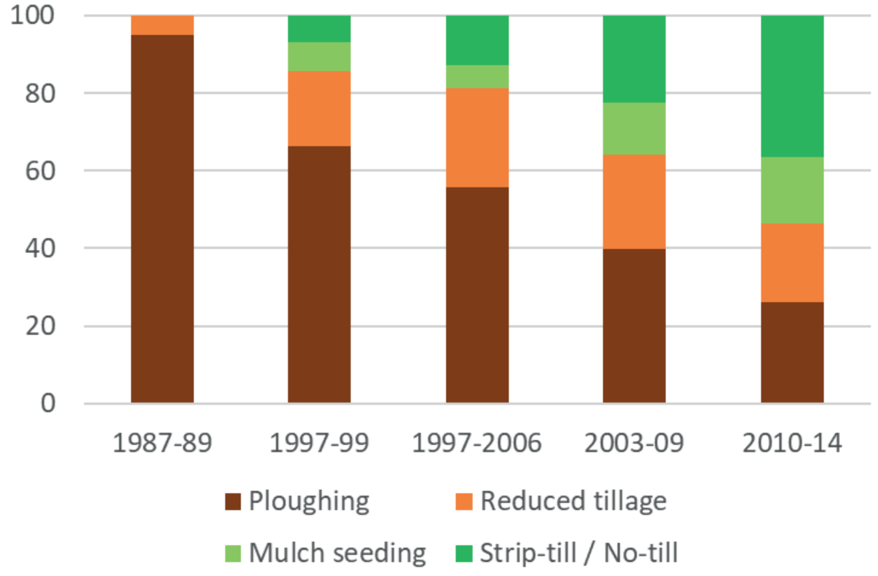

Fig. 3: Tillage practices of the main crops in five periods on the arable land of the study area.

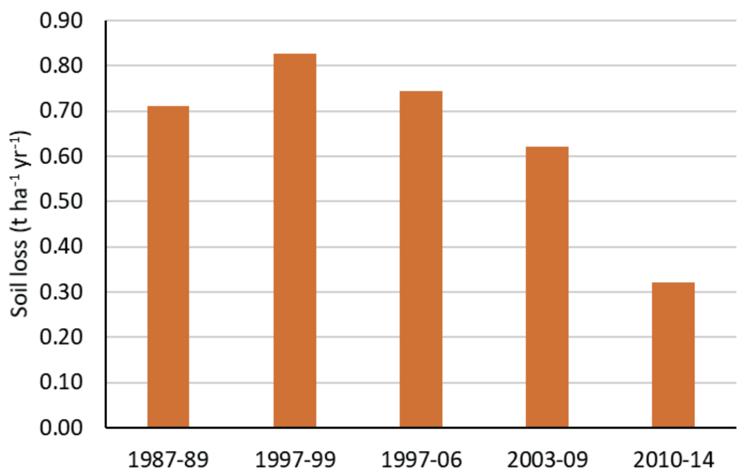

Fig. 4: Average measured soil loss rates for the five different investigation periods with information on tillage practices in the study area.

CONCLUSIONS

The field measurements show that soil erosion can be significantly decreased by changes in tillage practices. This finding also underpins that conservation tillage can be a successful production system in real-life agriculture in Switzerland. Primarily social and socioeconomic factors determine the extent to which such mitigation strategies are disseminated and accepted. Extension services, education, rising awareness, exchange with colleagues and field inspections through a farmer-to-farmer approach (same profession, same language, same culture) are crucial aspects for the adoption of measures. In this respect, the Frienisberg region should be considered a case example of successful erosion control.

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Impacts of cropping practices on the production of field crops (bread wheat and rapeseed) in the context of climate change in the Sais region of Morocco

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Morocco is severely affected by climate variability; the projections suggest that by 2050 aridification undergoes a further increase in temperature and a decrease in rainfall. Consequently, the future of agriculture and correspondingly that of the national economy could be compromised. Also, the fragility of its ecosystem, causing erosion and chronic water deficit, is influencing the productivity of cropping systems. This difficult situation and random, is aggravated by conventional agricultural practices that result in the deterioration of soil quality, fertility, structure and soil organic matter due to the soil disturbance which has potential negative consequences for yield. Conservation Agriculture (CA) presents several advantages in agronomic, environmental and socio-economic terms. It decreases soil disturbance, allows crop residue retention and crop diversification. It is an important approach to address declining soil fertility and the adverse effects of climate change in Morocco. Nonetheless, the aim of this work was the comparison and evaluation of the impact of four cropping systems (no-till, minimum-till, chisel plough and deep work) on agronomic parameters to increase the production of bread wheat, rapeseed and faba bean, on a semi-arid climate. In this context, a field experiment was conducted at the experimental station of Douyet of the National Institute of Agronomic Research of Meknes, Morocco. The experiment was according to the Split-plot design with three replications. The crop was attributed to the large blocks. While the tillage sequence has been assigned to the sub-blocks. The sowing date was 24-12-2019. The results showed that Conservation Agriculture has a positive effect when compared to conventional agricultural. The highest grain yields were obtained with no-till, especially in rapeseed compared to other cultural practices. The average yields were0.61 q/ha, 0.42 q/ha and 0.33 q/ha for no-till, chisel plough, minimum-till and deep work, respectively. Whereas, the non- germination was showed in disc plough. This decrease the grain yield due to late sowing and to drought stress caused by the decrease of rainfall during this cropping season, the annual rainfall was 135 mm. However, the results showed in faba bean have a high yield (10.14 q/ha) in cover crop comparing with no-till (7.98 q/ha), followed by chisel (7.32 q/ha) and the deep work (5.75 q/ha). On the other hand, the conventional tillage showed the highest yield in the bread wheat compared with other cultural practices (chisel plough, minimum-till and no-till) which had shown a similar yield.

Keywords: *Conservation Agricultural, cropping practices, bread wheat, faba bean, rapeseed, yield*

Introduction

Morocco is severely affected by climate variability; the projections suggest that 2050 aridification undergoes a further increase in temperature of +1.5 °C (+2 °C) and a decrease in rainfall of about -15% (Woillez, 2019).

In the context of climate change, Conservation Agriculture (CA) played an essential role in contributing to food supply; indeed, increased soil moisture helps increase drought resistance and reduces risks of crop failure (Ekboir et al., 2002). Scientists have already shown positive effect of CA on wheat production under dry Mediterranean climate (Mrabet, 2002; Kassam et al., 2012).

Conservation Agriculture (CA) is based on three principles of integrated management of soil, water and other agricultural resources in order to reach the objective of economically, ecologically and socially sustainable agricultural production: minimal soil disturbance, crop residue retention, and crop diversification (rotations and/or associations) (FAO, 2016). The concept of CA evolved from the no-till (NT) technique. In NT, seed is put in the soil without any prior soil disturbance or only with minimum soil mechanical disturbance (Jat et al., 2014). The adoption of no-till has occurred over approximately 157 million hectares, of global arable land (Kassam et al., 2015). Nevertheless, the adoption rate of CA is still very low in Morocco 4600 ha (Errahj, 2017).

A large number of researches support the idea that, compared to conventional tillage, no-till has a greater potential to sequester carbon in the soil through no-till and the presence of soil cover (Bernoux et al., 2006), improve soil functioning and quality, and also reducing the risk of soil erosion (Laghrour et al., 2018).

Soil cover improves water retention in the soil by limiting soil, water evaporation, runoff and by favoring water infiltration into the soil (Scopel et al., 2004), and lower soil temperatures (Licht and Al-Kaisi, 2005). This allows conserving moisture and preventing soil drying (Boame, 2005).

Planting diversity and decomposition of residues retained on the soil surface may enhance soil nutrient (Maltas et al., 2007). CA helps to reduce weed pressure (Ranaivoson et al., 2017) and improve biological activity in the soil through the release of high amounts of biomass (Kladivko, 2001). The aim of this study was the comparison and evaluation of the impact of four cultivation techniques (no-till, minimum till, chisel plough and deep plough) under semi-arid climate conditions on production of bread wheat and rapeseed.

Materials and methods

The experimental site was located at the experimental station of Douyet of National Institute of Agronomic Research of Meknes, Morocco during the 2019-2020 agricultural season. The Saïs plain belongs to the semi-arid climate (34°2'N, 4° 50'E, altitude: 416 m). The annual mean precipitation is 400-600 mm, the amounts of rainfall recorded during the cropping season between December 2019 and June 2020 is 135 mm (very dry season). The soil is clayey soil, mainly dark Vertisols with limestone concretions, characterized by a fairly deep topsoil layer. Its texture is silty-clayey (48.50% silt and 39.90% clay and 11.60% fine sand).

The field experiment was established on 24-12-2019 (very late sowing), to the experimental design is a Split-plot with three replicates. Crops (bread wheat and rapeseed) were attributed to the large plots and the tillage sequences were assigned to the sub-plots. Four tillage treatments have been tested (no-till [NT], minimum till [MT], chisel plough [CP] and deep plough [DP]).

Data were analyzed by analysis of variance (ANOVA) and coefficient of variation using the SPSS software (version 21.0).

In addition, samples of above-ground biomass of whole plants were collected at harvest. After drying (80°C and 48 hours). Then the dried samples were weighed to determine grain yield. As a sampling method, random meter squares were taken in each plot, on the four modes of work, while avoiding the border effect.

Results

Impact of cultural techniques on bread wheat

Effect of practices cultural on wheat yield components

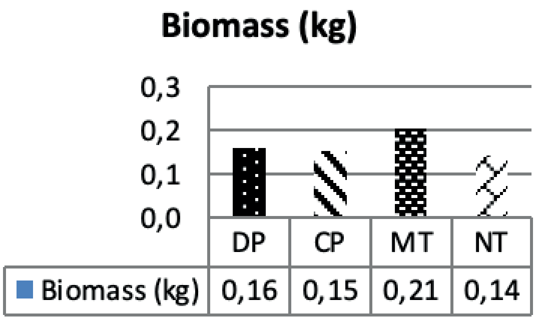

Figure. 1 Effect of practices cultural on wheat biomass production.

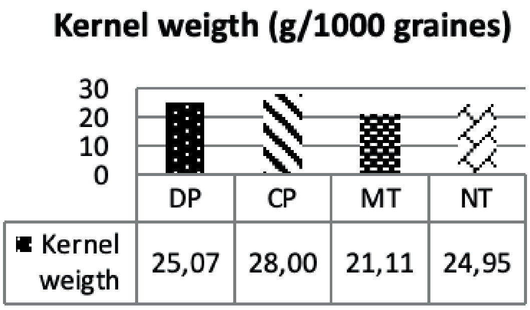

Figure. 2 Effect of practices cultural on wheat kernel weight.

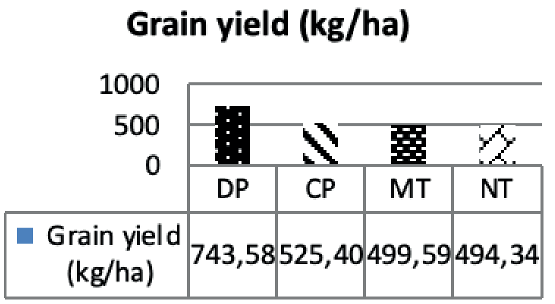

Figure. 3 Effect of practices cultural on wheat grain yield.

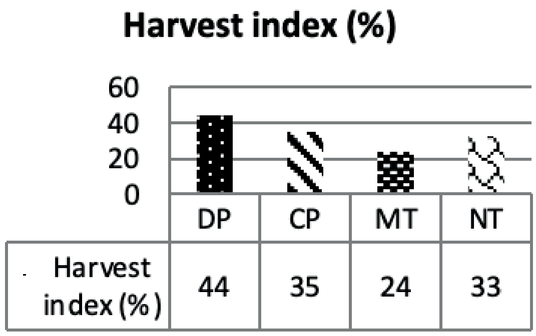

Figure. 4 Effect of practices cultural on wheat harvest index.

Biomass production

The analysis of variance on the calculated yield components indicates no significant difference between the practices cultural. Figure (1) shows that dry matter of no-till is lower than the conventional tillage, chisel plough and minimum till. However, the minimum till shows the highest biomass.

Kernel weight

Figure (2) reports that kernel weight under chisel is higher than that obtained for other sequences: conventional tillage, no-till, minimum till with an average of 28g, 25.07g, 24.95g, 21.11g respectively.

Grain yield

The conventional tillage showed the highest yield for bread wheat compared with other cultural practices (chisel plough, minimum till and no-till) which had showed a similar yield (figure 3).

Harvest index

Higher harvest index was calculated in deep plough (44%) followed by chisel plough (35%) and no till (33%), and the lower harvest index revealed in minimum tillage crop (24%) (figure 4).

Impact of cultural techniques on rapeseed Effect of no-till on rapeseed yield components

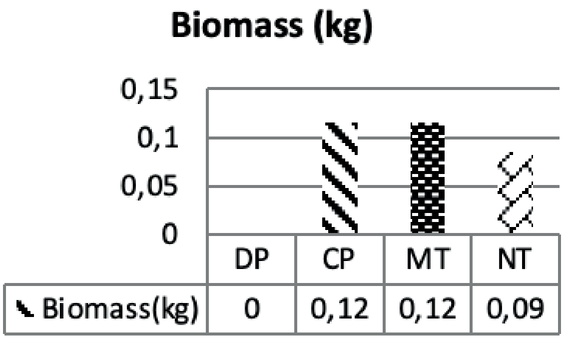

Figure. 5 Effect of practices cultural on rapeseed biomass production.

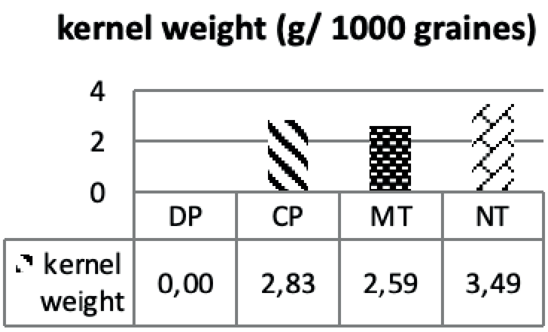

Figure. 6 Effect of practices cultural on rapeseed kernel weight.

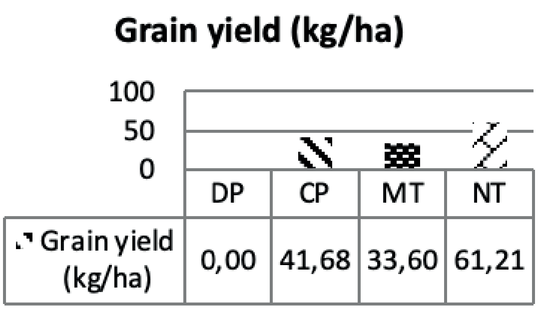

Figure. 7 Effect of practices cultural on rapeseed grain yield.

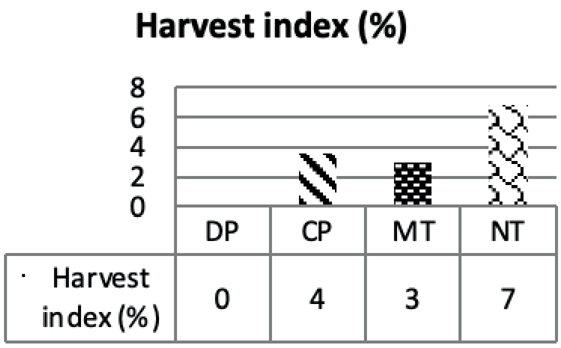

Figure. 8 Effect of practices cultural on rapeseed harvest index.

Biomass production
The practices cultural effect tended to be greater but no significant difference indicted in yield components. Figure (5) the no-till showed the lowest biomass compared to the chisel plough and minimum till, while it is observed that the deep plough recorded no biomass. Whereas, the non-germination was showed in deep plough due to the difficult climatic conditions.

Kernels Weight (KW)
No-till recorded the highest KW relative to chisel plough, minimum till and conventional tillage, respectively (figure 6).

Grain yield
The cropping systems showed a positive effect on grain yield. However, in no-till recorded the highest grain yield (61 kg/ha) compared to the chisel plough (42 kg/ha) and minimum till (34 kg/ha). While for deep plough showed zero production due to drought (figure 7).

Harvest index
The rapeseed under no-till registered the best harvest index compared to other cultural techniques (chisel plough, minimum till and deep plough) (figure 8).

Discussion

Comparison of the behavior of two crops (bread wheat and rapeseed) under different tillage methods showed that the wheat grain yield was better expressed in conventional tillage, reflecting decreases in the no-till, minimum work and the chisel plough. This result is in agreement with the one of Dayou et al. (2017). On the other hand, the highest rapeseed grain yield showed in no-till compared to chisel plough and minimum till. This result is in according to Malhi et al. (2001) found that barley revealed the highest yield under no-till than under conventional tillage, probably due to moisture conservation under no-till. Other results indicate the advantage of no-till and minimum tillage over conventional tillage (Bendidi, 2006; Fellahi et al., 2010; Chenaffi et al., 2011).

However, other authors included that yields are very close under no-till and deep plough (Büchi et al., 2017). While other studies, Pittelkow et al. (2014) showed that yields under no-till are decreased compared to the tillage system.

The effect of tillage method on crop yield differs depending on soil depth, turning and non-turning of the soil, and the degree of horizon mixing (Labreuche, 2007).

In contrast, other studies show that crop yields at the transition period are generally lower than those obtained after tillage, but improve after about three years of no-till (Anken et al., 2006).

As far as harvest index was concerned; higher wheat harvest index was calculated in deep plough followed by chisel plough, no-till and minimum till, this result is similar than Thapa et al. (2019) their revolved that neither grain yield, straw yield and harvest index were significant to the different tillage practices used of wheat. Similar results were observed by Bhattacharyya et al. (2008); Javeed et al. (2015), they recorded that the deep plough produced a higher harvest index than no-till of maize crop. These results are also in accordance with those of Ahadiyat and Ranamukhaarachchi (2007).

Conclusion

The crop systems showed no significant effect on the yield parameters of the two species studied. However, there was a positive effect for rapeseed. This technique the no-till seems to have the potential for significant gains in soil water status and crop yields. The contradictions in the results may be related to the poor conditions of the crop installation (late sowing) and the climatic conditions (drought).

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SUBTHEME 3

MAINSTREAMING OF CA WITH NATIONAL POLICY AND INSTITUTIONAL SUPPORT AND FOR GLOBAL GOVERNANCE TO SUPPORT NATIONAL AND INTERNATIONAL NEEDS AND COMMITMENTS

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Capacity development of agricultural mechanization hire service providers: opportunities for promoting Conservation Agriculture

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With climate breakdown and aggravated natural resource (especially soil) degradation, Conservation Agriculture (CA) offers exceptional potential over the coming years as a means to produce food sustainably for the planet's growing population while conserving natural resources and sequestering carbon at the same time. However, and especially in developing regions, CA implementation on the ground remains complex and the role of agricultural mechanization (especially for crop establishment and care) has been seen to be crucial. Consequently, over the past ten years, FAO has developed a program for the promotion of sustainable agricultural mechanization, in particular through support for private sector mechanization hire services provision.

This paper highlights the main results achieved after a program of capacity development for actors involved in agricultural mechanization hire services provision. This started with a training needs assessment and then organizing two regional workshops on sharing experiences of sustainable agricultural mechanization hire service provision practices in sub-Saharan African countries, one in Côte d'Ivoire with the participation of Benin, Burkina Faso, Côte d'Ivoire, Morocco and Senegal and one in Uganda with the participation of Ethiopia, Ghana, Kenya, Tanzania, Uganda and Zambia.

The exercise showed that there is great potential for developing agricultural mechanization hire services provision and different models were highlighted such as private enterprises of different types and sizes and cooperative use of shared equipment. Mechanization hire service providers, who are typically engaged in other activities such as crop production and processing and product commercialization, will play a crucial role, particularly in the promotion and dissemination of new practices such as CA. It was confirmed that, particularly for enterprises run by young people, there is openness to the introduction of new agricultural practices (such as CA) and information technologies which allow better monitoring of the use and management of equipment used for service provision.

Based on these considerations, a training manual for sustainable mechanization service providers was developed (by FAO and CIMMYT), including modules on management, technical issues and CA. It is aimed at trainers and its implementation is planned this year through a series of training sessions in English-speaking and French-speaking countries in collaboration with the African Conservation Tillage Network (ACT) in Kenya and the University Nazi Boni of Bobo Dioulasso in Burkina Faso.

In addition to the issue of developing the capacity of mechanization service providers, other factors must be taken into consideration, two of which are essential. The first relates to financing the acquisition of equipment and farming system transition to CA. As an example, in the case of Senegal the system of financing through the agricultural bank has encouraged private investment in agricultural mechanization and the creation of several hire service providers. The second point relates to the issue of the resistance of some producers to adopt CA and therefore reduce the demand for CA mechanization service providers. In this context, sensitization and extension activities need to be strengthened and sharply focussed.

Keywords: *Conservation Agriculture, sustainable mechanization, hire service provision.*

Abstract

With climate breakdown and aggravated natural resource (especially soil) degradation, Conservation Agriculture (CA) offers exceptional potential over the coming years as a means to produce food sustainably for the planet's growing population while conserving natural resources and sequestering carbon at the same time. However, and especially in developing regions, CA implementation on the ground remains complex and the role of agricultural mechanization (especially for crop establishment and care) has been seen to be crucial. Consequently, over the past ten years, FAO has developed a program for the promotion of sustainable agricultural mechanization, in particular through support for private sector mechanization hire services provision.

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Introduction

With climate breakdown and aggravated natural resource (especially soil) degradation, Conservation Agriculture (CA) offers exceptional potential over the coming years as a means to produce food sustainably for the planet's growing population while conserving natural resources and sequestering carbon at the same time. However, and especially in developing regions, CA implementation on the ground remains complex and the role of agricultural mechanization (especially for crop establishment and care) has been seen to be crucial. Consequently, over the past ten years, FAO has developed a program for the promotion of sustainable agricultural mechanization, in particular through support for private sector mechanization hire services provision.

Indeed, mechanization hire services have played a key role in countries with mechanized agriculture (Olmstead, A. 1995). In some African countries, private sector-driven markets are gradually emerging (Berhane, G. 2017). Nevertheless, challenges remain – for example, in Ghana, service providers avoid providing mechanization hire services to smallholder farmers because of the high transaction costs associated with small farm size and spatial dispersion (Daum T. 2017). Other factors hampering the uptake of agricultural mechanization include low incomes of farmers, absence of infrastructure in rural communities, poor skills of operators and technicians, and lack of incentives for private sector investments. A critical issue to address is how to ensure that business models for mechanization hire services driven by the private sector (including farmers, cooperatives and small and medium enterprises [SMEs]) are not only profitable, sustainable and inclusive for smallholder farmers and vulnerable community members including women and youth, but also resilient to the effects of climate change.

This paper highlights the main results achieved after a program of capacity development for actors involved in agricultural mechanization hire services provision and organizing two regional workshops on sharing experiences of sustainable agricultural mechanization hire service provision practices in sub-Saharan African countries, one in Côte d'Ivoire with the participation of Benin, Burkina Faso, Côte d'Ivoire, Morocco and Senegal (Houmy, K. 2019) and one in Uganda with the participation of Ethiopia, Ghana, Kenya, Tanzania, Uganda and Zambia (Mkomwa, S., 2020). Based in case studies, it aims to (i) showcase a variety of business models of private-sector businesses providing agricultural mechanization hire services in Africa, (ii) compare between these business models, and (iii) identify success factors.

The business model canvas tool was adopted to understand how mechanization service providers operate, interact with customers, cover costs and make a profit. The approach enables the comparison between the different business models and highlights the key factors for success. The canvas tool has become popular in recent years as markets are required to constantly evolve their economic processes, practices and operations in order to ensure competitiveness and sustainability (Osterwalder, A. 2005). It is based on mapping of the following nine building blocks: customer segments, value proposition, delivery channels, customer relationships, revenue streams, key resources, key activities, key partnerships and cost structure.

Typology of Business Models: provision of mechanization hire services in africa

Based on the analysis of the main characteristics of the enterprises encountered in the workshop combined with documentary analysis, two variables were chosen for the typology of business models:

- Ownership of the business – including farmer groups and individual entrepreneurs.
- Types of services provided – including agricultural mechanization hire services, other services related to agricultural activities or the agricultural mechanization supply chain and acting as an intermediary between farmers and service providers.

Based on these two variables, business models of agricultural mechanization hire service providers were identified as follows (Table 1):

- Model I – Individual farmer service providers.
- Model II – Farmer group service providers.
- Model III – Entrepreneur service providers involved in agricultural services.
- Model IV – Entrepreneur service providers involved in the agricultural mechanization supply chain.
- Model V – Entrepreneurs as intermediary hire service providers.

	Model I	Model II	Model III	Model IV	Model V
Ownership	Individual farmers	Farmer groups	Private entrepreneurs	Private entrepreneurs	Private entrepreneurs
Services	Agricultural mechanization hire service	Agricultural mechanization hire service	Agricultural mechanization hire service and agricultural services	Agricultural mechanization hire service and mechanization supply chain services	Intermediary for agricultural mechanization hire service and digital services

Table 1. Types of business models according to ownership and services

Model I – Individual farmer service providers is the most widespread model and customers are generally small-scale farmers cultivating less than an average of 1 ha of land (Sims, B. 2011). Mechanization services not only concern production but cover the entire agrifood chain from planting or transplanting to post-harvest, processing and transport operations. These kinds of hire service providers do not generally operate as businesses in their own right, but provide occasional services as opportunities arise (Hilmi, M. 2018). This model is less conducive to innovation in hire service provision; farmers typically operate within a small radius of their location and the service is characterized by customer loyalty. Model I has provided and continues to provide a means for small-scale farmers to access mechanization services in rural communities; for this reason, support for enhancing this model in the field can be envisaged in the framework of sustainable agricultural mechanization development.

Model II – Farmer group service providers comprises a group of individual farmers who come together principally to serve their own interests. There are several possible forms (e.g., associations and cooperatives) and it represents an interesting means for farmers to pool their resources and increase access to agricultural mechanization services. Services cover all operations in the agricultural value chain, from tillage to post-harvest activities, processing and transport. Services first meet the needs of members and are then extended to neighbouring non-member farmers. In general, the machinery and equipment of the cooperatives can range from very simple tools (e.g., women's processing cooperatives in Benin) to more sophisticated equipment.

Model III – Entrepreneur service providers involved in agricultural services represents various kinds of enterprises with differing status, such as sole proprietorship enterprise,[1] limited liability

1 In a sole proprietorship enterprise, there is no legal distinction between the business entity and the owner.

company (LLC)[2] and economic interest group (EIG).[3] They vary in size from very small to medium sized; several cases were encountered during the workshop, some of which run by women and youth. The services cover all activities in the agricultural value chain, from tillage to post-harvest operations, processing and transport.

These enterprises are run by managers with entrepreneurial skills who are more inclined to adopt new ideas and innovation. They are motivated to generate a profit and cover all hire activities in the agrifood value chain. Model III enterprises are characterized by the diversification of their activities, which are not limited to agricultural mechanization hire services but include, as example, sale of agricultural inputs.

Model IV – Entrepreneur service providers involved in the agricultural mechanization supply chain comprises businesses supplying machinery and equipment while also providing agricultural mechanization hire services. These businesses repair and sell agricultural machinery and equipment; the provision of mechanization services does not represent the core of the business but complements the other activities.

Model V – Entrepreneurs as intermediary hire service providers of which the business does not have agricultural machinery at its disposal, but rather plays the role of intermediary between the owners of the machinery and farmers. It's important to mention how an intermediary can use an on-demand platform to optimize local resources and provide timely agricultural mechanization services to farmers in the vicinity. Such a platform allows tractor owners to use Global Positioning System (GPS) to monitor the movement and work progress of their equipment.

Comparing the Business Models

Each enterprise is created according to the business model that makes it profitable and viable. By using the business model canvas tool to compare the models, it is possible to understand how mechanization service providers operate and in what context, and to identify where there is room for improvement and innovation. This section compares the nine building blocks of the canvas tool across all the business models.

The first building block is ***the customer segments*** which, for mechanization service providers, include mainly small-scale farmers, small-scale farmer groups, large-scale farmers. In SSA countries, small-scale farmers represent 70 percent of the population and produce 80 percent of the food consumed (AfDB, 2015). They tend to be characterized mainly by:

- cash flow problems – specifically the lack of capacity to pay in certain periods (e.g., beginning of the cropping season);
- fragmentation and dispersion of plots of land – which reduces the capacity and efficiency of machinery;
- poor quality plots – if poorly grubbed up, they can damage tractor tyres.

Model III remains versatile and provides services to all segments, while Models IV and V only provide mechanization services for on-farm crop production. Models I and II respond to the needs of small-scale farmers. Model IV, given the size of its fleet, can only offer services to farmer groups or large-scale farmers. Other less common customer segments include actors in the construction sector, mainly for transport services.

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2 Limited liability implies that all the shareholders are accountable for all debts which the company incurs. In most cases, an LLC is formed when two or more business individuals come together and form a partnership.

3 An EIG is a type of legal entity designed for companies to join forces and carry out projects that exceed their individual capacities.

The second building block is ***the value proposition*** which defines what kind of problem the service provider is solving for the producers. Models II and III cover almost all agricultural services, whereas models IV and V are limited to on-farm operations. However, Model IV offers advantages in terms of control of the supply chain of agricultural machinery and equipment and, in particular, resolution of maintenance problems. Model V, on the other hand, offers very interesting value propositions both for farmers by reducing waiting time and for tractor owners by optimizing tractor use. Finally, in the case of Model V, where digital platforms are used for tractor reservation, the installation of GPS trackers provides an additional service to tractor owners as the machinery is monitored and security is improved.

In terms of innovation, Model III enterprises tend to be characterized by more open and flexible management and can thus be an important channel for technology dissemination. Therefore, businesses following this model can also provide farm advisory services. Advice could cover the latest topics such as Conservation Agriculture practices.

The third building block is the ***Delivery channels*** which are developed according to the services offered. For Models I, II and III, customers are generally located close to the service providers. This is not the case for other models such as Model IV, which tends to be located in large cities and it is the business that moves to agricultural areas to provide the service requested by a group of farmers.

The fourth building block is ***Customer relationships*** which are generally based on human interaction. The exception is Model V where all connections are made by mobile phone. Word-of-mouth marketing is common to all business models as a spontaneous means to reach new customers in the community. The relationship can also be long term, where customers become loyal over time and an atmosphere of trust is created.

The fifth building block is ***the Revenue streams*** which are generally comes from the income generated by the payment of mechanization hire services. The exception is Model V, where revenue comes from the commissions paid by farmers for booking tractors and from the sale and installation of GPS devices. Several innovations were made due to a favourable ecosystem comprising close linkages with processors and/or aggregators. Payment in kind (i.e., part of the harvest) is easier when the provider also sells crop products. Where trust exists between farmers and providers, delaying payment until after the harvest can resolve the problem of farmers' lack of cash flow.

The sixth building block is ***the Key resources*** which refer to all the human, financial and material resources needed to generate profits. In terms of physical assets, the models have a range of equipment to cover the various activities in the value chain. With regard to human resources in Model I and II enterprises, staff generally lack professional qualifications and have simply gained experience on the job. This is the case for both managers and operators. On the other hand, for Models III, IV and V, the staff does have the necessary skills to carry out the various operations.

For the seventh building block, it concerns ***the Key activities*** that are performed in different areas depending on the model. All the models – except Model V – carry out mechanized operations for crop production and/or post-harvest and processing activities. The period of activity varies greatly from one operation to another. In general, however, processing equipment operates almost all year round, while on-farm operations take place during specific periods. For Model III in particular, some enterprises comprise a technical framework to guide farmers in agronomy-related issues. In addition to hire service provision, these businesses are involved in other agricultural activities such as commercialization of agricultural inputs and products. Finally, a key activity relevant in particular to Model V is digital development with information and communications technology (ICT) skills.

The eight building block ***is the key partnerships.*** A hire service provider is in contact with several partners who may be national or international. Farmer organizations (associations, unions etc.)

are strategic partners. The UN-CUMA union in Benin, for example, plays an important role in the supervision and support of CUMA cooperatives. Financial institutions are also key partners and their support is crucial for enterprises in Models III, IV and V, in particular.
The last building block ***is the cost structure*** which includes fixed and variable costs that fluctuate depending on the activity. For Models I and II, the fixed costs are relatively low because most investments are in second-hand equipment. In contrast, for Models III and IV, the fixed costs are high due to the high prices of machines, which also fluctuate over time depending on the currency market.

Success factors

Both internal and external factors can determine the long-term sustainability of the business models for the provision of agricultural mechanization hire services. Eight success factors have been identified (Figure 1).

Skilful staff and leadership: For all models, the businesses are run by highly motivated people with entrepreneurial and managerial skills, whether heads of enterprises or presidents of cooperatives.

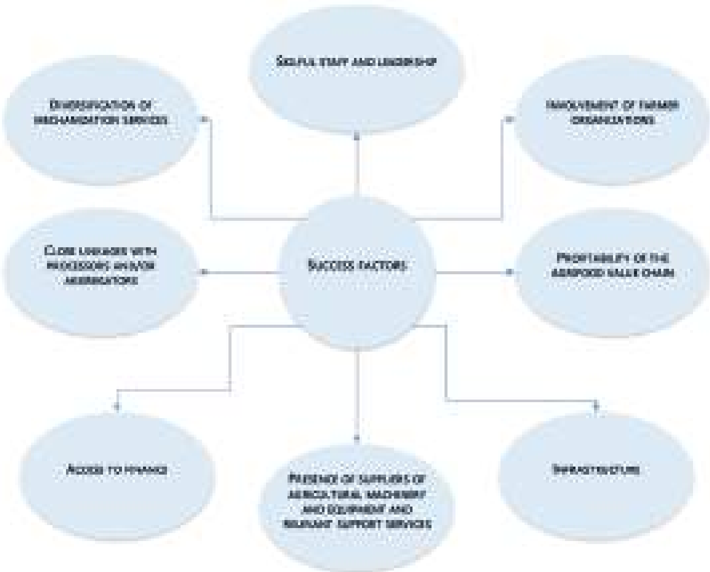

Figure 1. Success factors

Diversification of mechanization services: Model III is characterized by diversification of the mechanization services provided in the value chain. Diversification allows the business to generate income throughout the year by providing, for example, land preparation, harvesting and milling services. Complementary services or sales also present opportunities; for example, Model III is involved in areas such as marketing of agricultural inputs and seed production.

Involvement of farmer organizations: Farmer organizations (FOs) can also play an important role in the success of hire service providers. The cooperative movement in Benin – thanks to UN-CUMA, NGOs and development partners – has gained significant momentum and has become a sub-Saharan African success story.

Close linkages with processors and/or aggregators: Processors and aggregators can play an important role in the development of mechanization service provision by linking up farmers in need of specific services with the appropriate hire services. Contracts between mechanization service providers and processors or aggregators allow service providers to have a stable source of income and to plan their operations during the year.

Presence of suppliers of agricultural machinery and equipment and relevant support services: Retailers and distributers of agricultural machinery and equipment supply the necessary technology. Support services carry out repairs and maintenance, sell spare parts, and provide aftersales support and capacity building for appropriate operation by users.

Profitability of the agrifood value chain: Among the enterprises consulted, those involved in the production of market-oriented agricultural products such as irrigated rice manage to generate sufficient income for farmers to pay for services and thus create demand for agricultural mechanization

Access to finance: Financing has been important for the viability of some businesses, particularly those located in Senegal receiving support from the Agricultural Bank. Banks have granted credit for the development of Model II, III and IV enterprises based on the viability of the projects submitted. Indeed, as already mentioned, the managers of these models are equipped with the necessary skills to develop bankable projects worthy of credit.

Infrastructure: Some enterprises emphasized the role of infrastructure for business viability. Infrastructure includes irrigation scheme developments, rural electrification, roads and ICT networks.

Conclusion

This study focused on the provision of agricultural mechanization hire services by conducting case studies in sub-Saharan African countries: Five business models were identified, namely: Model I – Individual farmer service providers; Model II – Farmer group service providers; Model III – Entrepreneur service providers involved in agricultural activities; Model IV – Entrepreneur service providers involved in the agricultural mechanization supply chain; and Model V – Entrepreneurs as intermediary hire service providers. The models were presented and a comparative analysis conducted based on the nine canvas building blocks.

Models I, II and III are managed by the farmers themselves and cover all services in the value chain, whereas Models IV and V are involved mainly in on-farm operations with specific value propositions. The findings regarding Model II indicate that when a cooperative is created on farmers' own initiative and there is external support, sharing of machinery and equipment is an effective way for small farmers, especially vulnerable groups including women, to pool resources.

Businesses can also provide services unrelated to agricultural mechanization; in the case of Model III, in particular, additional services may include sale of agricultural inputs (e.g. seeds, fertilizers and pesticides), creation of a market for farmers' products and provision of technical advice. These services strengthen the relationship between providers and customers, facilitate transactions and can an important channel for technology dissemination as CA.

Model IV limits its services to on farm operations, but it offers advantages in terms of control of the agricultural machinery and equipment supply chain and resolution of maintenance problems. It can be also an important channel to disseminate CA as it has the possibility to invest in on farm machinery as seeders. Model V concentrates mainly on tillage operations, but it offers very interesting value propositions both for farmers by reducing waiting time and for tractor owners by optimizing tractor use.

Finally, not only has the business model canvas tool enabled an understanding of the situation of service providers, it is also a powerful tool – as per its original development – for designing new, more innovative and creative models, in the knowledge that there remains immense potential for improvement in SSA countries. Value propositions, customer relationships and partnership development are all examples of business model building blocks that the new generations of hire service providers should explore in the coming years.

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The future of farming
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LIFE Agromitiga: development of climate change mitigation strategies through carbon-smart agriculture

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In agricultural systems, one of the most relevant natural resources for fighting climate change is soil, thanks to its potential to capture CO_2 from the atmosphere. Proof of this is that soil, with three times more carbon than the atmosphere, is recognized as the second largest stock of Carbon (C) on the planet after the oceans, in addition to constituting one of the most important components of the biosphere, for its provision of ecosystem functions and services. Some agricultural practices, such as Conservation Agriculture, can increase carbon sequestration in soils. Therefore, this practice is considered by the 4per1000 initiative as one of the most effective practices to mitigate climate change. On this basis, LIFE Agromitiga, a European project financed by the EU LIFE Program, will promote a low-carbon agricultural system to battle climate change from the agricultural sector, through the use of Conservation Agriculture, providing validated results applicable to EU commitments on global climate alliances. To do so, LIFE Agromitiga will carry out the implementation of Conservation Agriculture practices at 3 scales (pilot, regional and transnational scale). Therefore, a Demonstration Farm Network will be established, which will include more than 35 farms, in countries such as Spain, Italy, Greece and Portugal, in which techniques such as no tillage and groundcovers will be monitored, as well as the amount of carbon that each practice would produce.

It is expected that, thanks to the implementation of LIFE Agromitiga project, a methodology for quantifying C footprint during the cultivation period of crops in different soil management systems will be developed. As a consequence of the proposed methodology, environmental policies in the EU on climate change and agriculture could be developed and promoted. Another result will be a report on how to increase the carbon sink in soils while reducing Greenhouse Gas emissions in the project area, which will be useful for international commitments like the Paris Agreement on Climate Change, the Sustainability Development Goals, among others. It is expected to increase the soil carbon sink by 1 Mg $ha^{-1}yr^{-1}$ in both annual and permanent crops. Therefore, a technological tool will be created, which will enable stakeholders, including farmers and technicians, to evaluate its practices regarding carbon sequestration in agricultural soils. Since Conservation Agriculture improves soil quality, leading to an optimized use of inputs (including Nitrogen fertilizers), resulting in lower emissions, energy savings and energy efficiencies superior to conventional agriculture, it is expected to achieve energy savings of around 30% in the crop rotations. Energy productivity is expected to increase by 50% and fuel consumption would drop by half.

Keywords: *Conservation Agriculture, No-till, Groundcovers, Carbon sequestration, energy saving*

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In agricultural systems, one of the most relevant natural resources for fighting climate change is soil, thanks to its potential to capture CO_2 from the atmosphere. Proof of this is that soil, with three times more carbon than the atmosphere, is recognized as the second largest stock of Carbon (C) on the planet after the oceans, in addition to constituting one of the most important components of the biosphere, for its provision of ecosystem functions and services. Some agricultural practices, such as Conservation Agriculture, can increase carbon sequestration in soils. Therefore, this practice is considered by the 4per1000 initiative as one of the most effective practices to mitigate climate change. On this basis, LIFE Agromitiga, a European project financed by the EU LIFE Program, will promote a low-carbon agricultural system to battle climate change from the agricultural sector, through the use of Conservation Agriculture, providing validated results applicable to EU commitments on global climate alliances. To do so, LIFE Agromitiga will carry out the implementation of Conservation Agriculture practices at 3 scales (pilot, regional and transnational scale). Therefore, a Demonstration Farm Network will be established, which will include more than 35 farms, in countries such as Spain, Italy, Greece and Portugal, in which techniques such as no tillage and groundcovers will be monitored, as well as the amount of carbon that each practice would produce.

It is expected that, thanks to the implementation of LIFE Agromitiga project, a methodology for quantifying C footprint during the cultivation period of crops in different soil management systems will be developed. As a consequence of the proposed methodology, environmental policies in the EU on climate change and agriculture could be developed and promoted. Another result will be a report on how to increase the carbon sink in soils while reducing Greenhouse Gas emissions in the project area, which will be useful for international commitments like the Paris Agreement on Climate Change, the Sustainability Development Goals, among others. It is expected to increase the soil carbon sink by 1 Mg $ha^{-1}yr^{-1}$ in both annual and permanent crops. Therefore, a technological tool will be created, which will enable stakeholders, including farmers and technicians, to evaluate its practices regarding carbon sequestration in agricultural soils. Since Conservation Agriculture improves soil quality, leading to an optimized use of inputs (including Nitrogen fertilizers), resulting in lower emissions, energy savings and energy efficiencies superior to conventional agriculture, it is expected to achieve energy savings of around 30% in the crop rotations. Energy productivity is expected to increase by 50% and fuel consumption would drop by half.

Introduction

According to the special report "Climate Change and Land" published by the IPCC in 2019, (Shulka *et al.*, 2019) agriculture, together with forestry and other land uses, constitutes an important net source of Greenhouse Gasses (GHG) emissions. Specifically, it is estimated that CO_2 emissions from these land uses will reach 23% of the global total from 2007 to 2016.

Agriculture, far from being just a GHG emitting sector, also suffers the consequences of climate change, because, as the IPCC states in the above-mentioned report, the increase in temperatures provoked by global warming, is altering the beginning and the end of the vegetative periods and is reducing the availability of fresh water. This leads to a decrease in crop yields. Therefore, the European Environment Agency states that "the EU needs to reduce GHG emissions in its agriculture and adapt its food production system to face climate change".

In this context, agricultural soils can play a determining role in mitigating climate change. With three times more Carbon (C) than the atmosphere, soils are recognized as the second storehouse of this element on the planet after the oceans (Burjano-Orjuela, 2018). Historically, soils have undergone various processes (erosion, desertification, salinization, among others), therefore a large part of C stored in their interior has been released into the atmosphere in the form of CO_2. Agricultural practices based on tillage are one of the promoting causes of these processes as they accelerate the decomposition and mineralization of Organic Matter (OM). It is estimated that this type of agriculture has contributed to the loss of between 30% and 50% of C in the last two decades of the 20th century (Reicosky, 2011). This fact only highlights the great potential that agricultural soils have to sequester atmospheric CO_2 through the implementation of agricultural management practices that favor C fixation processes, taking into account the amount of this element that they have been losing decade after decade.

The LIFE Agromitiga project endorses this premise, and with the aim of contributing to a low-carbon agricultural system, it promotes the implementation of Conservation Agriculture (CA) in both herbaceous and woody crops. The project, through its actions, will demonstrate how, thanks to the use of this type of practices, the C content in the soil is increased while reducing GHG emissions, providing agents of the agricultural sector with tools used to quantify mentioned increase and adopt practices such as no-tillage or groundcovers. In addition, and thanks to the development of a methodology used to calculate the Carbon Footprint in the agronomic phase of crops, the competent administrations will be able to standardize the protocols for quantifying the Carbon Footprint by integrating this methodology into international regulations.

The technical solution proposed to achieve the objectives set in the project is, as mentioned above, the implementation of CA, either no-tillage in the case of herbaceous crops or groundcovers in the case of woody crops. These agricultural practices are based on three fundamental principles: elimination of tillage, maintenance of a vegetation cover on the soil surface and the application of crop rotations. These management practices are implemented in a network of demonstration farms that serve to evaluate and demonstrate, at a pilot, regional and transnational scale, their potential to mitigate climate change through C sequestration and reduction in GHG emissions.

Material and Methods

In order to implement CA practices and monitor sequestration rates in the soil, demonstration farms at various work scales (pilot, regional and transnational scale) have been established. This article shows the results achieved to date in the demonstration farms network established at regional scale, therefore, for this purpose, the methodology carried out at the mentioned scale is described.

Agroclimatic zoning of Andalusia

Prior to the selection of demonstration farms that would be included in the network, an agroclimatic characterization of Andalusia (Spain) had been carried out what led to zoning. That helped establish, in every area, representative farms according to their climate, soil and crop characteristics. Thus, it will be possible to establish representative sequestration rates in each specific study area according to the crop and soil management system.

Taking into account the main factors that determine the soil C content, the most appropriate digital information was identified and treated in a simplified way to optimize it for the indicated purpose, identifying three types of sources to characterize the agroclimatic zones: climate, soil and use. (Fig. 1).

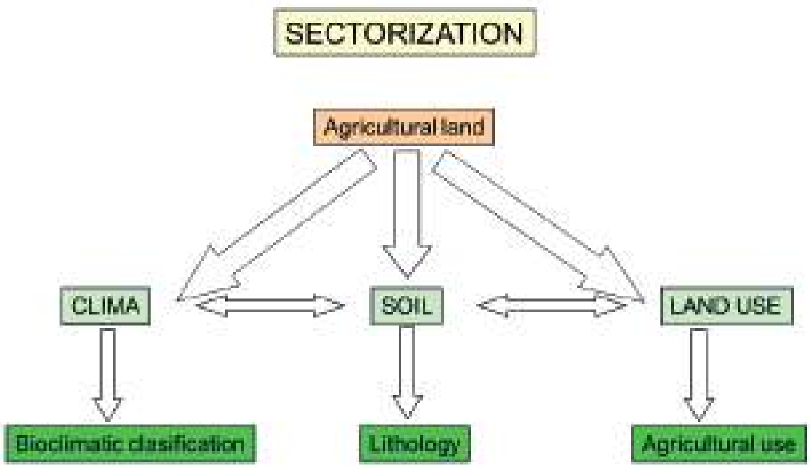

Fig. 1. Scheme of the sectorization process methodology.

As a climatic variable, a bioclimatic classification has been used based on information regarding the mean temperature (T) of the coldest month, the mean T of the warmest month, photosynthetic potential and accumulated precipitation as significant variables, identifying 16 areas regionally. (Fig. 3). The used bioclimatic classification has been prepared by the Ministry of Agriculture, Livestock, Fisheries and Sustainable Development of the Junta de Andalucía within the framework of the work carried out periodically to update the climate change scenarios to the different IPCC reports, specifically in this case to 5th Report.

As a variable linked to the edaphic characterization, the lithological aspect of the soils in the region has been chosen, and which represents a synthesizing characteristic of their main characteristics. The regional lithological information has been grouped into a set of 20 superficially significant units.

The identification of the main agricultural uses has been carried out using the information available in the Ministry of Agriculture, Livestock, Fisheries and Sustainable Development of the Junta de Andalucía regarding uses and groundcovers. Bearing in mind the main object of the study, the available information has been analyzed, using the most relevant to this study and identifying the main types of use at regional level and grouping them into 10 major classes.

The different types of information have been crossed, generating statistical tables regarding different aspects in order to carry out the quantitative distribution of experimental plots on the most representative areas of regional agricultural use, and obtain a cartographic location of the distribution of the most important strata.

Thanks to the tasks performed in the action, a digital coverage has been generated with the sectorization from which to extract statistics and locations according to representativeness criteria. In total, 8 sectors have been defined in the study region (Fig. 2):

1. *Sub*-humid *Mediterranean* climate
2. Sub-humid warm Mediterranean climate
3. Dry continental Mediterranean climate with warm summers.
4. Sub-humid continental Mediterranean climate with very cold winters.
5. Dry continental Mediterranean climate with cold winters.
6. Sub-humid continental Mediterranean climate with cold winters and warm summers.
7. Continental Mediterranean climate with dry and cold highlands.
8. Sub-desert Mediterranean climate.

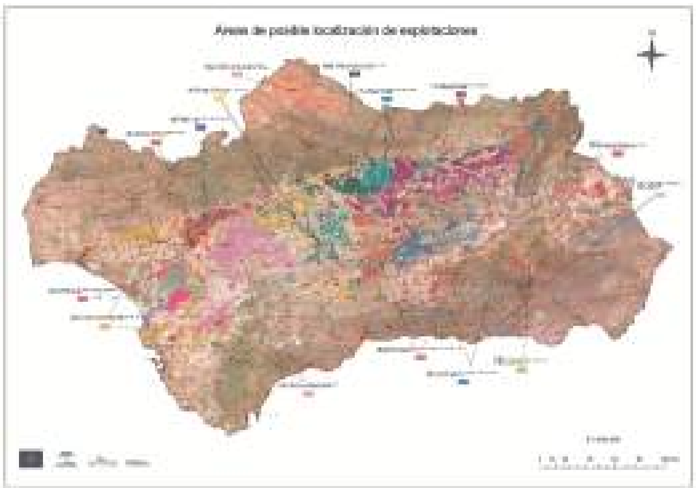

Fig. 2. Agroclimatic sectors for the location of the farm network at regional scale.

Demonstration farms

Once the sectorization has been carried out, the demonstration farms that would be included in the study network have been selected and on which the analyzes of the soil C content are being carried out. The selection has been made in such a way as to guarantee that, for each sector, there is at least one farm with the most representative crops of that sector, under Conservation Agriculture and Conventional Agriculture, in order to compare the results in both management systems. Finally, the network is made up of 36 demonstration farms (Table 2).

Table 2. Number of demonstration farms and types of management systems (in parentheses) selected in each agroclimatic zone (CA: Conservation Agriculture, CT: Conventional Tillage).

	Subhumid Mediterranean climate	*Subhumid warm Mediterranean climate*	*Dry continental Mediterranean climate with warm summers*	*Sub-humid continental Mediterranean climate with very cold winters*	*Dry continental Mediterranean climate with cold winters*	*Sub-humid continental Mediterranean climate with cold winters and warm summers*	*Continental Mediterranean climate with dry and cold highlands*	*Sub-desert Mediterranean climate*	TOTAL
Rainfed herbaceous	3 (CA+CA+CT)	2 (CA+CT)	2 (CA+CT)	-	2 (CA+CT)	-	2 (CA+CT)	-	**11**
Irrigated herbaceous	2 (CA+CT)	2 (CA+CT))	2 (CA+CT)	-	-	-	-	-	**6**
Olive grove	-	-	2 (CA+CT)	2 (CA+CT dry land)	3 (CA+CA+CT irrigation) 3 (CA+CA+CT dry land)	2 (AC+LC)	-	-	**12**
Fruit-trees	-	-	-	-	-	-	2 (CA+CT)	2 (CA+CT)	**4**
Citrus	3 (CA+CA+CT)	-	-	-	-	-	-	-	**3**
TOTAL	**8**	**4**	**6**	**2**	**8**	**2**	**4**	**2**	**36**

Soil sampling

For each farm belonging to the network, representative study plots have been established on which soil samplings would be performed in order to analyze the C content, georeferencing the points with the view to study the evolution of those contents over time. The number of sampling points and their distribution on the farm are based on the orography. The samplings began in October 2019.

For sampling, an auger with a helix-shaped head is used which allows us to reach up to 30 cm in depth. Samples are taken at three different depths: 0 to 5 cm, 5 to 10 cm, and 10 to 30 cm. Total C content was determined using the Walkley–Black method (Nelson and Sommer 1982).

Results and discussion

In the studies carried out in different farms, the influence of two variables on the soil C content is being analysed:

- Management system used in the test plot.
- Agroclimatic sector in which the farm is located.

The results show the information collected through the soil samplings carried out during the 2019/2020 season.

Influence of the management system on the C stocks in the soil.

In this case, the differences in the C content in the soils have been studied for the same agroclimatic sector comparing the crops managed by CA (No-tillage in herbaceous crops and Groundcovers in woody crops) and the crops managed by conventional tillage. To date, in all agroclimatic sectors, higher C contents have been observed in soils managed by CA techniques (Table 2 and Table 2). Although in most of them these differences with respect to soils managed by conventional tillage are not statistically significant, in many cases they represent a very important increase in the soil's sink capacity.

An example of this in herbaceous crops, in the case of the agroclimatic sector 2, are the farms in which the farmer has opted for no-tillage management system, which present up to 40% and 20% more C than the soils under conventional tillage in the towns of Villalba del Alcor and Las Cabezas de San Juan, respectively.

In woody crops, in all cases except in the agroclimatic sector 2, the farms that have used groundcovers have shown higher OC contents on the surface. The olive groves with groundcovers, located in the agroclimatic sector 7, stand out above all, because their soils show 35% more OC than those managed by conventional tillage.

Table 2. Average soil C contents on farms destined to extensive farming under the two studied management systems and located in the different climatic units of the study. (NT: No Tillage, CT: Conventional Tillage). The tables show the average value according to depth and management system.

Management System	Depth (cm)		
	0-5	5-10	10-30
	CLIMATE UNIT 2		
NT	1,32 a	1,30 a*	1,33 a*
CT	1,13 a	1,13 ab*	1,18 ab*
	CLIMATE UNIT 4		
NT	1,91 a**	1,34 a	0,83 a
CT	1,04 b**	1,06 a	0,66 a
	CLIMATE UNIT 6		
NT	0,82 a	0,72 a	0,75 a
CT	0,55 a	0,52 a	0,46 a
	CLIMATE UNIT 8		
NT	1,21 a	1,23 a	1,10 a
CT	0,99 a	0,76 a	0,75 a

Different letters indicate significant differences. Tuckey's T test for the probabilities of (p*<0,05, p**< 0,0005, p***<0,0001).

Table 3. Average soil C content in farms destined to woody crops under the two studied management systems and located in the different climatic units included in the study. The tables show the average value according to depth and management system. GC: Groundcovers, CT: Conventional Tillage).

Management System	Depth (cm)		
	0-5	5-10	10-30
	CLIMATE UNIT 2		
GC	0,61 a	0,56 a*	0,50 b*
CT	1,33 a	1,17 ab*	1,17 ab*
	CLIMATE UNIT 6		
GC	0,95 a	0,96 a	0,96 a
CT	0,84 a	0,84 a	0,85 a
	CLIMATE UNIT 7		
GC	1,43 a*	1,0 a	0,89 a
CT	0,92 b*	0,88 a	0,76 a
	CLIMATE UNIT 8		
GC	1,23 a	1,36 a	1,47 a
CT	1,15 a	1,31 a	1,43 a
	CLIMATE UNIT 13		
GC	1,67 a	1,40 a	1,28 a
CT	1,65 a	1,56 a	1,51 a

Different letters indicate significant differences. Tuckey's T test for the probabilities of (p*<0,05, p**< 0,0005, p***<0,0001).

Influence of edaphoclimatic conditions on C stocks in the soil

It is not only important to consider the management system to assess its effect on the increase in the soil C content, but it can be also influenced by the climatic conditions and edaphic characteristics. Therefore, comparisons are made, for the same crop and management system, between different agro-climatic sectors (Table 4). The first results show that the edaphoclimatic characteristics greatly influence the C content in the soils with the same crop and management system, showing values in a climatic area that are double than those in another area. This only highlights the potential of some areas compared to others for the implementation of CA practices, offering information on the areas where to prioritize the implementation of strategies that promote C sequestration as a mitigation measure.

Table 4 CO contents in the soil according to the management system and the climatic unit.

Climate Unit	Depth (cm)		
	0-5	5-10	10-30
	Herbaceous Crops under No-till		
2	1,32 ab*	1,30 a	1,33 a*
4	1,91 a*	1,34 a	0,83 ab*
6	0,82 b*	0,72 a	0,75 b*
8	1,21 ab*	1,23 a	1,10 ab*
	Herbaceous crops under conventional tillage		
2	1,13 a	1,13 a	1,18 a*
4	1,04 a	1,06 a	0,66 ab*
6	0,55 a	0,52 a	0,46 b*
8	0,99 a	0,76 a	0,75 ab*
	Woody crops under Conservation Agriculture-Groundcovers		
2	0,61 b	0,56 b	0,50 b
6	0,95 ab	0,96 ab	0,96 ab
7	1,43 a	1,0 ab	0,89 ab
8	1,23 a	1,36 a	1,47 a
13	1,67 a	1,40 a	1,28 a
	Woody crops under conventional tillage		
2	1,33 a	1,17 a	1,17 a
6	0,84 a	0,84 a	0,85 a
7	0,92 a	0,88 a	0,76 a
8	1,15 a	1,31 a	1,43 a
13	1,65 a	1,56 a	1,51 a

Different letters indicate significant differences. Tuckey's T test for the probabilities of ($p^*<0,05$, $p^{**}< 0,0005$, $p^{***}<0,0001$).

Aknowledgements

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The future of farming
Profitable and Sustainable Farming
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Multi-pronged theory of change drives successful Conservation Agriculture systems

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The American Farmland Trust (AFT) takes a comprehensive approach to Conservation Agriculture. Our mission reflects our multi-pronged theory of change in that we work with farmers and their partners to implement regenerative practices; we recognize that both protection of farm and ranchland and their transfer to new farmers is critical to the survival of Conservation Agriculture because without these lands, we will not have sufficient land for food, fiber and fuel production. We then "feed" these levers of change by taking learnings from our work and providing them to policy makers at the state and federal level to develop and implement policies that can incentivize and fund each of these actions that are necessary to support Conservation Agriculture. In this presentation, we will explore various examples of our work with farmers on adoption of regenerative agriculture practices and complementary work undertaken with a variety of AFT tools to quantify the economic and environmental outcomes from implementation of these practices thus illustrating to other farmers the benefits realized by investing in soil health. For example, through the use of AFT's Carbon Reduction Potential Evaluation Tool (CaRPE), a web-based interactive tool used to visualize and quantify greenhouse gas emission reductions from implementation of a suite of cropland and grazing land conservation management practices, we can work with farmers to run scenarios comparing practices, their estimated costs, and see where across a state or region the greatest impact can be achieved. Furthermore, through CaRPE's data and maps, policymakers and land managers can prioritize efforts for mitigating climate change from agriculture. We will talk about our work protecting farmland not only as a tool for meeting national and global food security demands and ensuring land is available for current and future generations of farmers, but also as a preferred methodology for offsetting greenhouse gas emissions when done in tandem with climate smart urban development. Research conducted in California as part of our Greener Fields project indicates that an acre of agricultural land in California emits 58-70 times less greenhouse gases than developed land and thus farmland protection is a critical tool in fighting climate change. And finally, we will discuss the critical role that the outcomes from our work can provide to enabling policy makers to develop relevant and much needed policies such as the role that AFT plays in the US Climate Alliance where we are working to ensure that agriculture is included in state climate action plans or our work with the Illinois Department of Agriculture to develop a crop insurance premium discount program for cover crops. In this innovative and impactful program, farmers who plant cover crops are offered a $5/acre discount on their crop insurance bill.

Keywords: *farmland protection, policy, regenerative practices, soil health, climate change*

Introduction

The American Farmland Trust (AFT) takes a comprehensive approach to Conservation Agriculture. Our mission reflects our multi-pronged theory of change in that we work with farmers and their partners to implement regenerative practices; we recognize that both protection of farm and ranchland and the transfer of these lands to new and beginning farmers is critical to the survival of agriculture because without these lands, we will not have sufficient land for food, fiber and fuel production.

Between 2001 and 2016, 11 million acres of farmland and ranchland were converted to urban and highly developed land use or low-density residential land use (Freedgood, J. et al 2020). This is equal to two thousand acres of agricultural land converted per day to uses that threaten the future of agriculture – or all the US farmland devoted to fruit, nut and vegetable production in 2017. In short, this is some of our most productive, versatile and resilient land. With every acre of farmland we lose, we not only lose the ability of that land to provide environmental benefits, we put more pressure on the remaining land to be farmed more intensely, further reducing environmental benefits.

At the same time, 40% of US agricultural land will change hands in the next 15 years due to the age of our landowners. The only way we will retain sufficient land to manage for agricultural production is if we attract and train a new generation of farmers and ranchers.

Finally, as we protect sufficient agricultural land and are able to transition in a new generation of successful farmers and ranchers, we need to ensure these farmers and ranchers are stewarding the land with healthy soils, water quality and quantity, wildlife habitat, carbon sinks and other ecosystem service co-benefits coming from healthy management of the land with the use of regenerative practices. If we manage towards all three of these levers of change, we are optimistic that we'll have the land base we need, stewarded for the long term, for food, fiber and fuel production on a scale that is necessary for our survival.

These are ambitious levers of change, which we feed or work towards by taking learnings from our research and on-the-ground collaboration with farmers, ranchers and landowners, and share with policy makers at the state and federal level to develop and implement policies that can incentivize and fund each of these actions necessary to support Conservation Agriculture.

In this presentation, focusing on examples relevant to meeting the challenges posed by climate change, we will explore various examples of our work with farmers on adoption of regenerative agriculture practices and complementary work undertaken with a variety of AFT tools to quantify the economic and environmental outcomes from implementation of these practices thus illustrating to other farmers the benefits realized by investing in soil health. And we will explore how we feed these outcomes into policy recommendations that can in turn help support the trifecta outcome we believe is so critical to meeting the challenges facing us whether due to climate change or simply due to needing a healthy land base and producers working that base to ensure a sustainable food supply and healthy planet.

The Case for Agriculture in Combatting Climate Change

To combat climate change and keep planetary warming well below 2°C as outlined by the Intergovernmental Panel on Climate change, and meet the goals of the Paris Agreement, conserving farmland, increasing the amount of carbon sequestered, and reducing agricultural greenhouse gas (GHGs) emissions are essential to mitigating climate change and increasing climate resilience. To do this holistically, we need widespread adoption of regenerative farming practices, and sufficient farmland, and enough farmers and ranchers who are trained in everything they need to know to succeed in farming for the long term.

Research and Regenerative Practices to Combat Climate Change

We have promoted soil health and regenerative practices with farmers and ranchers since our inception over 40 years ago. Over time and with a growing base of peer reviewed research carried out by the scientific community, the focus has shifted from solely improving soil health to the co-benefit of sequestering carbon and reducing carbon emissions. We quantify the impacts of regenerative ag practices on soil health metrics, climate benefits and farm operation economics through on-farm research and modeling. And we evaluate and develop new decision-support tools to help guide decision-making from the field-scale to the federal level.

Through a recently released report "Combatting Climate Change on US Cropland" we carried out a review of the scientific literature regarding the potential of no-till and cover crop practices to increase soil carbon sequestration and reduce nitrous oxide emissions for a net reduction in GHG emissions.

Using AFT's Carbon Reduction Potential Evaluation Tool (CaRPE)[1], a web-based interactive tool used to visualize and quantify greenhouse gas emission reductions from implementation of a suite of cropland and grazing land conservation management practices, we can work with farmers to run scenarios comparing practices, their estimated costs, and see where across a state or region the greatest impact can be achieved.

We can use this same tool to generate data and maps to demonstrate to state-level policymakers and land managers how they can prioritize efforts for cost-effective optimal climate benefits from agricultural practices at the landscape level. This is critical information for states that are integrating agricultural solutions to their state level climate action plans along with other approaches such as smart solar siting, climate smart urban development and farmland protection.

We share our research findings and modeling tools on-the-ground with farmers, train them on the effective application and scale-up of these findings, and support farmers in sharing these outcomes with one another in peer-to-peer networks in various projects such as our Genesee River Demonstration Farms Network in New York and our sustainable grazing project in Virginia. Farmers in the Genesee River Network learn from one another and see what practices are most cost effective and have the biggest impact on conservation. Livestock producers in the Virginia grazing project learn about regenerative practices that enhance soil health, sequester carbon, and increase productivity on farms.

As we know, farming is a risky business in which farmers encounter and try to control for numerous uncertainties on a regular basis. So, even though many believe the scientific evidence that soil healthy practices improve soil and water quality, they may also be reluctant to change management techniques without know how much implementing the practices will cost or benefit them. To help inform these decisions and mitigate some of the unknowns, we worked with a handful of farmers who have successfully implemented soil health practices and conducted cost-benefit analyses. We used a partial budget analysis to estimate the net economic benefits these farmers have experienced from investing in soil health practices (no till, strip till, cover crops, nutrient management etc) and quantified water quality and climate benefits of these practices using USDA's Nutrient Tracking Tool and COMET-Farm Tool.

We are hopeful these case studies will help farmers decide investment in these practices is worth the risk and continue to do them with other cropping systems and other geographies. From the first 8 partial budget analysis case studies completed, we saw that yields for all eight farmers increased from 2-22%. The six field crop farmers improved their bottom line by an average of $41/acre/year and due to the high value of the almond crops, those California growers saw an increase in annual net income of $824/ac. The average return on investment for the eight farmers was 207% meaning that on average, case study participants received over three dollars back for every dollar they invested. All eight farmers saw improved water quality outcomes and reduced soil and water runoff on their fields due to the soil health practices. The Nutrient Tracking Tool estimated that soil health practices implemented on each field, on average, reduced nitrogen losses 43%, phosphorus losses 74% and sediment losses 81%. Estimations from COMET-Farm indicated that total ghg emissions reductions for five of the six crop farmers averaged 217% and was 28% for the two almond growers.

Knowing what we do about the value of cover crops in improving water quality, building soil health, sequestering carbon and enhancing farm operation resilience, AFT worked with the Illinois Department of Agriculture and a handful of other people from various agricultural, environmental and conservation organizations to develop a crop insurance premium discount program for farmers planting cover crops in the state. For two years running now, there has been a line item in the IDoA

1 https://carpe.shinyapps.io/CarpeTool/ Carbon Redcution Potentail Evaluation (CaRPE) Tool TM, Jennifer Moore, Daniel Manter, Tabitha Brown.

budget to fund this premium discount program for cover crops. Applicants receive a $5/acre insurance premium discount on the following year's crop insurance invoice for every acre of cover crop enrolled and accepted in the program. This will help the state meet its nutrient loss reduction goals while simultaneously incentivizing farmers to develop more resilient operations through cover crops. It's a win-win-win situation where research and work on the ground with farmers drove policy discussions and implementation which in turn is driving greater adoption of cover crops within the state. It's been so successful in fact, that it has been 135,000 acres oversubscribed in 2021!

Research and Farmland Protection for Combatting Climate Change

As was mentioned earlier, our groundbreaking research known as Farms Under Threat has shown us that agricultural land is being lost at an alarming rate in the United States. As part of this work, we created an Agricultural Land Protection Scorecard to show how states have – or have not – responded to the threats of agricultural land conversion. We assessed 6 policy tools commonly used to protect farmland, support agricultural viability, and provide access to the land for a new generation of farmers. All 50 states have taken some type of step such as property tax relief, land use policies to offset development pressure on agricultural land, purchase of ag conservation easement (PACE) programs, or leasing programs for farming and ranching on state-owned land; but most have not fully utilized all six of these policy tools. All could do significantly more.

Not only is farmland protection critical for food production but it becomes even more critical in our efforts to combat climate change because of the ability of farmland soils to sequester carbon with the very same practices we need to continue to adopt and scale to improve and maintain soil health. Also, as we have found through our Greener Fields research in California (a state that has lost more than 1 million acres of farmland in the past three decades), cutting farmland loss by 75% by 2050 would reduce our ghg emissions by an amount equivalent to taking 1.8 million cars off the road each year (American Farmland Trust), 2018. Another way to think of this is that an acre of farmland in California produces 58-70 times fewer greenhouse gases than an acre of urban land. Low density development produces more ghgs per capita than efficient or climate smart high-density development. These findings have given us the tools we need to meet with policymakers at both the state and federal level to provide data-based recommendations to impact policies that will drive and finance farmland protection and climate smart land-use protection.

Conclusion

Using research and on-the-ground work with farmers, we develop recommendations for policy makers that serve to further promote farmland protection, regenerative agricultural practices and land access and transfer for a new generation of farmers and ranchers who need to take on and steward resilient operations. With these more resilient operations, American Farmland Trust believes we will come closer to having the agricultural lands necessary to both provide for our food security as well as the ecosystem services needed for a healthier planet.

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Conservation Agriculture in Brazil: a comparison of no-tillage adoption between the South and Central-West regions according to classes of farm holdings size based on the 2017 Agricultural Census

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This paper analyses the adoption of No-Till System (NTS) by farmers comparing the two most important agricultural regions in Brazil based on data from 2017 Brazilian Agricultural Census (5.05 million farm holdings surveyed), considering size classes defined by the total land area of holdings, as NTS represents a key practice for Conservation Agriculture in tropical soils. The two regions have been selected as together they participate with around one half of country's total gross value of agriculture production (US$ 100 billion in year 2019) and also amount to more than three quarters (77.56%) of the 33.1 million hectares (ha) total area of NTS in Brazil, respectively 13.5 million ha in Central-West and 11.9 million ha in South region. Emerged from the analysis that the overall rate of adoption of NTS was substantially different between the regions, as in the Central-West 20.13% of the total number of farm holdings which used soil preparation declared to use NTS, a figure very close to the 20.11% Brazilian average, compared to 57.58% of holdings declaring to adopt NTS in the South region. In the latter, NTS was the predominant soil management adopted considering all size classes of holdings with area of more than 5 ha and, when considering all the classes of more than 50 ha, the rate of adoption was above 70 per cent in the South region. Conversely, the highest NTS rate of adoption estimated for Central-West region was 45.09%, for size classes above 2,500 ha. Regarding to the average area under NTS per class of farm holding size, there was close similarity between the two regions of study for the classes up to 500 ha, whereas for classes above 500 ha the average size of holdings was 139.56% bigger in the Central-West than in the South region. It is suggested for further study to research on the factors that influence the adoption of NTS and explain the differences identified between the regions and size classes of farm holdings, including farm typology, land tenure situation, characteristics of the farming systems, integration of cropping and livestock activities, type of technical assistance provided to farmers, and climatic, especially rainfall, regime.

Keywords: *soil management, best agricultural practices, soil and water conservation*

ABSTRACT

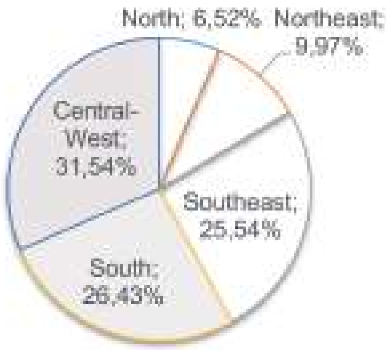
This paper analyses the adoption of No-Till System (NTS) by farmers comparing the two most important agricultural regions in Brazil based on data from 2017 Brazilian Agricultural Census (5.05 million farm holdings surveyed), considering size classes defined by the total land area of holdings, as NTS represents a key practice for Conservation Agriculture in tropical soils. The two regions have been selected as together they participate with around one half of country's total gross value of agriculture production (US$ 100 billion in year 2019) and also amount to more than three quarters (77.56%) of the 33.1 million hectares (ha) total area of NTS in Brazil, respectively 13.5 million ha in Central-West and 11.9 million ha in South region. Emerged from the analysis that the overall rate of adoption of NTS was substantially different between the regions, as in the Central-West 20.13% of the total number of farm holdings which used soil preparation declared to use NTS, a figure very close to the 20.11% Brazilian average, compared to 57.58% of holdings declaring to adopt NTS in the South region. In the latter, NTS was the predominant soil management adopted considering all size classes of holdings with area of more than 5 ha and, when considering all the classes of more than 50 ha, the rate of adoption was above 70 per cent in the South region. Conversely, the highest NTS rate of adoption estimated for Central-West region was 45.09%, for size classes above 2,500 ha. Regarding to the average area under NTS per class of farm holding size, there was close similarity between the two regions of study for the classes up to 500 ha, whereas for classes above 500 ha the average size of holdings was 139.56% bigger in the Central-West than in the South region. It is suggested for further study to research on the factors that influence the adoption of NTS and explain the differences identified between the regions and size classes of farm holdings, including farm typology, land tenure situation, characteristics of the farming systems, integration of cropping and livestock activities, type of technical assistance provided to farmers, and climatic, especially rainfall, regime.

INTRODUCTION

Brazil points out among countries with high capacity to increase agricultural production, having vast areas that are suitable for agriculture and a generally favorable climate (Dias, 2016). According to the Food and Agriculture Organization, the country was in the year 2018 one of the four major exporters of agricultural products in the world and the major net exporter of food (FAO, 2020). Brazil is expected to have a continuous increase in crop and livestock production and export, as the Brazilian Ministry of Agriculture, Livestock and Food Supply estimates that national grain production will increase by 26.9% (means a rate of 2.4% per annum, p.a.), whereas beef and poultry meat production may increase respectively 16.2% (1.4% p.a.) and 28.1% (2.5% p.a.) in the period from 2019/20 to 2029/30 (MAPA, 2020). The production and exports of soybean, which the most produced crop, predicted to increase by in the 10-year period, respectively, 30.1% and 23.15 according to the same source.

Although Brazilian agriculture comprises a diverse number of crops, the three major cultivates species (soybean, maize, and sugarcane) account for 72% of total crop area and about 90% of the production of temporary crops (DIAS et al., 2016). The authors indicate that large areas of soybean are found in South region since 1990, and, in lower concentration, in some parts of Southeast (states of São Paulo and Minas Gerais) and Central-Western (states do Mato Grosso do Sul, Mato Grosso and Goiás), and, in addition, in parts of Cerrado biome of Northeast region (state of Bahia). Dias at al. (2016) also describe that after 1990 has happened an extended northward move of the soybean area, further moving into the Cerrado and new soybean crop areas began to appear in Mato Grosso and in the so-called MATOPIBA territory (acronym of states of Maranhão, Tocantins, Piauí e Bahia, comprising Cerrado areas of Northeast and North regions of Brazil).

The two regions have been selected for analysis as together they participate with around one half of country's total gross value of agriculture production, US$ 139 billion in year 2019 (Figure 1) and also amount to more than three quarters (77.56%) of the 33.1 million hectares (ha) total area of NTS in Brazil, respectively 13.5 million ha in Central-West and 11.9 million ha in South region (Table 1).



*GPV year 2019, crops + livestock, US$ 139 billion (579 billion Brazilian reais).

Figure 1 - Participation of the South and Central-West regions in the Gross Production Value of Brazilian agriculture sector, year 2019. Source: Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA, 2021).

Even though Brazil is highly ranked in the world in the adoption of Conservation Agriculture (CA) practices (FRIEDRICH et al., 2012), which comprise NTS, there are serious concerns about the quality of the CA adoption. The authors attribute this situation to market pressures, strengthen by part of government policies, having as affect a farmer´s option for soya monocropping or a simple binomial of maize between two soya crops. It is assumed that, despite applying NTS, it may result in erosion and soil degradation (ANACHE et al. 2017). Fuentes-Llanillo et al. (2006), describe that traditional tillage systems in Brazil consist of ploughing or harrowing as a primary preparation step, followed by use of levelling harrows as a secondary stage of preparation, operations that cause pulverization of the surface soil and formation of a sowing bed, which is followed by soil compaction and, therefore, increased losses of soil, organic matter and nutrients by rainfall and deterioration of yield capacity of the land.

This paper analyses the adoption of No-Till System (NTS) by farmers comparing the two most important agricultural regions in Brazil based on data from 2017 Brazilian Agricultural Census (5.05 million farm holdings surveyed), considering size classes defined by the total land area of holdings, as NTS represents a key practice for Conservation Agriculture in tropical soils.

The objective of the present study was to present, analyse and discuss the types of soil tillage used in annual cropping systems in Brazil following the release of the 2006 Agricultural Census data by IBGE. Data used in the study were obtained from special tabulations of the 2006 Agricultural Census4 requested from the IBGE.

Material and Methods

The expansion of NTS in Brazil has been substantial and from 2006 it has become part of the Agricultural Census conducted by the Brazilian Institute of Geography and Statistics (IBGE), in its section on soil tillage practices in annual crops. The analysis carried out in this article is based on data from the Brazilian Agricultural Census 2017, considering size classes defined by the total land area of farm holdings and focusing in the two regions selected for study (Figure 2).

Figure 2 – Brazilian great geographical regions and the two regions selected for study. Source: IBGE Estat-Geo - https://estatgeo.ibge.gov.br/EstatGeo2020/mapa.

Brazil has 27 federal units (26 states and one Federal District) divided into five geographical regions shown in Fig.1. Regarding the two regions of study, South region comprises the states of Paraná, Rio Grande do Sul and Santa Catarina, whereas Central-West region includes the states of Goiás, Mato Grosso and Mato Grosso do Sul, and also the territory of the Brazilian federal district, Distrito Federal. With 850 million ha of area, Brazil contains six biomes: Amazonia, Atlantic Forest, Caatinga, Cerrado (Brazilian savanna), Pampas (grasslands), and Pantanal.

Results and discussion

The analysis shows that the overall rate of adoption of NTS was substantially different between the regions, as in the Central-West 20.13% of the total number of farm holdings which used soil preparation declared to use NTS, a figure very close to the 20.11% Brazilian average, compared to 57.58% of holdings declaring to adopt NTS in the South region (Table 1).

Table 1 – Number of farm holdings, number of farm holdings that used soil preparation, number of holdings that used NTS, total area under NTS and rate of adoption of NTS by Brazilian great region and states of the area of study

Great Region of Brazil / State*		Number of farm holdings - total (A)	Number of agricultural holdings which used soil preparation (B)	Number of agricultural holdings using NTS (C)	NTS adoption rate % (C/B)	NTS area (hectares)	% of total NTS area
North		576,027	179,331	28,964	16.15%	1,170,981	3.54%
Northeast		2,304,796	1,316,662	61,163	4.65%	3,326,725	10.06%
Southeast		968,140	468,893	63,479	13.54%	2,916,464	8.82%
South		851,658	644,2 68	370,953	57.58%	11,912,434	36.04%
	Paraná	304,485	208,394	131,670	63.18%	4,860,777	14.71%
	Rio Grande do Sul	364,489	300,784	165,283	54,95%	6,051,978	18.31%
	Santa Catarina	182,684	135,090	74,000	54.78%	999,679	3.02%
Central-West		346,945	143,123	28,823	20.14%	13,726,367	41.53%
	Distrito Federal	5,242	4,228	552	13.06%	76,252	0.23%
	Goiás	152,116	58,873	11,752	19.96%	3,123,424	9.45%
	Mato Grosso	118,522	45,398	9,264	20.41%	8,149,382	24.66%
	Mato Grosso do Sul	71,065	34,624	7,255	20.95 %	2,377,309	7.19%
BRAZIL		5,047,566	2,752,277	553,382	20.11%	33,052,969	100.0%

Source: elaborated using data from the Brazilian Agricultural Census (IBGE, 2017).
*Note: states are shown only for the two regions of study, South (Paraná, Rio Grande do Sul and Santa Catarina) and Central-West (states of Goiás, Mato Grosso and Mato Grosso do Sul, and Distrito Federal, which is the territory of the Brazilian federal district).

Concerning the analysis according to classes of farm size, it points out that in the South region NTS was the predominant soil management adopted considering all classes of farm size with area of more than 5 ha and, when considering all the classes of more than 50 ha, the rate of adoption was above 70 per cent in this region. Conversely, the highest NTS rate of adoption estimated for Central-West region was 41.65%, for size classes above 500 ha (Table 2).

Table 2 – Number of farm holdings that used soil preparation, number of holdings that used NTS and rate of adoption NTS by farm holding size class

Brazil and great region	Farm holding size class (hectares)	Holdings that used soil preparation		Holdings that used NTS		% NTS participation in soil preparation in the class	Average area of NTS (hectares)
		Number	% class	Number	% class		
Brazil	< 2 ha	504,599	18.33%	51,203	9.25%	10.15%	0,75
	2 < 5 ha	462,417	16.80%	58,096	10.50%	12.56%	1,86
	5 < 10 ha	383,497	13.93%	75,494	13.64%	19.69%	3,28
	10 < 20 ha	444,518	16.15%	121,260	21.91%	27.28%	6,20
	20 < 50 ha	487,652	17.72%	126,180	22.80%	25.88%	13,76
	50 < 100 ha	201,322	7.31%	49,759	8.99%	24.72%	42,67
	100 < 500 ha	185,643	6.75%	49,358	8.92%	26.59%	117,57
	> 500 ha	62,276	2.26%	21,578	3.90%	34.65%	1.030,90
	without area	20,353	0.74%	454	0.08%	2.23%	-
	Total	**2,752,277**	**100.00%**	**553,382**	**100.00%**	**20.11%**	**59,78**
South	< 2 ha	37,586	5.83%		2.88%	28.46%	0,58
	2 < 5 ha	84,059	13.05%	33,039	8.91%	39.30%	1,87
	5 < 10 ha	112,161	17.41%	57,197	15.42%	51.00%	3,58
	10 < 20 ha	165,885	25.75%	102,153	27.54%	61.58%	6,59
	20 < 50 ha	148,531	23.05%	98,967	26.68%	66.63%	15,06
	50 < 100 ha	46,410	7.20%	33,617	9.06%	72.43%	39,97
	100 < 500 ha	38,586	5.99%	27,702	7.47%	71.79%	130,74
	> 500 ha	10,749	1.67%	7,487	2.02%	69.65%	602,38
	without area	301	0.05%	94	0.03%	31.23%	-
	subtotal	644,268	100.00%	370,953	100.00%	57.58%	32,12
Central-West	< 2 ha	6,183	4.32%	1,043	3.62%	16.87%	0,43
	2 < 5 ha	10,264	7.17%	1,086	3.77%	10.58%	1,74
	5 < 10 ha	12,413	8.67%	1,245	4.32%	10.03%	4,01
	10 < 20 ha	18,536	12.95%	2,540	8.81%	13.70%	7,92
	20 < 50 ha	32,424	22.65%	3,991	13.85%	12.31%	16,50
	50 < 100 ha	17,463	12.20%	3,220	11.17%	18.44%	40,38
	100 < 500 ha	25,241	17.64%	7,143	24.78%	28.30%	164,46
	> 500 ha	20,512	14.33%	8,543	29.64%	41.65%	1.443,08
	without area	87	0.06%	12		13.79%	-
	subtotal	143,123	100.00%	28,823	100.00%	20.14%	476,43

Font: elaborated using data from the Brazilian Agricultural Census (IBGE, 2017).

Regarding to the average area under NTS per class of farm holding size, there was close similarity between the two regions of study for the classes up to 500 ha, whereas for classes above 500 ha the average size of holdings was 139.56% bigger in the Central-West than in the South region, probably related to the larger scale of agriculture in the former region.

As a consequence of the results shown, it may be inferred that a special effort is required from public policies to increase the rate of adoption of NTS in the Central-West. It is because the Cerrado, being more representative biome of the Central-Western region, is regarded as the target region for the efforts in mitigating CO_2 emissions through the adoption of no-till systems (CORBEELS at al, 2016). According to Pereira et al (2012), the region has experienced a rapid expansion of large-scale commercial agriculture since the early 1970s, mainly thanks to governmental policies aimed to increase production of commodities for export to meet a growing global demand for protein foodstuff and meat production.

The adoption of NTS by farmers in the Cerrado region started in the early 1980s onwards, which was driven by their need to combat soil erosion, but NTS also delivered reduction of labor use and diminished fuel and machinery costs (BOLLIGER et al, 2006). The suppression of tillage operations allows farmers to plant earlier in the season, which in combination with the use of shorter-cycle crop varieties (mainly soybean), enabled the planting of a second crop during the same growing season, argue the authors, generally with soybean followed by a cereal crop, mostly maize.

One possible source of speed up NTS is already in place by means of the Brazilian Ministry of Agriculture, Livestock and Food Supply program named *Agricultura de Baixo Carbono* -ABC (Action Plan for Low Carbon Agriculture), which initiated in 2010 and is augmenting the area cropped under NTS in Brazil, specially throughout reforming degraded pastures areas into cropland.

Ending Remarks

Brazil is one of these countries with high capacity to increase agricultural production, and has to do it in a sustainable way. That is why is import to have efforts in diffusion o CA practices in general, and particularly NTS, considering its enormous social and ecological diversity and agriculture heterogeneity. It is suggested for further study to research on the factors that influence the adoption of NTS and explain the differences identified between the regions and size classes of farm holdings, including farm typology, land tenure situation, characteristics of the farming systems, integration of cropping and livestock activities, type of technical assistance provided to farmers, and climatic, especially rainfall, regime.

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How will new agriculture technologies impact the future of CA?

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From my perspectives as a Farmer, Agronomist, and the Director of a large Agriculture Investment Firm, I am extremely fortunate to be able to witness, through all stages, many of the new breakthroughs in agriculture technology, not only in North America, but around the world. The farmland our investment firm owns in the USA is managed using CA practices (where possible) and the Ag Tech we invest in Globally often has the potential to directly impact our farms. In the past six years venture capital investment in new ag technologies has increased an incredible tenfold! The $20 billion of new venture capital invested in ag tech in these recent years is expected to be very minor compared to these next six years. Partly because of this investment, there has recently been truly profound scientific advancements that have opened the door to countless additional new technologies that could help all farmers and consumers, but specifically they could improve and expand Conservation Ag as well. Technology, that in some cases should be accessible to most regardless of where they farm and yet cost less than the conventional options we have today, some of these emerging technologies are creating whole new categories of crop inputs/science. Technologies that will help *minimise soil disturbance*, lower pesticide use, improve nutrient use efficiency, allow for *greater biodiversity*, and facilitate the precise use of all crop inputs, just to name a few.

Drones, Satellite images, Robots, Autonomy, and even “Biologicals” are usually associated with new Ag Tech. These are important, but I intend to go beyond these categories in discussing exciting new ag tech and its relevance to Conservation Agriculture and to crop production in general. For example:

Designer Proteins –the potential now exists to replace most current pesticides with “natural” products that are more specific, less harmful, and non persistent.

Precise Fermentation – this process is now refined to the point of being able to create thousands of bio-based products at incredibly low cost, i.e., pennies an acre.
Inexpensive genetic testing - LAMP tests that facilitate fast, inexpensive, genetic testing, that leads to the creation of disease and insect traps that can operate in the field in real time! Genetic testing of a plant or soil for less than $5! Epigenetics creating a new non-gmo crop variety in 2 weeks!

Advanced AI Imaging – can now evaluate all soil properties inexpensively on the fly, including disease and microbe levels, ability to “see” pathogens from harvest through to retail as well.

Nutrient Availability - supercomputing has designed systems that can create N fertilizer without the need for a carbon-based energy system and are scalable from a small field to a large ag retailer system. Systems that will allow the reduction of P fertilizer by 75%. Microbes could play a role here as well.

Keywords: *Pathway Optimization, Robotics, Epigenetics*

Introduction

From my perspectives as a Farmer, Agronomist, and the Director of a large Agriculture Investment Firm, I am extremely fortunate to be able to witness, through all stages, many of the new breakthroughs in agriculture technology, not only in North America, but around the world. The farmland our investment firm owns in the USA is managed using CA practices (where possible) and the Ag Tech we invest in Globally often has the potential to directly impact our farms. In the past six years venture capital investment in new ag technologies has increased an incredible ten-fold! The $20 billion of new venture capital invested in ag tech in these recent years is expected to be very minor compared to these next six years. Partly because of this investment, there has recently been truly profound scientific advancements that have opened the door to countless additional new technologies that could help all farmers and consumers, but specifically they could improve and expand Conservation Ag as well. Technology, that in some cases should be accessible to most regardless of where they farm and yet cost less than the conventional options we have today, some of these emerging technologies are creating whole new categories of crop inputs/science. Technologies that will help minimise soil disturbance, lower pesticide use, improve nutrient use efficiency, allow for greater biodiversity, and facilitate the precise use of all crop inputs, just to name a few.

Drones, Satellite images, Robots, Autonomy, and even “Biologicals” are usually associated with new Ag Tech. These are important, but I intend to go beyond these categories in discussing exciting new ag tech and its relevance to Conservation Agriculture and to crop production in general. For example:

Autonomous Robot Cover Crop Seeders

Some agricultural robot companies are now developing autonomous robots to seed cover crops prior to harvest. Many ag robot start-ups initially focused on the mechanical weeding of crops with systems using pulling or cutting appendages on their robots, but some are also developing weed control systems using electrocution or lasers. However, there are significant challenges in using robots to control weeds in broadacre crops and in real world situations so some of these companies are looking to diversify their application of robots to agriculture. I know of a few companies pivoting to this new use of cover crop seeding, one being “Rowbot” and the other being “Earth Sense”. Earth Sense has developed a niche market for their autonomous robots to phenotype plants/crops in a truly short period of time. In talking with the company recently they can phenotype a standard 4-metre-long corn plot in about 6 seconds. Now they hope to modify their small robots to plant cover crop seed in row crop situations long before a field such as corn is harvested. These are rechargeable robots that return to their charging and tendering stations automatically. They estimate their cost of seeding in this “in-crop” situation will be a fraction of the other alternatives out there such as seeding by air or using those high clearance cover crop seeders. It is proposed a small fleet of these robots will sneak up and down the crop rows under the crop canopy – leaving very little compaction and applying cover crop seed when most optimal. The challenges they are redressing involve making the re-filling automatic and using cover crops that require low seed volumes per acre. Earth Sense supplied me with these photos of their proposed cover crop seeding system.

Fig #1: Earth Sense's autonomous robotic cover crop seeder, actual on left, model on right

Farm Equipment Pathways optimization

One of our own ag tech investments is called VergeAg and they are a Calgary, Alberta based company that provides farmers with optimal pathway direction for all implements working in a field. You supply them with your field boundaries and equipment details, and they supply the direction in which those machines should operate in that specific field. This company came out of the frustration of many new oilwells popping up across Prairies Farms in the past couple of decades. Farmers were sometimes compensated for their land that was no longer in ag production but there was no compensation for the massive disruption this caused farmers in their normal farming activities. With these many obstacles how should you seed or harvest a field to minimize time and effort? It quickly became apparent that this service had merit if there are any obstacles in a field from a power line to a tree or for any field that has an irregular boundary. Despite many of the main farm equipment companies over the years trying to address this problem of creating optimized pathways it has been an elusive problem to master, even in fields that only have a few obstacles. Verge appears to be the first to master this challenge and they have now partnered with a company in South America that optimizes pathways in relation to topography. As a result, when you now put the two systems together you can create field pathways that also take into consideration the soil erosion risk based on slope and distance and try to mitigate that with pathway design as well. There could eventually be a programing of machinery speed in their Rx maps as well in relation to the topography to further mitigate erosion risk. VergeAg provides with their service a pathway prescription map that is loaded into your GPS monitor wirelessly and not only creates the most efficient direction possible but can also take into consideration the directions that will contribute the least to potential soil erosion. The pathways they send you can be modified in the cap on the go as well to account for whatever might be changing such a wind direction or other weather issues. This system works excellent at coordinating multiple units working in the same field and positioning the support vehicles appropriately as well. The interesting thing is that even if you do not have a GPS or even a tractor, they can still email you a pathway map – like you see in the image below (fig 2) - that gives you a clear indication of where that specific field activity take place to maximize efficiency and minimize erosion potential.

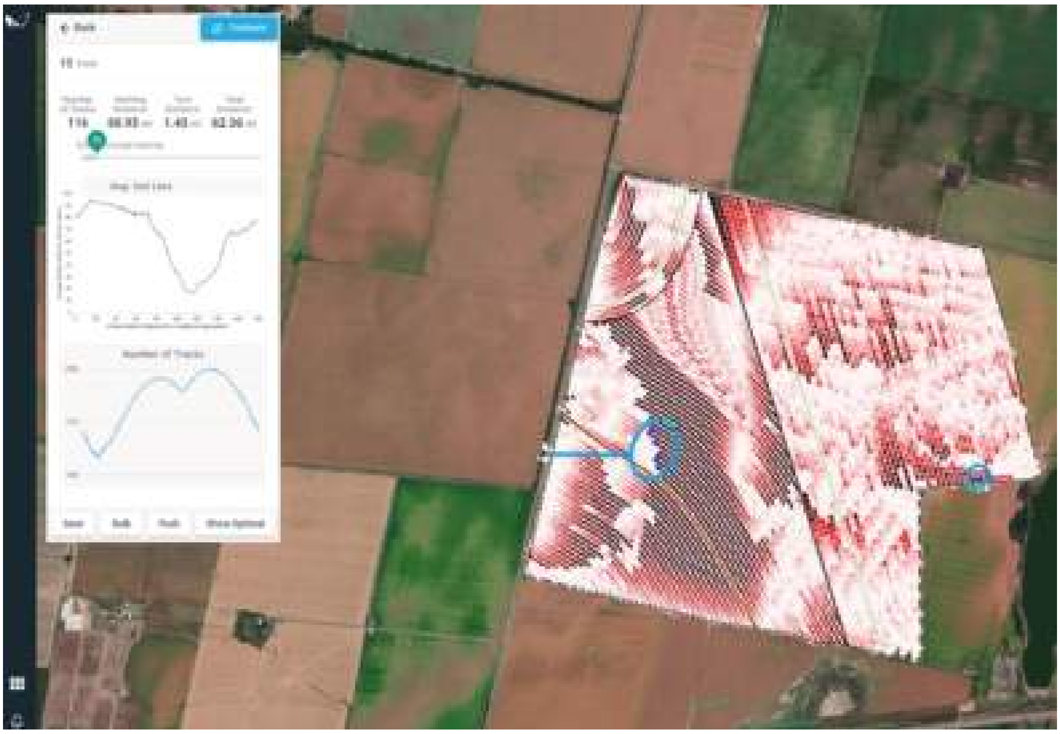

Fig 2: Pathway optimization for use efficiency and erosion mitigation created by Verge Ag.

On Demand Breeding

SoundAg was one of our early ag tech investments and original interest in their company was the desire to create a new type of synthetic chemistries that promote plant growth, essentially, they are chemistries (not biologicals) that promote plant growth by improving fluid dynamics in a plant and by improving nutrient availability and uptake. They have launched their first breakthrough in this space last year under the trade name “Source”. However, their amazing team of scientists have recently come up with a totally new plant breeding platform called On Demand Breeding or ODB for short and it is a modified epigenetics system. It is not a GMO or CRISPR crop breeding system, yet it can achieve similar results in much less time. Certain genes can do extremely specific things even when it is just the volume of expression of that gene that is adjusted. With those older breeding systems, it was usually just an on/off switch for a specific gene that creates desired traits. This new type of epigenetic platform will allow an incredible number of traits to be easily improved such as: taste, protein levels, plant structure, virtually everything that is controlled with the existing genome of the plant can be fine tuned with this platform. However, here is the amazing part: these changes will be simply created with a specific, custom made “solution” that will be applied to your seed prior to planting – just like a regular seed treatment! This will “methylate” the DNA in accordance with the trait needs and presto! your crop will then have that trait you desire: maybe higher protein? or shorter stature? or better pod shatter resistance? The seeds from that crop will carry those traits to the next generations and/or you could treat your seed the next year with a different seed treatment solution and have different traits that add value in that year. Essentially, this process can create a new crop variety in about 2 weeks. This is one tenth of the time needed to create a new variety by using CRISPR, which itself needs only a small fraction of the time compared to that needed to create a new variety using conventional breeding programs, which would often take up to 3 years or more. SoundAg’ s first success with this system was a new epigenetically improved heirloom tomato that they quickly created late last year (fig.3). They were trying to create an heirloom that looked more consistent and had a much longer shelf life, but still looked like an heirloom tomato, and as you can see from the photo that SoundAg supplied me they have succeeded.

Fig 3: The new "On Demand Breeding" tomato from SoundAg is on the left and the original variety is on the right.

Imagine being able to focus on specific crop traits in a seed treatment just prior to seeding? Experiencing a dry spring? - then maybe you can change some traits accordingly? Markets showing strength for protein premiums in wheat – then maybe you can modify the wheat at seeding to produce more protein at harvest? Imagine designing traits that optimize conservation ag techniques?

Inexpensive Genetic Testing

Another tool that has leap frogged new ag technology into the future is the ability to now genetically test things at incredibly low cost. There are new start up companies that expect to genetically test a plant for under $5. This would be a boon to plant breeders and to nurseries as well – it would be like the "23 & Me" service for the plant and animal world. We have invested in a company called Trace Genomics that can quickly do a DNA test on any soil sample and give you a full report of the soil's biology along with providing regular soil test results like nutrient availability and other physical characteristics. The ability to do Genetics testing so easily and quickly is being held back by understanding all the genetic markers out there to consider, but that is being dealt with quickly now too. Trace has a commercial soils lab providing this service to growers already – and as the data builds exponentially from farms all over the USA the effectiveness and usefulness of their results becomes more robust and relevant. They are also helping scientists to quickly identify microbes that are relevant to many specific conditions and outcomes (Fig 4). I have also talked with a couple of companies this past winter that are looking to create perfectly accurate and specific field pest trapping systems using LAMP technology or a "Lab on a stick" (loop-mediated amplification testing system). This is the same system that most of us have used to be tested for Covid-19. What these companies are proposing is a genetic testing system using a bespoke reagent in a field-based trap so you could identify disease spores as they arrive in your field in real time. This could also be possible for insects as well – especially tiny disease carrying vector insects like aphids, thrips or even mosquitoes that could be identified down to the species level in real time and quantified as well. This will allow producers to quickly commence or modify mitigation methods in the most efficient and appropriate manner. It seems the actual genetic testing of the spores or the insects is not such a difficult part of the puzzle - designing the suitable trap structure, so contamination and capacity is kept to a reasonable level is still a significant obstacle. This is another example of why rural broadband service needs to be robust.

Fig 4 – an example of a couple of the pages from Trace Genomics' genetic test results on a soil sample.

Nutrient production and availability

I have visited with couple of companies that apparently have figured out the incredibly challenging quest to make N fertilizer without a carbon-based energy source. I am not talking about the small Haber-Bosch systems that can now use electricity instead of natural gas, but rather new N making processes altogether that may allow you to make N on your own farm in a way that essentially eliminates GHG emissions and may still be cost competitive to what we can buy now for N fertilizers. One system simply re-creates lightning from solar derived power but has a unique storage method of its N production as well. Another system is using a series of very intricate and specific membranes along with electrolysis to make NH3 from air and water. Once again using electricity from any source and both systems can work in direct relation to the power supply, starting and stopping without notice, so they are ideal methods to store the energy produced (as N fertilizer) from intermittent sources of electricity such a wind and solar. There is also new technology that could allow us to use ¾'s less P fertilizer without any impact on crop yields!

Precise Fermentation

One thing that has become very apparent as I am now immersed in this world of new ag tech is that the science of precise fermentation has become an extremely important aspect in food production and in human health as well. Being able to "grow" things in a controlled environment has opened an incredible new world of possibilities when it comes to just about anything to do with the living world. Many of the plant-based protein companies are only possible because some of the very specific but very important protein and other components are being created in a fermenter. In some cases, genetically modified yeast has been developed to create specific proteins and other microbes. Companies like Greenlight Bio are using fermentation systems to make their biological products at commercial volumes and at costs that are incredibly competitive. Some of the proteins that go into your new plant-based burgers or go into the designer protein pesticides that I mentioned below are being "grown" in fermentation systems.

Designer Proteins

There are several companies that are developing new crop pesticide products from designer proteins. Many are simply creating proteins that have the shapes and characteristics that mimic synthetic chemistries, so they can attach to the same "receptor" sites in pests that conventional pesticides use and therefor cause the same expected outcome (death to only the pest). This is an exciting new field of science, where "natural" and highly specific pesticides are being created that are extremely effective but have no impact on any other living thing besides the target. These new pesticides are entirely proteins, so they quickly degrade to simple Nitrogen, there are no residues or restrictions to be concerned about. It is as if we made weapons or tools out of ice that quickly melted into only water when we were done using them. One of our most exciting ag tech investments at this time is in a company called Greenlight Bio – they are creating mRNA-based crop protection products for pests like insects and diseases and should soon have their first commercial launch with a Colorado Potato Beetle insecticide that works amazingly well, for reasonable value, and has no affect on any other insects (Fig 5). You might recognize that RNA technology is also being used to create some of the new vaccines to combat Covid-19. Ultimately many new crop protection products could be considered "organic" in the foreseeable future yet be even safer than some of the organic pesticides used now.

Fig 5 – Greenlight Bio's nRNA Colorado Flea Beetle control product on the right – untreated on the left.

Conclusion

Considering all I have shared; it will be exceptional that most of these new ag tech ideas are successful or even make it to market but I sure some of them will. I am simply sharing the promise and potential they all possess at this time. There are many other technologies that we have looked at over the past few years that would have a direct impact on Conservation Ag and to Agriculture in general, but these I have mentioned are some of the highlights. A complete list of the tech investments Fall Line Capital has supported are outlined on our website: http://fall-line-capital.com/ or you are welcome to contact me at any time via the address provided at the beginning.

The future of farming
Profitable and Sustainable Farming with Conservation Agriculture

WCCA
8th World Congress on Conservation Agriculture

The 4CE-MED project - Camelina: a cash cover crop enhancing water and soil conservation in Mediterranean dry-farming systems

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To increase food security and sustainability, ecologically sound, reliable and profitable farming systems should be identified and promoted. Conservation Agriculture (CA) is well documented for bringing environmental benefits; yet, it is surprisingly not widespread in the Mediterranean basin, mostly due to the lack of technical knowledge including specific machinery. Within the framework of the EU PRIMA joint program, the 4CE-MED project (May 2020 - October 2023) aims at developing innovative, diversified and resilient cropping systems suitable for the Mediterranean climate, adopting a participatory approach (national platforms of stakeholders) to serve as main basis for identifying the urgent needs of smallholder farmers. The project consortium includes eleven partners of seven countries (four EU and three non-EU countries). Local socio-economic barriers will be analyzed to understand major constraints in the deployment of specific CA systems. In particular, 4CE-MED focuses on camelina [*Camelina sativa* (L.) Crantz] as a cash cover crop under CA. Cash cover crops are defined as crops able to reach seed maturity before the establishment of the main crop, thus providing additional sources of income for farmers. Among alternative species, camelina, belonging to *Brassicaceae* family, was selected because of its considerable resilience and a likely expected suitability for CA systems. Moreover, camelina can be a multipurpose crop able to source oil (~40%) and protein (~28%), and also straw, for a number of food, feed, and non-food applications. In each participating country (Italy, Greece, Spain, France, Tunisia, Morocco, and Algeria), field and plot trials have been undertaken aimed to investigate different camelina genotypes under diverse climatic conditions. Site-specific crop rotations will be evaluated in term of productivity, profitability and environmental benefits. In addition, field visits and training courses will be organized to allow farmers and stakeholders to become familiar with these likely innovative and sustainable cropping solutions. The ultimate goal of 4CE-MED project will be to transfer its results to farmers, farmers', cooperatives, industries, and policy makers by developing a collaborative network of stakeholders, who will adopt, modify and improve the locally 4CE-MED solutions.

Keywords: *Mediterranean, Conservation Agriculture, Sustainability, Cover Crops, Smallholder Farmers*

ABSTRACT

To increase food security and sustainability, ecologically sound, reliable and profitable farming systems should be identified and promoted. Conservation Agriculture (CA) is well documented for bringing environmental benefits; yet, it is surprisingly not widespread in the Mediterranean basin, mostly due to the lack of technical knowledge including specific machinery. Within the framework of the EU PRIMA joint program, the 4CE-MED project (May 2020 - October 2023) aims at developing innovative, diversified and resilient cropping systems suitable for the Mediterranean climate, adopting a participatory approach (national platforms of stakeholders) to serve as main basis for identifying the urgent needs of smallholder farmers. The project consortium includes eleven partners of seven countries (four EU and three non-EU countries). Local socio-economic barriers will be analyzed to understand major constraints in the deployment of specific CA systems. In particular, 4CE-MED focuses on camelina [*Camelina sativa* (L.) Crantz] as a cash cover crop under CA. Cash cover crops are defined as crops able to reach seed maturity before the establishment of the main crop, thus providing additional sources of income for farmers. Among alternative species, camelina, belonging to *Brassicaceae* family, was selected because of its considerable resilience and a likely expected suitability for CA systems. Moreover, camelina can be a multipurpose crop able to source oil (~40%) and protein (~28%), and also straw, for a number of food, feed, and non-food applications. In each participating country (Italy, Greece, Spain, France, Tunisia, Morocco, and Algeria), field and plot trials have been undertaken aimed to investigate different camelina genotypes under diverse climatic conditions. Site-specific crop rotations will be evaluated in term of productivity, profitability and environmental benefits. In addition, field visits and training courses will be organized to allow farmers and stakeholders to become familiar with these likely innovative and sustainable cropping solutions. The ultimate goal of 4CE-MED project will be to transfer its results to farmers, farmers', cooperatives, industries, and policy makers by developing a collaborative network of stakeholders, who will adopt, modify and improve the locally 4CE-MED solutions.

1. INTRODUCTION

"*Environmental and social changes are deeply affecting Euro-Mediterranean agro-food systems and water resources. Unsustainable agricultural practices, lack of water, over exploitation of natural resources, new lifestyle behaviors (diet, physical activity and socio-cultural) and low profitability of smallholders are challenging the sustainable and healthy development of the Region, with major impacts on our societies.*" (PRIMA, SRIA 2018). These are the fundamental concepts at the basis of the PRIMA - Partnership for Research and Innovation in the Mediterranean Area – framework program which started in 2018 and will last seven years. The partnership will be financed through a combination of funding from PRIMA Participating States (currently €274 million), and a €220 million contribution from the EU through Horizon 2020. PRIMA consists of European Union Member States, Horizon 2020 Associated Countries and Mediterranean Partner Countries and includes the Participation of the European Commission. To date, 19 countries are committed to the PRIMA initiative, namely: Algeria, Croatia, Cyprus, Egypt, France, Germany, Greece, Israel, Italy, Jordan, Lebanon, Luxembourg, Malta, Morocco, Portugal, Slovenia, Spain, Tunisia and Turkey. Each year several research topics are launched in three main thematic areas: i) management of water; ii) farming systems; iii) agro-food value chain. In 2019, in the thematic area "farming systems", a research and innovation action topic was launched entitled "Conserving water and soil in Mediterranean dry-farming, smallholder agriculture". The 4CE-MED project was one the three funded in that topic with 1.5 M€. It started in May 2020 and the Department of Agricultural and Food Sciences of Bologna University (Italy) is the coordinator.

2. THE 4CE-MED PROJECT

2.1. The concept and the objectives

Mediterranean dry-farming systems mostly rely on cereal production, often on sole crops, due to a lack of alternatives. Conservation Agriculture (CA), which relies on the three principles of i) minimum soil disturbance, ii) permanent organic soil cover, and iii) crop diversification, offers the opportunity to reduce soil erosion and nitrogen leaching, while increasing water availability, soil organic matter and biodiversity. In this view the 4CE-MED project aims at wide spreading the adoption of CA by introducing a new oilseed crop, camelina (*Camelina sativa* L. Crantz), which can be grown as a cash cover crop (Gesch, R.W. et al. 2014) in the Mediterranean region. The inclusion of camelina, as a cash cover crop, within conventional Mediterranean farming systems will match environmental benefits related to cover crop "attitude" and additional revenue for farmers, that can get profit from selling seeds, oil and protein. Among concurrent cover crops, camelina was chosen as the most suitable for the Mediterranean climate being extremely drought tolerant (Zanetti, F. et al. 2021), very suitable to CA techniques (Berti, M. et al. 2016) and characterized by short growth cycle allowing double cropping systems in several environments. Camelina seeds are rich in oil (35-40%) and protein (25-35%) highly suitable for both food and feed applications (Zanetti, F. et al 2021). Basing on a strong participatory approach the locally tailor-made 4CE-MED systems, including camelina, will be tested, adjusted and finally demonstrated to farmers and other stakeholders in order to finally foster the adoption in the Mediterranean of CA. The concept behind the 4CE-MED project is presented in Figure 1.

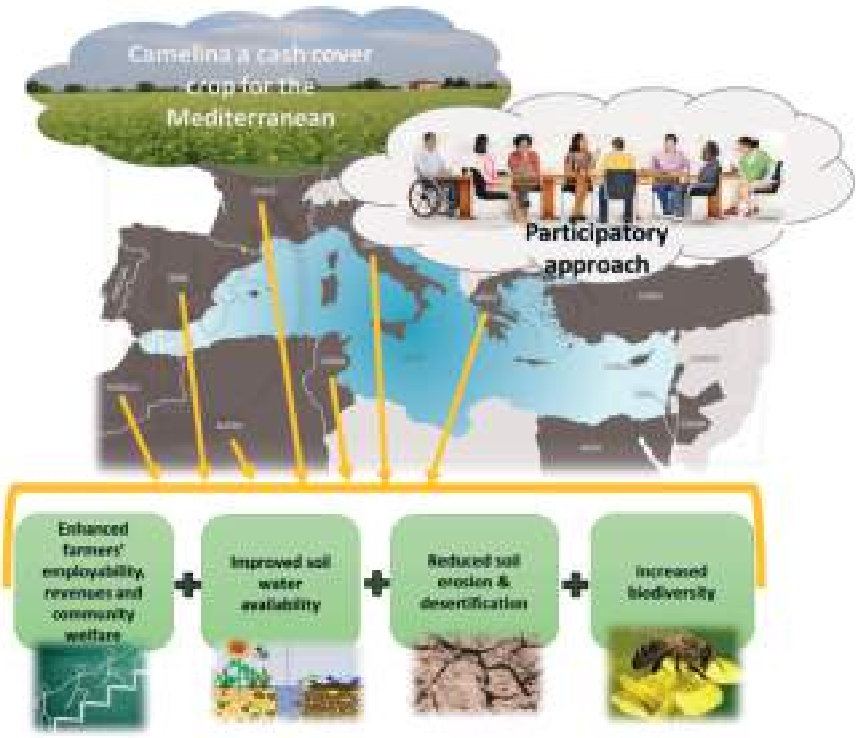

Fig. 1. Concept behind the 4CE-MED project.

In particular, three cropping systems will be investigated within 4CE-MED: *i*) camelina replacing fallow in cereal monoculture (very common in Mediterranean marginal land); *ii*) camelina replacing a winter crop to enable double cropping with typical Mediterranean summer crops, i.e., sunflower, sorghum, soybean; *iii*) camelina replacing a summer crop to enable double cropping with winter cereals or pulses, particularly in the areas with colder climate (e.g., central/northern France or Germany).

2.2. The consortium

The 4CE-MED consortium was conceived in order to follow a multi-actor approach. The consortium includes 11 partners from 7 different PRIMA countries (Fig. 2): 4 EU (MED-EU = Italy, Greece, Spain and France) and 3 non-EU (MED = Algeria, Morocco and Tunisia), including research organizations, universities, SMEs, and farmers' cooperatives. The consortium is well-balanced with 7 partners belonging from the R&D and 4 others representing the productive world, with the aim of maximizing the impact of 4CEMED's results. The consortium combines the experiences of CCE, CRES, and UNIBO on camelina; ICARDA, INRAA, and INRAT on cropping systems tailored for semi-arid environments of northern Africa; ARVALIS, CRES, UNIBO, BIOS and Spanish Co-ops on cropping systems tailored for environments of southern Europe; CREA on the fine tuning of locally available mechanization systems to the 4CE-MED solutions; and INI on effective dissemination, communication and exploitation strategies.

Fig. 2. Geographical localization of the eleven 4CE-MED partners.

3. PRELIMINARY RESULTS

Since its start in May 2020, the 4CE-MED project established in each participating country a local multi-stakeholder platform including farmers, practitioners, long-term CA adopters, scientists, representatives from farmer associations and political venue. Each local platform included at least 10 stakeholders, and the scope is to keep them growing in the future engaging other stakeholders for the discussion and exploitation of the 4CE-MED results at local level. A first consultation was carried during summer 2020 at the scope of engaging local stakeholder in the co-design of the tailor-made 4CE-MED solutions, which will be then tested in the field trials established in autumn 2020.

In each participating country, three different field experiments have been established during autumn/winter 2020. The main scopes of each field trial are: *i*) investigating the suitability of different camelina lines, provided by CCE, to local environmental conditions; *ii*) defining the optimal sowing strategy for camelina as a cash cover crop, investigating the following factors: tillage (no-tillage vs. minimum tillage), sowing date (early vs. late), seeding method (row seeding vs. broadcasting); *iii*) defining the optimal harvesting method in order to optimize camelina seed yield and quality. Despite the novelty of camelina in the northern Africa countries, early results show that camelina can grow successfully in all Mediterranean countries involved in this project (Fig. 3) . The emergence rate and soil coverage were always remarkably high. Weed control was the only concern as only monodicot herbicides are at the moment selective for camelina.

Fig. 3. Field trials with camelina established in the 4CE-MED project in Algeria, Morocco and Tunisia (late February 2021, all right reserved to 4CE-MED partners).

4. CONCLUSION

Including cash cover crops in the Mediterranean farming systems will help deployment of Conservation Agriculture with consequent beneficial effects in term of greenhouse gas emission savings, reduction of soil disturbance, increased soil cover, crop diversification and farmer revenue. These first positive results of the 4CE-MED project lead us to believe that camelina can be a promising short-term candidate to integrate main crops in the existing Mediterranean farming systems.

5. ACKNOWLEDGMENTS

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Next steps for taking directly seeded rice (DSR) to scale in the Eastern Gangetic Plains of India

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Directly sown rice (DSR) addresses some of the major drivers of change in the agricultural systems of the Eastern Indo-Gangetic Plains. Because of this, DSR have been the focus of targeted interactions, particularly in central Bihar where promotion has centred around districts with suitable agro ecological conditions (ex. areas with reduced weed pressure such as lowlands, assured early irrigation to control inundation and to avoid stand mortality before the chance of heavy monsoonal rains increase), adequate machinery, and high potential for productivity increases and production risk reduction through DSR. Agronomic results highlight an increased average yield of 0.34t/ha against transplanted rice under normal conditions, and an increase to 0.8t/ha when aided with one supplemental irrigation.

Despite this, supply and demand have not synced. By strengthening the service economy over the last 10 years, more than 5,000 Bihari farmers are now using DSR for the establishment of rice across regions through service providers. Yet only 10% of service providers are engaged in providing DSR services, and the scaling up of DSR has been slower than expected. This study applies an in-depth analysis through five stakeholder typologies namely: DSR service provider, DSR dis-adopter (i.e. stopped usage), DSR farmer, Zero Tillage (ZT) wheat service provider and lastly, the ZT wheat farmer to explore the various dimensions of DSR adoption from farmers, as well as the experiences, challenges and opportunities faced by DSR service providers.

The results highlight the emergence of trends in farmer perspectives on DSR, as well as issues with demand for and viability of DSR services. Key themes emerged in the skill level of service providers, both for seeding and in weed management due to a more complex weed flora. There is also an increasing number of rotovator owners and operators and investment in tillage machinery that is counter to DSR service provision. In many cases, there exists an expectation of support from the department of agriculture, KVK and NGOs for operation, service and awareness creation of machine that service providers see as outside their scope. These learnings and more provide an important point of reflection for future scaling efforts on DSR.

Keywords: *Direct Seeded Rice; Service provision; Lived Experience and Perspectives*

ABSTRACT

Directly sown rice (DSR) addresses some of the major drivers of change in the agricultural systems of the Eastern Indo-Gangetic Plains. Because of this, DSR have been the focus of targeted interactions, particularly in central Bihar where promotion has centred around districts with suitable agro ecological conditions (ex. areas with reduced weed pressure such as lowlands, assured early irrigation to control inundation and to avoid stand mortality before the chance of heavy monsoonal rains increase), adequate machinery, and high potential for productivity increases and production risk reduction through DSR. Agronomic results highlight an increased average yield of 0.34t/ha against transplanted rice under normal conditions, and an increase to 0.8t/ha when aided with one supplemental irrigation.

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The results highlight the emergence of trends in farmer perspectives on DSR, as well as issues with demand for and viability of DSR services. Key themes emerged in the skill level of service providers, both for seeding and in weed management due to a more complex weed flora. There is also an increasing number of rotovator owners and operators and investment in tillage machinery that is counter to DSR service provision. In many cases, there exists an expectation of support from the department of agriculture, KVK and NGOs for operation, service and awareness creation of machine that service providers see as outside their scope. These learnings and more provide an important point of reflection for future scaling efforts on DSR.

1. INTRODUCTION

Population growth during the Green Revolution increased labour supply and made labor-intensive rice-systems possible (Pandey & Velasco, 2002). This change in labor supply, coupled with improved transplanting methods led to a transition in broadcasting rice cultivation methods to Puddled Transplanted Rice (PTR) (Pandey and Velasco, 2005). PTR encompasses growing rice seedlings in a nursery, continuously irrigating fields and transplanting seedlings into puddled fields. PTR currently dominates rice cultivation methods in the Indo-Gangetic Plains and globally (Farooq *et al.*, 2011)Click or tap here to enter text.).

While initially catalysing vast improvements in rice yields, more recently the productivity of PTR has stagnated across the Indo-Gangetic Plains, and even declined in certain areas (Bhardwaj and Sidana, 2017). This is concerning in two ways. Firstly, rice is a staple crop that nourishes over half of the world's population (Kaur and Singh, 2017) and is especially important in India, where rice meets 43% of the calorie requirement for over two-thirds of the population (Kaur & Singh, 2017). Secondly, the demand for rice in India is expected to rise 26% by 2035 to meet population growth demands (Kumar and Ladha, 2011). This means that efforts must be made to explore alternative pathways to rice intensification.

Beyond stagnating production, PTR contains additional challenges in the context of the Eastern Gangetic Plains. As mentioned, Population growth enabled PTR to transform rice production systems, based on intensive labor use for transplanting and frequent irrigation (Kaur & Singh, 2017; Kumar & Ladha, 2011). Yet accessing reliable labourers in the eastern gangetic plains is a key constraint, driven by opportunities in non-agricultural sectors (Kakumanu *et al.*, 2019), making hired labor more costly (Farooq *et al.*, 2011; Kaur and Singh, 2017; Devkota *et al.*, 2020). This is particularly problematic as labor requirements are concentrated in short periods of time, specifically during the transplanting stage, resulting in labor bottlenecks (Kumar and Ladha, 2011; Kaur and Singh, 2017).

While labour constraints may be partly overcome through mechanised PTR (Guru *et al.*, 2018), it does not address climatic concerns. PTR is also a notable source of greenhouse gas emissions and resultant global warming. Puddling submerges the soil and creates anaerobic conditions that facilitate methanogen activity, and globally PTR contributes 10-20% of annual methane emissions (Kakumanu et al., 2019). Methane is one of the three main greenhouse gases that contributes to climate change(Saharawat *et al.*, 2010; Kaur and Singh, 2017).

To address the need for alternatives to PTR, a growing body of research had interrogated the potential of Directly seeded rice, which uses a zero tillage drill to plant rice seed in un-puddled fields. DSR has been shown to address the above limitations of PTR, namely

- **Water scarcity:** Kumar & Ladha, 2011 reviewed 44 studies and concluded that DSR, on average, uses 12-33% less irrigation water. Strategies that promote judicial use of irrigation water can escalate rice production in water scarce regions of India.
- **Labour Scarcity:** DSR requires less total labor because it avoids nursery raising, seedling uprooting, transplanting, and puddling (Kaur and Singh, 2017). In addition to saving human labor, DSR also reduces machine labor requirements by 34-60% compared to PTR (Kumar *et al.*, 2015).
- **Environmental:** DSR avoids puddling and facilitates aerobic soil conditions, preventing methanogenic bacteria activity (Singh, Paikra and Aditya, 2019)Click or tap here to enter text.. Kumar & Ladha, 2011 found that DSR releases 80-85% less methane gas than PTR
- **Soil health:** DSR avoids puddling, so soil structure remains intact, enabling wheat root development and leading to higher wheat yields (Kaur & Singh, 2017; Singh et al., 2019)

Despite mixed results regarding DSR yields, the literature agrees that DSR has higher relative economic returns, even when DSR yields are lower (Bhardwaj and Sidana, 2017; Kakumanu *et al.*, 2019; Devkota *et al.*, 2020). This is because DSR offsets any loss of income from yield losses by reducing crop establishment and input costs (e.g., irrigation, human and machine labor) (Singh et al., 2019). DSR costs savings up to Rs 5000-6000/ha (Kumar & Ladha, 2011). Thus, DSR is a worthwhile economic investment, even accounting for potential yield risks.

While there are now large volumes of theoretical knowledge developed and a wide level of recognition and ownership among national partners to endorse DSR as a potential technology at scale, the uptake of DSR has remained relatively constrained. The assumed theory of change that those who have purchased Zero Tillage drills for wheat could be convinced to both transition to ZT on Rice and provide services to others appears to have limitations. While more than 5,000 farmers are now using DSR for the establishment of rice across the EGP through service providers, only 10% of service providers are engaged in providing DSR services. This has slowed the scaling of DSR compared to original expectations. However, the literature on these factors in relation to DSR adoption are more limited. While the literature had proven the theoretical benefits of DSR agronomically, economically and environmentally, there is still a void in how DSR can be scaled. This raises the need for an in-depth enquiry to explore the various dimensions of DSR adoption from farmers, as well as the experiences, challenges and opportunities faced by DSR service providers. An understanding of various dimensions from farmers and service providers will give insights for DSR adoption at scale. To date, there are no in depth, qualitative studies that aim to achieve this. The literature has primarily focused on Quantitative analyses that identify the constraint but cannot draw conclusions on potential solutions.

2. METHODS

Answering our research question requires discussion with more than one type of ZT drill user. To do this, we employed a purposive sampling procedure that involved a combination of selection criteria and typology differentiation that was applied as part of a snowball sampling methodology. For inclusion in the study, a respondent needed to have personally purchased a zero tillage drill and have previously used it, either personally or as a service provider, with wheat in the Rabi (winter) season. Within this, we purposively targeted four different DSR typologies (Figure 1):

1. Those who have never used their ZT drill for rice;
2. Those who currently use their ZT drill for rice on their own farm but not for services in their community;
3. Those who have disadopted the use of their ZT drill for rice;
4. Those who currently provide DSR services to those in their community.

This study was implemented in two districts (Samastipur, Buxar,) in Bihar which have had ongoing zero tillage promotional activities since 2009-10. These communities were selected due to the presence of a varety of different typologies related to participant selection.

Two locations were selected on the basis of number of ZT drill service provider and area coverage of DSR. The specific districts were targeted in two typologies: First, a district that CSISA assumed there would have substantial DSR uptake but there was not and second, a district where CSISA assumed that there would not be substantial uptake but there has been. Based on the data available and after consultation with CSISA team Samastipur and Buxar districts were selected. Buxar falls in the first category and Samastipur falls under second category.

Open ended and unstructured qualitative research has its place, but can become difficult to assess more narrow research questions. In order to attempt to cover a wide spectrum of issues involved in decision making, this study applies a structured qualitative framework that modifies the Livelihood platform approach (LPA) (Brown, Nuberg and Llewellyn, 2017) used previously to understand the decision making processes of smallholder farmers in relation to zero tillage and Conservation Agriculture by smallholder farmers in Africa. Modifications here enable a deeper understanding of perceptions, abilities and enabling environment. This approach, termed the Dartboard approach to Investment Decisions (DAID) framework hence builds on existing theory, but tweaked for exploration of new contexts. The DAID, like the LPA, disaggregates key decision processes into six core questions across four asset categories, which when combines explain the various considerations that individuals considered to reach their eventual typology outcome. This framework was then implemented in the development of the semi-structured question schedule and as the analysis framework used to structure the results section of this paper.

3. RESULTS

Our results highlight a complex web of constraints drive the limited utilisation of ZT drills by owners in the Kharif (rice/monsoon) season. These are primarily based around three interrelated yet independent decision processes, that highlight the need to ask the correct set of questions when exploring agricultural service provision: [1] Is there a problem with the technology? [2] is there a problem with service provision; and [3] is there a problem with providing services with the technology (Figure 1).

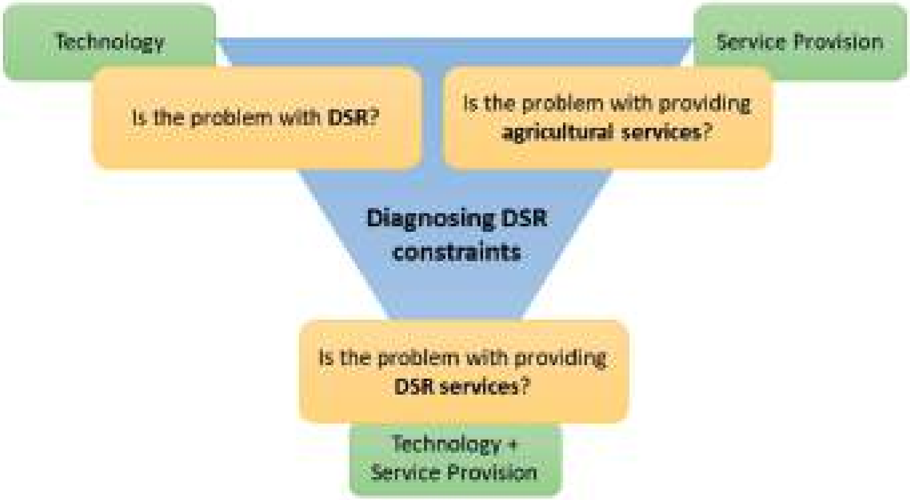

Figure 1: Three interrelated but independent questions to diagnose DSR scaling constraints.

3.1. Is there a problem with the technology (DSR)?

While respondents highlighted a board recognition of the benefits of DSR (from lowering production costs, reducing water use, reduced labour dependency and complementary benefits with following wheat crop), there was also a complex web of constraints discussed by both DSR users and non-users, some of which was directly experienced by them and some of which was reflected on as constricting the adoption of DSR by farmers in their communities (Figure 2).

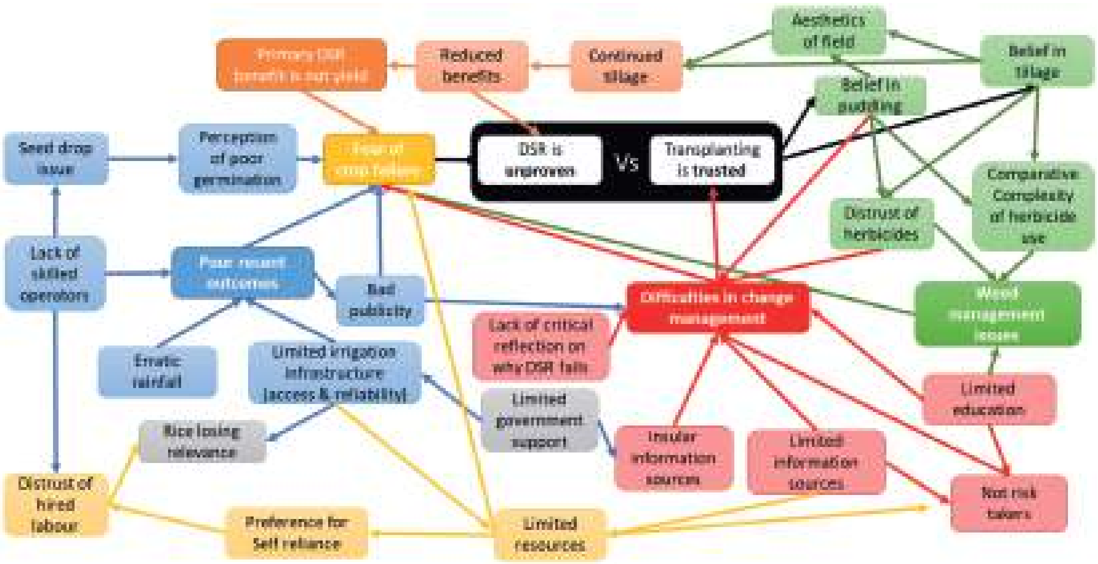

Figure 2: Web of issues raised by respondents on DSR as a technology.

Two key themes emerged related to issues with DSR: that there is a common fear of DSR leading to crop failure, and that Transplanting is a tried and tested production technique, while DSR remains to be proven as successful. These were linked to four key themes to lead to these common perceptions.

Recent poor DSR outcomes (blue web): Consistently mentioned by all respondents was recent issues with DSR, particularly in the prior Kharif season (2018). This performance seems to be related by most to two biophysical challenges: erratic rainfall (particularly in the prior season) and limited access to irrigation infrastructure.

Weed management issues (green web): Weed management was related to the transformation of how weeds are managed in rice cultivation from transplanting to DSR. In the 'proven' transplanting system, there is a belief in puddling and tillage as the primary and effective weed management system. Importantly, this is more profound a change than with wheat which I not puddled.

Benefits of DSR (Orange web): Users of DSR acknowledged that yield was not substantially improved by DSR implementation, and that other benefits were more noticeable and drove them towards DSR use. Constraints in terms of irrigation and labour were noted as drivers, but overall, for many in the community the primary driver of change is likely to be yield, especially on smaller farms where labour and irrigation requirements are less than larger farms.

Difficulties in change management (red web): While not directly related to DSR, the complexities of DSR feed into issues with managing and evaluating change in the community. In particular, community members were perceived to have limited education, limited sources of information and a lack of critical reflection on why DSR fails

Other learnings on DSR constraints: One unexpected outcome of this was the assertion that rice may be loosing relevance as the dominant preference for the Kharif/monsoon season.

3.2. Is the problem with Service provision?

Overwhelmingly, the main constraints raised by respondents were not related to DSR, but with agricultural service provision – and this was the main driver in a hesitance to provide DSR services in their community.

Provision of services on credit: Nearly all respondents mentioned issues with providing services to community members on present, and the time spend in trying to collect dues owing. This was traced back to a constraint with working resource poor smallholder farmers with considerable financial constraints

Reactive business models: None of the respondents in this study identified a proactive promotional strategy for their business of for DSR, with most expecting that customers would come to them directly. This was in part a reflection of cultural values in the region were proactive marketing may lead to negative communal perceptions. However, this also led to limited radius of operation.

3.3. Is the problem with DSR Service provision?

Competing business opportunities: A key issues was raised with the adage that tillage passes increases income, especially when machinery has already been purchased. By DSR reducing tillage passes and with already constrained customer bases, providing widespread DSR services is likely to reduce overall business income.

Additional and unfunded tasks: The primary issues with DSR service provision was related to the need for additional tasks as compared to other agricultural services. These constraints were traced to issues working with smaller, lesser resources smallholders. For instance, under resourced farmer were likely to use lower quality inputs that were not compatible with the ZT drill, or would require small volumes of seed and fertiliser returned from the drill.

Community demand: Most respondents also identified a limited customer base, requiring farmers to have assured irrigation and an open mindset which were both in short supply. This meant that an already small pool of potential customers was further limited, reducing the ability to provide services if that was deemed desirable.

Business risk and community perceptions: As per issues with DSR as a technology, the continued perception of technological risk is an impediment to providing DSR services, as failure will eb associated with the service provider and may impede the provision of other services in the future. The limited value communities provide for quality services further engrains a low demand for service providers to take a risk in DSR service provision.

Altruism Mindset: While resources available to provide services were important, more so a mindset of altruism was key to service provision. This meant that DSR service providers needed to prioritise community benefits over their own profitability, due to additional tasks, reputational risk and competing business opportunities. With the limited time they had, they needed to be willing to use that time not for their personal good but for communal good.

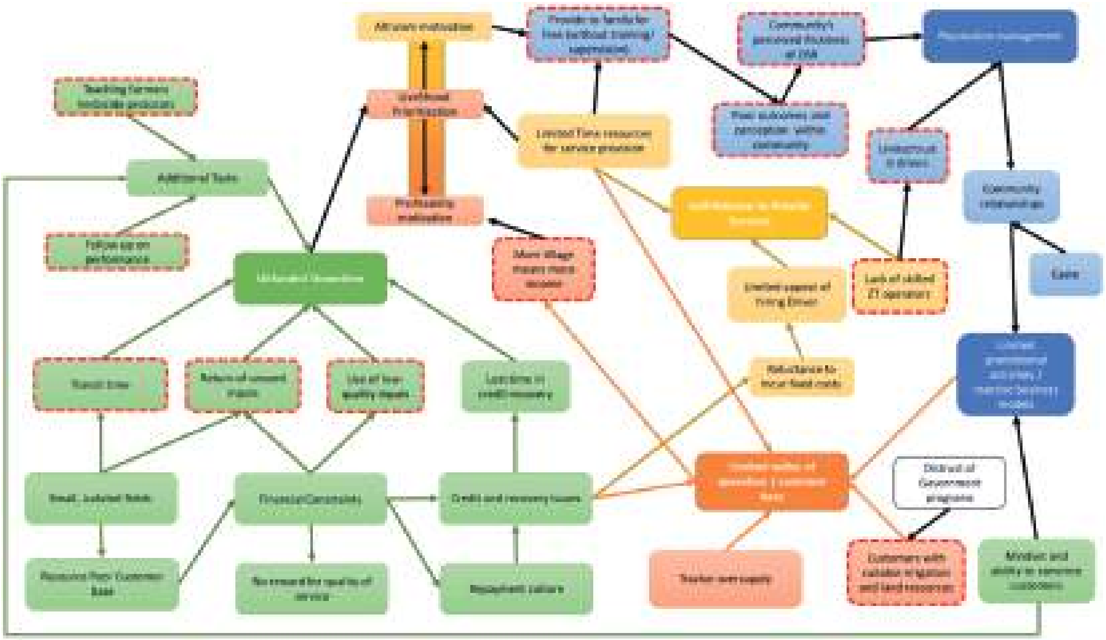

Figure 5: Service provider decision processes – red dash = DSR specific

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Soil biological response to cover crop termination methods with two levels of water availability

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The use of winter cover crops (CC) in annual rotations promotes the sustainability of agro-ecosystems by improving soil health. However, the benefits can be reduced or disappear depending on the CC termination method. Incorporating CC by tillage or glyphosate use are common to terminate CC, whereas roller crimping is emerging as a new promising technique. However, the reduced effectiveness of the roller crimper in certain conditions may call for its combination with glyphosate. The objective of this work was to evaluate the effect of different methods of terminating CC on the abundance of different groups of microorganisms and other microbiological parameters. Four methods to terminate CC (a mixture of barley and vetch) were evaluated (INC mowing and incorporation of CC residues; GLY glyphosate; ROL roller crimper; and RGL combination of roller crimper with glyphosate) and a control without CC (CON), with different water levels (high H and low L). Treatments were distributed in randomized blocks with five replicates, using microcosms with an alkaline soil, poor in organic matter. Sampling was conducted in the succeeding main crop (maize) at pre-emergence and 57 days after sowing (DAS). Abundance of microorganism groups (total bacteria, archaea and fungi, and Glomeromycota) were determined by qPCR. In addition, the length of extrarradical hyphae and mycorrhizal colonization in maize were determined.

We found that CC termination methods and its interaction with water level differentially affected the microorganism groups at both maize pre-emergence and 57 DAS. At maize pre-emergence, GLY decreased the bacteria abundance under both water levels, especially under high water level. By contrast, at this level, bacteria were stimulated by INC. The archaea abundance was less sensitive to water level and was favoured by the roller crimper, with or without glyphosate. Total fungi and Glomeromycota were favoured by RGL, regardless of the water level. At 57 DAS, the biological response of soil changed with respect to pre-emergence. Thus, the negative effect of GLY on total bacteria abundance disappeared at 57 DAS. Abundances of total bacteria, total archaea, total fungi, Glomeromycota, length of extrarradical hyphae and mycorrhizal colonization were enhanced by INC in both water levels. Therefore, the time elapsed since CC termination increased the benefits of incorporating CC residues regardless of the water level. By contrast, the positive or negative effects of glyphosate, roller crimper and its combination on certain microorganism groups were highly dependent on water level. Overall, we found that the time since CC termination and the water availability modulates the biological response of soil to CC termination methods. Further research is therefore needed to investigate the impacts on a variety of environmental conditions to better understand the processes involved.

Keywords: *glyphosate, roller crimper, qPCR, maize, soil health*

ABSTRACT

The use of winter cover crops (CC) in annual rotations promotes the sustainability of agro-ecosystems by improving soil health. However, the benefits can be reduced or disappear depending on the CC termination method. Incorporating CC by tillage or glyphosate use are common to terminate CC, whereas roller crimping is emerging as a new promising technique. However, the reduced effectiveness of the roller crimper in certain conditions may call for its combination with glyphosate. The objective of this work was to evaluate the effect of different methods of terminating CC on the abundance of different groups of microorganisms and other microbiological parameters. Four methods to terminate CC (a mixture of barley and vetch) were evaluated (INC mowing and incorporation of CC residues; GLY glyphosate; ROL roller crimper; and RGL combination of roller crimper with glyphosate) and a control without CC (CON), with different water levels (high H and low L). Treatments were distributed in randomized blocks with five replicates, using microcosms with an alkaline soil, poor in organic matter. Sampling were conducted in the succeeding main crop (maize) at pre-emergence and 57 days after sowing (DAS). Abundance of microorganism groups (total bacteria, archaea and fungi, and Glomeromycota) were determined by qPCR. In addition, the length of extrarradical hyphae and mycorrhizal colonization in maize were determined.

We found that CC termination methods and its interaction with water level differentially affected the microorganism groups at both maize pre-emergence and 57 DAS. At maize pre-emergence, GLY decreased the bacteria abundance under both water levels, especially under high water level. By contrast, at this level, bacteria were stimulated by INC. The archaea abundance was less sensitive to water level and was favoured by the roller crimper, with or without glyphosate. Total fungi and Glomeromycota were favoured by RGL, regardless of the water level. At 57 DAS, the biological response of soil changed with respect to pre-emergence. Thus, the negative effect of GLY on total bacteria abundance disappeared at 57 DAS. Abundances of total bacteria, total archaea, total fungi, Glomeromycota, length of extrarradical hyphae and mycorrhizal colonization were enhanced by INC in both water levels. Therefore, the time elapsed since CC termination increased the benefits of incorporating CC residues regardless of the water level. By contrast, the positive or negative effects of glyphosate, roller crimper and its combination on certain microorganism groups were highly dependent on water level. Overall, we found that the time since CC termination and the water availability modulates the biological response of soil to CC termination methods. Further research is therefore needed to investigate the impacts on a variety of environmental conditions to better understand the processes involved.

1. INTRODUCTION

Cover crops (CC) provide numerous ecosystem services (Schipanski, M.E. et al., 2014), including soil health enhancement (Sharma et al., 2018). CC management practices can greatly modulate the expected benefits. When CCs are used as winter cover crops in rotation with herbaceous main crops, the method of CC termination can greatly affect the development and yield of the subsequent main crop (Alonso, M. et al., 2020). Part of this effect may be exerted through changes in soil microorganisms (Rhomdane, S. et al., 2019), which play important roles in the soil, especially those that form symbiosis with plants. One of the most relevant groups of soil microorganisms are arbuscular mycorrhizal fungi (AMF). AMF symbiosis with plants provides benefits at the level of nutrient uptake, soil structure, water relations, protection against pathogens or plant productivity (Smith, S.E and Read, D.J, 2008).

A traditional method of CC termination has been mowing and incorporation into the soil by tillage, with possible negative effect on AMF (Hage-Ahmed, K. et al., 2018). In Conservation Agriculture, it is common to use herbicides such as glyphosate to terminate CC. The use of glyphosate is controversial (Van Brueggen, A.H.C. et al., 2018) and its effects on microorganisms are unclear due to the variety of responses. As an alternative to incorporation or glyphosate, the use of the roller crimper is spreading. The roller crimper breaks the stems at different heights, forming a layer of residues on the surface. As its effectiveness may be diminished in certain cases depending on the CC species and the phenological stage, the roller crimper can be combined with glyphosate, with effects on soil microorganisms. These effects may be modified by water availability (Rhomdane, S. et al., 2019), which is irregular in the Mediterranean climate and under changing climate conditions. To date, very few studies have focused on jointly analysing the impacts of CC termination method and water availability on soil microorganisms. Therefore, we have evaluated under controlled conditions the effect of different CC termination methods on a selection of soil microbiological parameters and their interaction with two water availability scenarios.

2. MATERIAL AND METHODS

In a greenhouse experiment, we evaluated four CC termination methods (INC: mowing and incorporation, GLY: glyphosate, ROL: roller crimper and RGL: glyphosate + roller crimper) and a control without CC (CON), which were applied under two water level conditions, high (H) and low (L), with irrigation dose L being 75% of H dose. The resulting 10 treatments (5x2) were randomly distributed in 5 blocks (50 microcosms). Pots of 30 x 12 x 10 cm and a substrate consisting of a mixture (1:2) of sand and soil were used. The soil had an alkaline pH (8.5), silt loam texture and low organic matter content (1.1%) and was extracted from the superficial horizon of a Haplic Calcisol located in the Tajo River basin in Aranjuez (Madrid).

The CC consisted of a mixture of barley (*Hordeum vulgare* L.) and vetch (*Vicia sativa* L.), which was sown on December 10, 2018 and irrigated according to irrigation level H or L. Approximately 3 months after sowing, glyphosate was applied (03/22/2019) in the treatments GLY and RGL) and a week later, termination was carried out according to the rest of the treatments (03/29/2019). A few days later (04/01/2019) maize (*Zea mays* L.) was sown (3 seeds per pot) and after one month a low dose of NPK fertilization was applied, the same in all treatments. During maize growing, the corresponding irrigation level H or L was applied.

Soil samples were taken with a cylindrical sampler (3.5 cm Ø and 10 cm depth) at maize pre-emergence (14 days after glyphosate application) and 57 days after maize sowing (DAS). In both samplings, DNA was extracted from soil and gene copy number was quantified by qPCR to estimate the abundance of total bacteria, total archaea, total fungi and Glomeromycota (Lopez-Gutierez J.C. et al., 2004; Ochsenreiter, T. et al., 2003; Schoch C.L. et al., 2012; Lee et al., 2008). In addition, the length of extrarradical hyphae was determined for both samplings and the percentage of AMF colonization in maize roots was obtained in the last sampling (García-González, I. et al., 2018). An analysis of variance was applied with a general linear model (Statgraphics Centurion XVIII) for a block design with two factors, checking for normality and homoscedasticity of the data. Differences between means were evaluated with Tukey's test for a p-value< 0.05.

3. RESULTS AND DISCUSSION

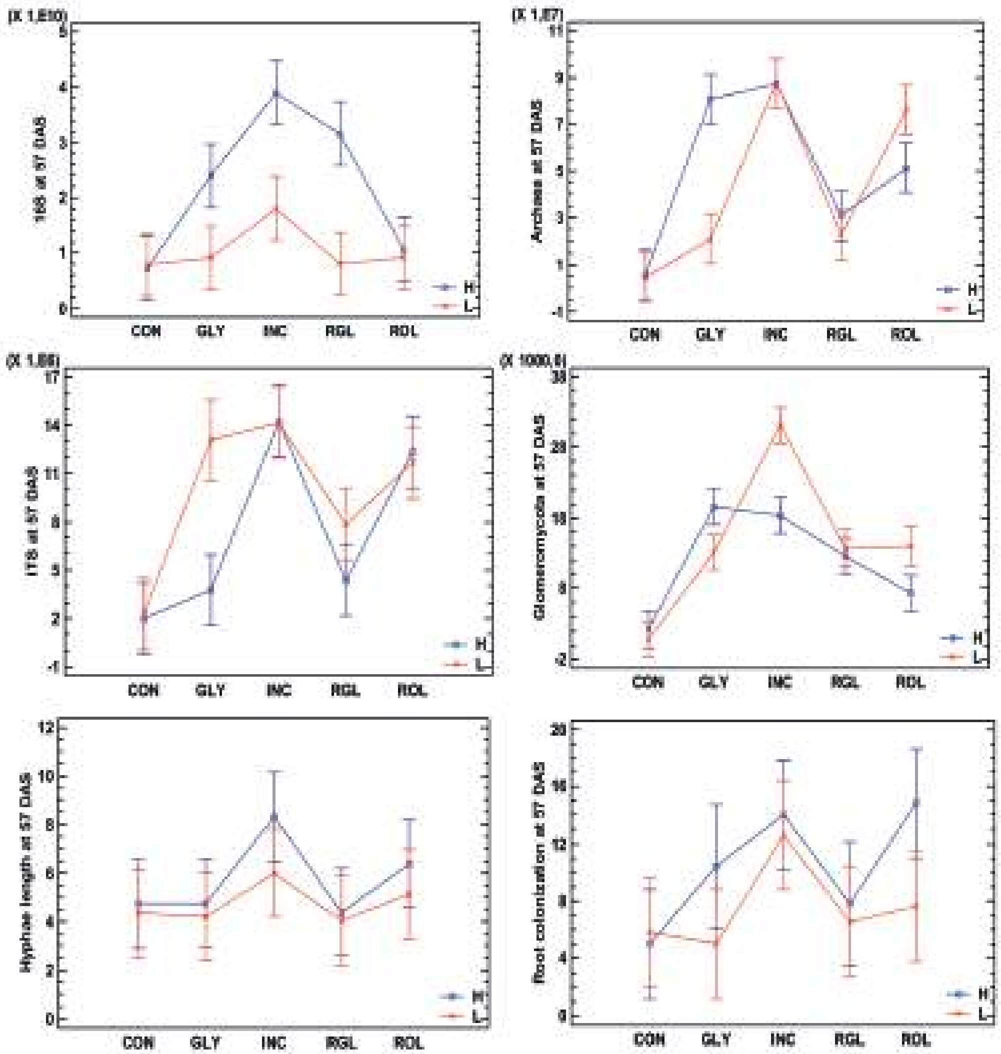
Termination methods and their interaction with water availability differentially affected the studied groups of microorganisms (Table 1 and Fig. 1). In maize pre-emergence, the GLY method reduced the abundance of bacteria at both water levels, being more negative at the high level. In contrast, for this level, the incorporation of residues (INC) increased bacteria abundance. The abundance of total archaea showed less sensitivity to water level and was favoured by the use of roller crimper, with or without glyphosate (ROL, RGL). On the other hand, total fungi were stimulated by the combination of roller crimper with glyphosate at both water levels. The last method also favoured Glomeromycota, especially at the high irrigation dose.

Table 1. Effects of CC termination methods, water level, and its interaction on microbiological parameters at maize pre-emergence and 57 days after maize sowing.

	Total bacteria		Total fungi		Total archaea		Glomeromycota		Hyphae length		Root colonization	
	Pre	57 d	Pre	57 d	Pre	57 d	Pre	57 d	Pre	57 d	Pre	57 d
CC Termination (T)	***	***	***	***	***	***	***	***	**	**	-	***
Water level (W)	***	***	***	***	ns	***	ns	***	***	ns	-	*
T * W	***	***	***	***	ns	***	***	***	ns	ns	-	ns

Pre: maize pre-emergence; 57 d: 57 days after maize sowing. * < 0.05; ** < 0.01; *** < 0.001; ns: not significant.

Figure 1. Abundance of total bacteria, total archaea, total fungi and Glomeromycota, length of extrarradical hyphae and % root colonization at 57 days after maize sowing (DAS) as affected by CC termination method (CON: no-CC, GLY: glyphosate, INC: mowing + incorporation, RGL: glyphosate + roller crimper, ROL roller crimper) and water level (H: high; L: low). Bars indicate 95% Tukey intervals.



In the second sampling (Fig. 1), the soil microbiological response changed with respect to pre-emergence. In general, the abundances of total bacteria, total archaea, total fungi, and Glomeromycota, as well as the length of extrarradical hyphae and the mycorrhizal colonization in maize roots were favoured by INC at 57 DAS, regardless of the water level. The time elapsed after CC termination made that incorporation of the CC residues into the soil enhanced all the analysed microbiological parameters to a larger extent than the other termination methods. The incorporation of CC residues into the soil facilitates their contact with microorganisms, favouring decomposition and their use as a source of C. After INC, ROL also favoured the abundance of fungi and archaea, as well as the hyphae length and root colonization. However, ROL erased the benefit of CC on bacteria abundance, which could be attributed to the absence of tillage (Six, J. et al., 2006). The combination of glyphosate and roller crimper tended to decrease all microbiological parameters at both water levels, except for bacteria abundance at high water level. The use of glyphosate alone showed an unequal and different effect depending on the water level: it favoured the abundance of total bacteria, total archaea and Glomeromycota at high water level and that of fungi at low one. Other studies have shown a positive effect of glyphosate on bacteria as they can degrade it to obtain carbon, but the effect was quite variable on fungi (Sheng, M. et al., 2012) in line with our study. Responses of total archaea and total fungi abundances to treatments were quite similar.

4. CONCLUSIONS

The method of CC termination can greatly modify the soil microbiota and this effect can last for some time afterwards, affecting the subsequent main crop. The time elapsed since CC termination and the water availability can modify the soil microbiological response to the termination methods. Therefore, a variety of effects can be expected depending on the weather conditions of each season. A better understanding of the effects of termination methods in a variety of soils and environmental conditions will elucidate the underlying mechanisms and support decision making in the field.

5. ACKNOWLEDGMENTS

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A private Conservation Agriculture label by farmers and a professional movie to reconcile farmers with citizens

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Farmers practicing Conservation Agriculture in France are still a little minority (2 to 4 %), like in most other European countries.Despite improved results of their farms versus conventional agriculture, proven by all data when properly and honestly assessed, they are facing many obstacles. Among them, the worst is the political management of agriculture by politicians, who follow public opinion and are influenced by diverse lobbies. Traditional farmers unions, unable to deal with this phenomenon, are now the target of anti-farmers activists (“Agri bashing”).

APAD (Association pour la Promotion d’une Agriculture Durable), a French farmers association specialized in CA, has now a rapid growth, due to its attractivity for farmers (thousand farmers and fifteen local groups). But it also faces the opposition of intellectual elites of media, politics, NGO’s and leading academics, for whom only organic agriculture is acceptable. However, APAD farmers have seen that a productive dialog is possible, even on pesticides or glyphosate use, every they give honest and transparent explanations of results and practices on their farms. Despite the great success of numerous meetings of citizens on CA farms, the impact is still too low to recover recognition of the public.

APAD has made a professional scientific study with a University specialist of the food chain, about perception by citizens/consumers of agriculture, environment, and CA.The findings show that citizens do not like traditional farmers anymore, hate pesticides, like “nature”, trust no one (food industry, politicians, media, NGO, scientists), but do not praise organic so much as expected. They are looking for nature and farmers they can trust. After having been introduced to CA, a large majority recognizes that they like it, and may even accept some level of pesticides, if farmers explain their effort to improve.

Based on these findings, APAD has launched a private label, owned by farmers, based on a process of progress, with an internal audit of candidates by a peer review process, led by the most experimented farmers. The first indications after one year and 200 labelled farms, are indicating a high level of interest of media and public for this process where farmers are bringing themselves their reality to citizens without any intermediate or filter. APAD wishes to mutualize with sister associations all experiences about productive dialog with citizens, to reconciliate farmers with citizens, and humans with nature.

Keywords: *farmers associations, recognition by citizens, label, consumer study*

Abstract

Farmers practicing Conservation Agriculture in France are still a little minority (2 to 4 %), like in most other European countries. Despite improved results of their farms versus conventional agriculture, proven by all data when properly and honestly assessed, they are facing many obstacles. Among them, the worst is the political management of agriculture by politicians, who follow public opinion and are influenced by diverse lobbies. Traditional farmers unions, unable to deal with this phenomenon, are now the target of anti-farmers activists ("Agri bashing").

APAD (Association pour la Promotion d'une Agriculture Durable), a French farmers association specialized in CA, has now a rapid growth, due to its attractivity for farmers (thousand farmers and fifteen local groups). But it also faces the opposition of intellectual elites of media, politics, NGO's and leading academics, for whom only organic agriculture is acceptable. However, APAD farmers have seen that a productive dialog is possible, even on pesticides or glyphosate use, every they give honest and transparent explanations of results and practices on their farms. Despite the great success of numerous meetings of citizens on CA farms, the impact is still too low to recover recognition of the public.

APAD has made a professional scientific study with a University specialist of the food chain, about perception by citizens/consumers of agriculture, environment, and CA. The findings show that citizens do not like traditional farmers anymore, hate pesticides, like "nature", trust no one (food industry, politicians, media, NGO, scientists), but do not praise organic so much as expected. They are looking for nature and farmers they can trust.

After having been introduced to CA, a large majority recognizes that they like it, and may even accept some level of pesticides, if farmers explain their effort to improve. Based on these findings, APAD has launched a private label, owned by farmers, based on a process of progress, with an internal audit of candidates by a peer review process, led by the most experimented farmers. The first indications after one year and 200 labelled farms, are indicating a high level of interest of media and public for this process where farmers are bringing themselves their reality to citizens without any intermediate or filter. APAD wishes to mutualize with sister associations all experiences about productive dialog with citizens, to reconciliate farmers with citizens, and humans with nature.

1. OFFICIAL SITUATION OF CA IN FRANCE

French farmers practicing real Conservation Agriculture (i.e according to the definition of CA-COP of FAO, as properly defined in every newsletter of Dr Amir Kassam) are still a little minority, like in most other European countries.

Until recently there was neither official definition not consensus between scientists and operators about what is CA. Most of them still include Reduced Tillage in their definition.

2. CHALLENGES FOR CA IN FARMING COMMUNITY

During the last fifteen years, APAD, the French member association of ECAF, the European Conservation Agriculture Federation, had been preaching in the desert for real CA as described in previous paragraph. Thanks to its continuous focus on advocacy, to the improved results of pioneer farmers, with now more than twenty years of good results on farm, and the global movement towards soil protection, sustainability as well as economic constraints, farmers and farming community became step by step aware that No-Till CA systems are possible and bring results.

Among farmers, there is now a strong and growing interest in cover-crops, in Reduced Tillage, and more recently in CA with Cover crops and No-Till. Many extension services, scientists, private consultants, make trials, most of them on their own initiative, with their own logic, and without wanting to learn from successful pioneer farmers. More and more are selling training to farmers, even if their real knowledge is recent and approximative.

On top of that, the political management of agriculture by politicians, who follow public opinion and are influenced by diverse lobbies, the threat of ban of glyphosate, the pressure on pesticides and fertilizers, makes most farmers uncertain of their future, and not ready to take the risk to change. Traditional farmers unions, unable to deal with this phenomenon, are now the target of anti-farmers activists (“Agri bashing”).

In this context, since approximately three years, some promoters of organic farming have seen an opportunity to develop their business, and have made a kind of revolution in their approach. Instead of opposing CA upfront, they now integrate a “CA like” approach of organic, naming it “Organic CA”. Practically, it is mostly Reduced Tillage with cover-crops with organic management. With animal productions and long rotations, the results are not too bad, except that the yields remain below “orthodox” CA, and there is a lot of mechanical interventions. For the promoters of original CA, it does not meet the definition of CA. This movement has now a rapid growth thanks to the support of the global Regeneration movement, originally launched by IFOAM, developed in California and in the US, promoting Organic Regenerative Agriculture, and is globally taking rapidly the leadership in all international organizations dedicated to agriculture.

In France some groups have developed a good business model based on story telling to politicians, ngo’s and citizens of cities, concerned about food and environment, but usually ignorant of realities on farms. Many farmers who are still in learning phase towards CA are seduced by the attractiveness of this beautiful story for citizens. They want to do good for environment and citizens, without knowing the limits of feasibility. Facing all this complex situation, with all these diverse messages and communications to all farmers, the CA farmers of APAD were facing many obstacles to go on convincing their more conventional colleagues, and even keep their members on board.

Despite their improved results of their farms versus conventional or organic agriculture, proven by all data when properly and honestly assessed, the pressure of the society of cities is so high that they had difficulties to compete with good story tellers promising to get the results of CA with at the same time the good image of organic.

3. ACTIONS OF APAD

APAD (Association pour la Promotion d’une Agriculture Durable), the French farmers association specialized in CA, has got a rapid growth in the past years, due to its attractivity for farmers (thousand farmers and fifteen local groups end 2020). But it also faces the opposition of intellectual elites of media, politics, NGO’s and leading academics, for whom only Organic Agriculture is acceptable, and now Organic Regenerative Agriculture. However, APAD farmers have seen that a productive dialog is possible, even on pesticides or glyphosate use, every time they give honest and transparent explanations of results and practices on their farms.

Despite the great success of numerous meetings of citizens on CA farms, the impact is still too low to recover recognition of the public. Thus, APAD Board has decided to launch a professional approach of communication towards general public. The need for a strategy of communication was obvious: how to talk with success to citizens who ignore most of the basic realities of farming? The first step had been to find a specialist of food chain knowing consumers needs and approaches.
After a common work of analysis of the benefits of CA, it became visible that none among the farmers employees of APAD really understands ordinary citizens and consumers mindsets and perceptions, nor reactions to images or feelings. The decision was taken to make a professional scientific study with Olivier Mevel, a Professor of University of Nantes, specialist of the food chain, about perception by citizens/consumers of agriculture, environment, food and CA.

4. THE STUDY OF CITIZENS PERCEPTION ABOUT AGRICULTURE, ENVIRONMENT, FOOD AND CA

The study was made in winter 2019-20, with usual method of representative clusters of socio-economic categories, on 1500 citizens, by phone, on a questionnaire built in common by APAD and Mr Mevel. The results were than completed by a second step of proposals about products of CA farms.

The findings show that:

- Citizens do not like traditional farmers anymore. This was a real shock for all, as the last studies had shown that most citizens still liked their farmers, despite not liking what they were doing, considering them as victims of big industry corporations. This rapid changed can be attributed to the success of the very active and aggressive campaign of activists against farming in general, promoting organic as the unique possible way.
- Citizens hate pesticides and chemistry. They like "nature" and "natural agriculture", despite not knowing how it could look like. This point is related to the first one. Activists have it easy to frighten people who ignore the risk / benefit balance, and find easily abundant food in their supermarkets, without wondering how this is produced.
- Citizens trust no one (food industry, politicians, media, NGO, scientists). Surprisingly, they do not praise organic so much as expected. Because they guess that this is also marketing and business for food industry as all other food chains.
- citizens are looking for farmers they can trust; real people they can question. They are eager to know and ready to learn, when farmers talk to them about what they do, why and how.
- After having been introduced to CA, a large majority recognizes that they like it, and may even accept some level of pesticides, if farmers explain their effort to improve**.**
- The first benefit of CA citizens like is not carbon sequestration, climate mitigation, soil conservation, organic matter, water quality, but biodiversity. They like wildlife and flora.
- when products of CA are proposed to them, with cost simulations, they are ready to give preference to CA, even with a premium price.

For all these reasons, the decision was taken to launch a label to identify the farms in CA.

5. THE LABEL "IN THE HEART OF SOILS"

Based on these findings, APAD has launched a private label, named in French "Au Coeur des Sols » = ACS = Agriculture de Conservation des Sols. It is owned by APAD. It is based on

- the strict respect of the three pillars of CA: zero tillage, permanent soil cover, rotation and diversity of crops (cash crops and service crops), with diverse levels of achievement,
- description of a process of progress
- with an internal audit of candidates by a peer review process,
- a steering committee led by the most experimented farmers.

The label has been launched march 2020 during the International Fair of Agriculture in Paris. The exhibit of APAD, the launch conference and the press conference, has been a huge and unexpected success. After one year, around 200 farms of APAD are labelled, for a total of 30 000 hectares. The limit is more due to the workload of the audit made by an engineer of APAD than to the number of candidates. Several benefits of this action are directly visible:

- true CA has now a precise definition, and it is the one of farmers practicing, recognized officially by the Minister of Agriculture and all operators.
- the success is attracting a lot of new farmers to CA and to APAD. The success is so big that many farmers feel obliged to say that they practice CA, even if using reduced tillage. Saying that you plough or even use tillage, is now more and more often seen as obsolete and old fashion.
- the positive rumor and APAD efforts now begin to attract mass media attention.
- the attractive story goes far beyond CA attractiveness. There is a high level of interest of media and public for the story of these farmers who take their destiny in hand, modify their farming ecosystems towards more sustainability spontaneously without official support and despite all obstacles, and are bringing themselves their reality to citizens without any intermediate or filter.

6. FUTURE STEPS

As nothing is perfect, the good signal APAD, but also all other CA organizations, got from other farmers and from citizens about their actions in favour of soil, climate, biodiversity, food... , have attracted the attention of the competition and opponents.

The lobbies of Organic, traditional and Regenerative, are now supported by alliances with big consortiums of food industry, wanting to regenerate their margins in food business by letting consumers pay much more for a supposed to be better food. Even if this leads to scarcity, it is not their problem, because poor people do not count as they are not a market. They use their huge lobbying capacity to intensify their effort at European Commission, to ban glyphosate, as well as all other chemistry, in order to kill CA development. And their intention is to gain the entire world, through international organizations, in which CA movement is nearly or totally absent, and lack of global structured coordination. In clear, while CA community is working at field level, the others are spreading their influence at political and mediatic level, with films, webinars, story telling...

In current world dominated by virtual reality, internet, social networks and mass media, farmers and their allies are condemned to loose politically of they do not find a way to be considered by policy makers.

APAD wishes to mutualize with sister associations in Europe in ECAF as well as with all sisters CA associations around the world all successful experiences about productive dialog with citizens. The key is to reconciliate farmers with citizens, and humans with nature. CA is the right way to do so. It is up to CA leaders who are present in this congress to take the decisions and to make it happen. Otherwise, who will?

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Legacy effects of cover crops mixtures differently affect soil microorganism groups

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Cover crops (CC) can promote arbuscular mycorrhizal fungi (AMF) compared to fallow, and can affect other soil organisms with key soil functions. However, benefits on soil health may depend on CC species and its combinations. This research quantifies the legacy effects of CC species (monocultures and mixtures) in rotation with two different main crops on selected plant and soil biological attributes. We established microcosms experiment with five replicas and low inputs (fertilizer and water) conditions. Three CC in monoculture (two legumes and one grass) and in two mixtures of one legume with one grass, in addition to a control without CC were evaluated in combination with two different main crops (MC); maize (C4 plant) or wheat (C3 plant). The experiment was carried out in a greenhouse after two rotation cycles with CC and MC. Plant and soil were sampled in the main crop of the second cycle. The mycorrhizal colonization, the length of extra radical hyphae, the total abundance of bacteria, archaea, fungi and glomeromycota in the soil, the plant biomass aboveground and the shoot P were measured. We found a strong interaction between CC treatments and succeeding main crops. All CC increased the mycorrizhal colonization compared to non-CC in wheat and maize, especially the CC with barley+vetch in maize. The hyphae length was increased by ~50% in the barley+melilotus in wheat in addition to improve the shoot P compared to the control. The abundance of total bacteria and glomeromycota was increased by all CC in wheat. On the other hand, in maize, all CC with barley showed the lowest abundances of total bacteria, total fungi and glomeromycota. Choice of CC species and species mixture and its interactions with the succeeding main crop can have large effects on soil microorganisms, at least at short time, with potential impact on soil key functions and agronomic aspects. Further research is needed to understand these interactions, especially concerning the mixtures, in a way that give support on the decisions of which CC is more appropriate in each case.

Keywords: *maize, wheat, bacteria, fungi, mycorrhization*

ABSTRACT

Cover crops (CC) can promote arbuscular mycorrhizal fungi (AMF) compared to fallow, and can affect other soil organisms with key soil functions. However, benefits on soil health may depend on CC species and its combinations. This research quantifies the legacy effects of CC species (monocultures and mixtures) in rotation with two different main crops on selected plant and soil biological attributes. We established a microcosms experiment with five replicas and low inputs (fertilizer and water) conditions. Three CC in monoculture (two legumes and one grass) and in two mixtures of one legume with one grass, in addition to a control without CC were evaluated in combination with two different main crops (MC); maize (C4 plant) or wheat (C3 plant). The experiment was carried out in a greenhouse after two rotation cycles with CC and MC. Plant and soil were sampled in the main crop of the second cycle. The mycorrhizal colonization, the length of extra radical hyphae, the total abundance of bacteria, archaea, fungi and glomeromycota in the soil, the plant biomass aboveground and the shoot P were measured. We found a strong interaction between CC treatments and succeeding main crops. All CC increased the mycorrizhal colonization compared to non-CC in wheat and maize, especially the CC with barley+vetch in maize. The hyphae length was increased by ~50% in the barley+melilotus in wheat in addition to improve the shoot P compared to the control. The abundance of total bacteria and glomeromycota was increased by all CC in wheat. On the other hand, in maize, all CC with barley showed the lowest abundances of total bacteria, total fungi and glomeromycota. Choice of CC species and species mixture and its interactions with the succeeding main crop can have large effects on soil microorganisms, at least at short time, with potential impact on soil key functions and agronomic aspects. Further research is needed to understand these interactions, especially concerning the mixtures, in a way that give support on the decisions of which CC is more appropriate in each case.

1. INTRODUCTION

Cover crops (CC) offer ecosystem benefits in order to improve the sustainability of agriculture (Schipanski, M.E. et al., 2014). The improvement of soil conservation and nutrient recycling are two contributions of the CC which have been largely studied. More recently, researchers have been focused on the CC´s capability to promote the belowground biodiversity and some beneficial microorganism as arbuscular mycorrhizal fungi (AMF) or suppressive-disease bacteria.

The benefits of CC differ depending on the species used. Thus, grasses can provide a greater amount of soil organic matter, while legumes fix atmospheric N to make it available to the subsequent crop (Snapp, S.S. et al., 2005). A mixture of grasses and legumes may be used to provide benefits for both families. The inclusion of CC in the rotations also stimulates AMF, favoring the mycorrhization of the subsequent MC (Bowles, T.M. et al., 2017). The response of AMF differs with the type of species used as CC, for example, legumes can increase the abundance of AMF (Benitez, M. et al., 2016), but grasses usually present higher ability to legate them to the next crop. Regarding the mixtures of CC species, these can increase the biodiversity of the soil microbiota (Vukicevich, E. et al., 2016), but there is discrepancy regarding their effect in different groups of microorganisms (Finney, D.M. et al., 2017). With this background, it is necessary to deepen the analysis of the impact of different types of CC on soil microorganisms and how each subsequent MC interacts with this microbiota. Therefore, this work studied the legacy of different types of CC on a selection of biological parameters analyzed in two different MC; maize and wheat.

2. MATERIALS AND METHODS

The first study factor was the type of CC (TCC) that consisted of three species in monoculture: vetch (*Vicia sativa* L.) (VET), melilotus (*Melilotus officinalis* L.) (MEL), and barley (*Hordeum vulgare* L) (BAR); and two mixtures, barley with vetch (B+V) and barley with melilotus (B+M), in addition to a control without CC (CON). The second study factor was the type of the main crop (MC): maize

(*Zea mays* L.) or wheat (*Triticum aestivum* L.) which were sown after the CC. The 12 resulting treatments (6x2) were randomly distributed in 5 blocks (60 microcosms in total). Pots of 18x18x25.5 cm size were used with a mixture of sand and soil (1:2 in volume). The starting soil (pH = 8.3, loamy texture and OM = 1.13%) was taken from the surface horizon of a Calcic Haploxeralf located in Alcalá de Henares (Spain) with a low nutrient content. The experiment was developed during two rotation cycles (CC + MC) in a greenhouse under semi-controlled conditions with 18.4 °C on average for CC and 22.4 °C on average for MC. In all the microcosms, a low input strategy was applied with an irrigation equivalent to 25 mm/month and the necessary fertilization to avoid very low levels of NPK. MC biomass and soil were sampled in the second cycle eight weeks after the CC termination in order to evaluate the legacy of CC in the early stages of the MC. Plant shoot, their main roots and adjacent soil were taken with a gouge auger (3.5 cm of diameter) at 10 cm depth. As biological parameters, the percentage of mycorrhizal colonization and the length of extra radical hyphae (García-González, L. et al., 2016), as well as bacteria, archaea, fungi and glomeromycota were determined using qPCR as an abundance estimate of total bacteria, total fungi (López-Gutiérrez, J.C. et al., 2004; Schoch, C.L. et al., 2012), total archaea, and glomeromycota. An analysis of variance was applied with a general linear model for a block design with two factors, ensuring the normality and homoscedasticity of the data. Differences between means were evaluated using Tukey's honestly significant difference at p-value <0.05.

3. RESULTS AND DISCUSSION

The results indicated important effects of both the CC and the subsequent MC in most of the variables analyzed, as well as a strong interaction between the two factors of study (Table 1). All CC improved the mycorrhizal colonization (Fig. 1), especially barley with vetch in maize (33.6% vs. 13.0% in the control). According to Njeru et al., (2014) the higher colonization could be due to a higher supply of carbon by host crop. However, the abundance of glomeromycota in the soil nearby the roots of maize was decrease with all CC.

Under maize, the CC mixtures (B+V and B+M) decreased the abundance of total bacteria and total fungi compared to the control. Other studies also observed that mixtures of grasses with legumes do not favor the abundance of total fungi compared to a monoculture of legumes (Finney, D.M. et al., 2017). Also, in our study the three CC monocultures (VET, MEL and BAR) increased the ratio Fungi:Bacteria which is considered as a soil quality indicator (De Vries, F.T. et al., 2006).

The pattern of results after CC in wheat was very different than in maize according to the principal component analysis (Fig.2). For example, the behavior of B+V in maize was radically different than in wheat. This shows the profound effect that the identity of the MC had on the interaction with the legated microbiota after each CC.

Table 1. Summary of ANOVA analysis for the mycorrhizal variables, abundance of total bacteria and fungi, glomeromycota and total archaea under the main crops according to the factors of study (type of cover crop [CC] and type of main crop [MC]) and their interaction.

Factor/ Variable	Colonization (%)	Hyphae length (cm/g)	Total bacteria	Total archaa	Total fungi	Total glomeromycota
Type of CC	***	*	***	***	***	***
Type of MC	***	ns	***	***	***	***
CC x MC	ns	ns	***	***	***	***

* p-value < 0.05; ** p- value < 0.01; *** p- value < 0.001; n.s: not significant (p-value > 0.05).

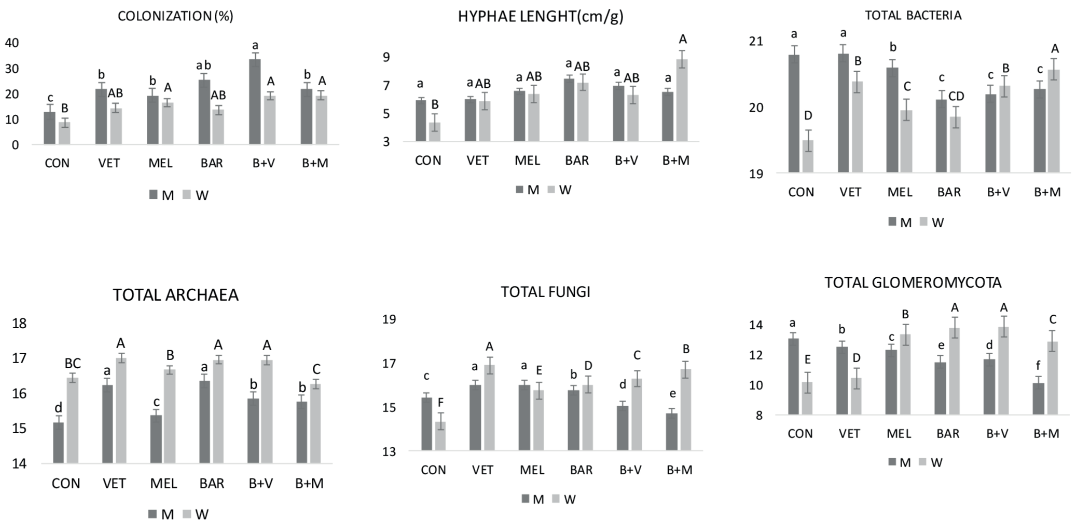

Figure 1. Multiple comparisons for the mycorrhizal variables, and abundances of total bacteria, total archaea, total fungi and total glomeromycota (LOG) in maize (M) and wheat (W) plants. Different letters indicate significant differences for p <0.05 according to Tukey. Lowercase letters indicate comparisons in maize, uppercase letters, comparisons in wheat. CON: control without DC; VET: vetch; MEL: melilotus; BAR: barley; B+M: barley with melilotus; B+V: barley with vetch.

The wheat (C3 plant) is less adapted than maize (C4) to the high temperatures recorded during the MC phase (22.4 °C). Under this adverse circumstance the CC benefices on soil microbiota were clearer than with maize and the behavior of control was totally different compared with all treatments with CC (Fig. 2). Thus, Control in wheat showed the lowest values in colonization, length of hyphae, abundance of total bacteria, total fungi and glomeromycota (Fig. 1). On the contrary, the mixture with B+M showed the highest values of colonization, length of hyphae and total bacteria. Meanwhile, the VET showed the highest abundance of total fungi and total archaea. The increase of the abundance of microorganisms observed after the treatments with CC could be interpreted as an improvement in soil health (Finney, D.M. et al., 2016).

The maize aboveground biomass was much higher than wheat one (Fig. 3) thanks to the high temperatures that facilitate the fixation of the carbon of C4 plants such as maize (Leipner, J. & Stamp, P. 2009). We observed a positive correlation between biomass and archaea (p-value <0.05). According to Timonen & Bomberg (2009) archaea could favor the availability of nitrogen compounds due to their nitrification function. Even when all CC in maize increased the abundance of archaea respect to the control, there were not significant differences in the biomass between the treatments according to Tukey.

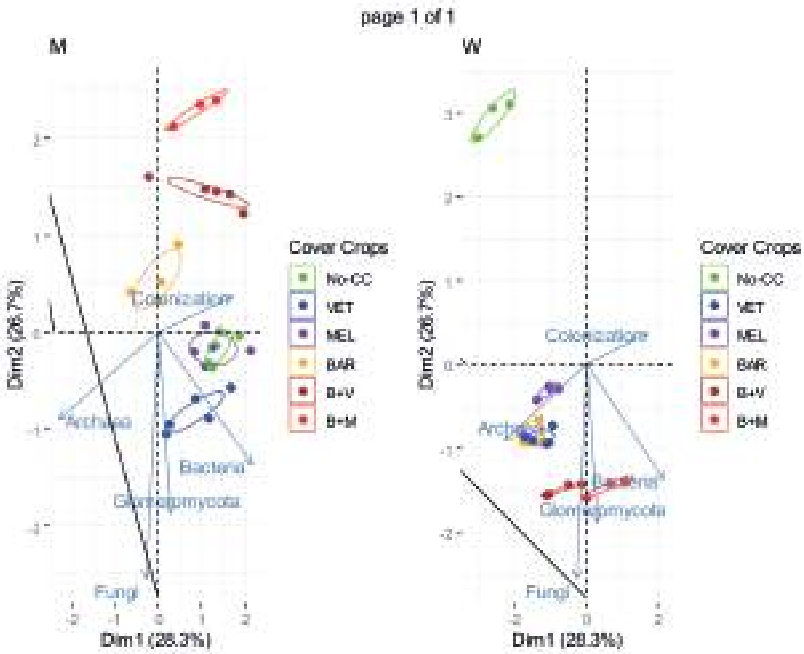

Figure 2. Analysis of principal components for the biological variables (a) Mycorrhizal colonization, abundance of total bacteria, total fungi and total archaea and, (b) hyphae lenght and abundance of glomeromycota in the main crops maize (M) and wheat (W) in the first and second component (55% of variability).

Also, despite the positive effects of CC on mycorrhizal colonization in maize, no differences were observed in shoot P in maize. Surely, the N and P fertilization, which was similar in all treatments, covered part of the effect of the archaea and/or of the mycorrhizal colonization on the MC aboveground biomass. Nevertheless, in wheat, the effects of B+M mixture were enough to improved P compared to the treatment without CC. Probably this result was due to the high colonization and hyphae length in this treatment (Gianinazzi, S. et al., 2010; Requena, N. et al., 2007) (Fig. 3). Furthermore, this treatment showed the highest abundance of bacteria in wheat; some of which could be phosphate-solubilizing bacteria (Liang, J. et al., 2020).

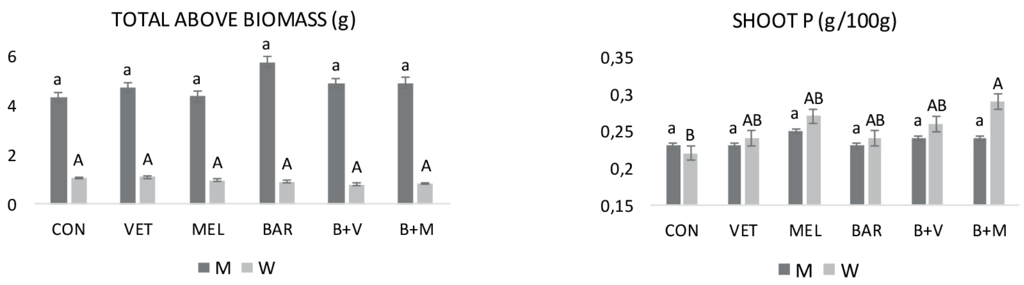

Figure 3. Multiple comparisons for total aboveground biomass and shoot P in maize (M) and wheat (W). Different letters indicate significant differences for p <0.05 according to Tukey. Lowercase letters indicate comparisons in maize, uppercase letters, comparisons in wheat. CON: control without CC; VET: vetch; MEL: melilotus; BAR: barley; B+M: barley with melilotus; B+V: barley with vetch.

4. CONCLUSIONS

The identities of the main crops were important in order to determinate the interactions with the legated microbiota after cover crops. These interactions between cover crops and main crops were strong ($p<0.001$) for soil biological variables as the abundance of total bacteria, total archaea, total fungi, and glomeromycota o. Therefore, the soil microbiota legated by CC in interaction with maize was very different than with wheat. E.g., the behavior of barley+vetch as cover crop in the maize increased the abundance of bacteria, fungi and glomeromycota compare with the control without cover crop, whereas in wheat the behavior of this treatment was the opposite. Therefore, it is necessary to deepen the study of different cover crop and their interaction with main crops under different conditions to select the cover crop that promotes the most appropriate soil microbial conditions.

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8th World Congress on Conservation Agriculture

Effectiveness of Conservation Agriculture in meeting the environmental objectives of the European Common Agricultural Policy

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In recent years, the European Union's Common Agricultural Policy (CAP) has increasingly focused on the environmental challenges facing the agricultural sector, such as climate change, pollution, soil degradation, among others. Through the successive reforms, these challenges have been increasingly present both in Pillar I of the CAP, which focuses on the commitments that farmers must make to have access to income support, and in Pillar II, which specifically provides for voluntary measures aimed at achieving certain environmental objectives. The Rural Development Programmes (RDP) compiles the voluntary measures of each Member State of the European Union, which in the case of Spain have been transposed into regional legislation. Conservation Agriculture has been contemplated in the RDP of some regions in Spain, as is the case of Andalusia. Thus, agricultural practices such as No-till and Groundcovers have been contemplated in some agri-environmental schemes like "Sustainable management systems in rainfed annual crops" and "Sustainable management systems in olive groves" during the period 2014-2020.

This work has aimed to determine the results achieved in Andalusia as a result of the application of the practices promoted by these agri-environmental schemes. To this end, a sustainability assessment has been carried out in a network of 8 demonstration farms located in Andalusia. The study has a focus on wheat (*Triticum durum*) and olive groves (*Olea europaea*) and the management practices evaluated have been Conservation Agriculture (No-till in the case of wheat and Groundcovers in the case of olive groves) and conventional tillage in both wheat and olive groves. The sustainability assessment has been based on the INSPIA methodology. This methodology is based on the calculation of 31 basic indicators, providing a final composite index of sustainability, bringing together the environmental, economic and social areas. The greater the implementation of sustainable farming practices, the higher the value of the composite index.

The results have shown that the sustainability index, in the farms under Conservation Agriculture, was between 11% and 32% higher than in the farms under conventional farming. Moreover, the overall sustainability index in the farms under Conservation Agriculture increased on average by 17% after four seasons.

Keywords: *Sustainability indicators, Sustainable agriculture, No-till, Groundcovers, INSPIA*

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INTRODUCTION

One of the most serious environmental problems that threatens the sustainability of agricultural ecosystems in Andalusia (Spain) is the degradation of the soil, which is an essential natural resource for the crop development. Therefore, erosion is one of the most important parts of this problem, acquiring great relevance in Andalusia, with average erosion rates of 8.6 t ha^{-1} year^{-1}, above the Spanish average (4.6 t ha^{-1} year^{-1}) and the European average (3.4 t ha^{-1} year^{-1}) (Eurostat).

One of the consequences of soil erosion is the loss of organic matter, capital in all the soil processes and in its quality. In Spain, soils in 88% of provinces have an average organic matter percentage below 2% (Rodríguez Martín *et al*., 2009), what implies a risk of significant soil quality losses (Loveland and Webb, 2003). In Andalusia, most of the provinces have an average percentage of organic matter below 2%.

Another challenge that the agricultural sector faces is climate change and the need to mitigate it, as well as to contribute to the adaptation of crops to its effects. The Mediterranean region is one of the most vulnerable areas to climate change in Europe (EEA, 2017). In addition, climate change projections foresee that its effects in Andalusia will intensify in the future. Agriculture, not only is affected by climate change, but it is also an emitting activity of Greenhouse Gases (GHG). Andalusia, with 11% of total emissions, is the third emitting activity after the industrial sector and transport.

These environmental issues have been addressed in the agricultural sector through successive CAP reforms since 1992. Therefore, the CAP has tried to promote the implementation of agricultural systems that make a responsible use of natural resources for high quality food production, posing not only challenges, but also environmental and territorial measures. Taking into consideration this regulatory framework, measures such as conditionality have not only been maintained, but they have even been reinforced with new mandatory measures such as greening. Pillar II has also contributed to strengthening of environmental policies within the CAP framework through The Rural Development Programmes. Specifically, Andalusia has historically applied a series of measures related to soil conservation, especially in woody crops and more recently, in herbaceous crops. For example, Operations 10.1.4. Sustainable rainfed herbaceous cropping systems, 10.1.6. Sustainable woody cropping systems (permanent) and 10.1.7. Sustainable olive grove systems within Measure 10: Agro-environment and Climate, where promoted Conservation Agriculture practices are No-till in the first case, and Groundcovers in the second one.

The new post-2020 CAP, currently in the negotiation phase, will give more importance, if possible, to the promotion of agricultural practices that are beneficial for the climate and the environment, not only through Pillar II, but also through Pillar I through the development of the new approach that involves the inclusion of Eco-schemes, which are non-mandatory measures for the farmer, whose objectives are to give an effective response to many of the needs that have been identified as environmental issues and increase support to the income of those farms that provide the greatest benefits to society.

In order to demonstrate the effectiveness of the practices promoted by mentioned operations in achieving the objectives established by Measure 10 of the Andalusian Rural Development Program, for the purpose of justifying the suitability of their implementation and development, and continue promoting their future application in the post-2020 CAP, the present study analyzes the impact that Conservation Agriculture practices, included in operations 10.1.4 and 10.1.7, have on agricultural holdings, through the application of a set of indicators based on the INSPIA methodology (Triviño-Tarradas *et al*., 2019), which assesses environmental, economic and social sustainability of farms.

MATERIALS AND METHODS

Demonstration farms network

In order to study the effectiveness of Operations 10.1.4 and 10.1.7, a demonstration farms network has been established, which could potentially benefit from the mentioned operations. In the present case, the crops studied have been durum wheat (*Triticum durum*) in rainfed and olive groves (*Olea europaea*) both in rainfed and irrigated areas. In order to also carry out an analysis compared with those farms that do not apply Conservation Agriculture practices, the network has considered plots managed under conventional tillage (Fig. 1).

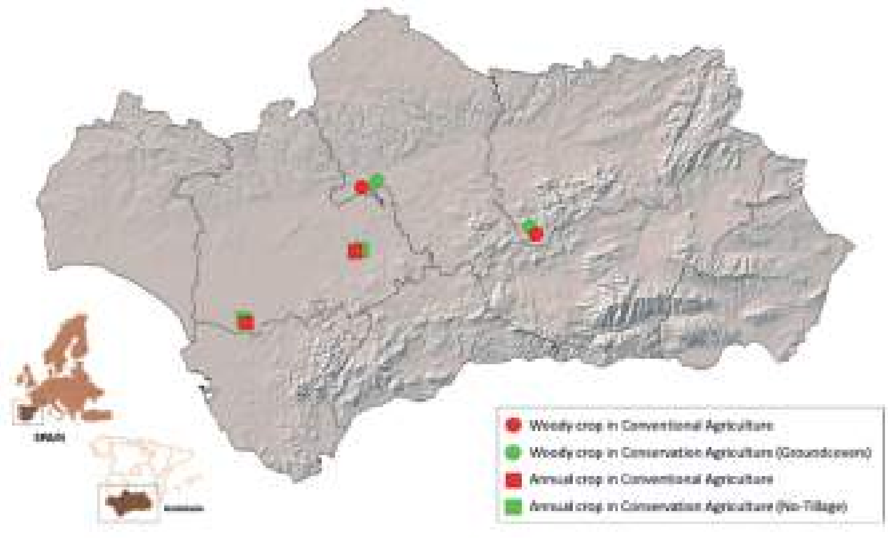

Fig 1. Locations of the farms included in the Study Network.

Table 1. Main characteristics of the demonstration farms

Demonstration farms	Management type	Crop	Characteristics of the plot	Location
Farm 1.1 cereal	No-till	Triticum durum	Area: 5 ha Years of implantation: 4 years.	Osuna (Sevilla)
Farm 1.2 cereal	Conventional Tillage	Triticum durum	Area: 10 ha.	Osuna (Sevilla)
Farm 2.1 cereal	No-till	Triticum durum	Area: 5 ha Years of implantation: 9 years.	Alcalá la Real (Jaén)
Farm 2.2 cereal	Conventional Tillage	Triticum durum	Area: 10 ha.	Alcalá la Real (Jaén)
Farm 3.1 olive grove	Groundcovers	Olea europaea	Area: 4,5 ha Years of implantation: 4 years.	Alcalá la Real (Jaén)
Farm 3.2 olive grove	Conventional Tillage	Olea europaea	Area: 1,5 ha.	Alcalá la Real (Jaén)
Farm 3.3 olive grove	Groundcovers	Olea europaea	Area: 14 ha Years of implantation: 10 years.	Fuente Palmera (Córdoba)
Farm 3. 4 olive grove	Conventional Tillage	Olea europaea	Area: 3 ha.	Palma del Río (Córdoba)

Indicators

In order to calculate the sustainability of the farms studied, the methodology collected by Triviño-Tarradas *et al*. (2019), which uses 31 indicators that cover the three study areas of a farm sustainability (Fig. 3). The values are calculated through direct samples in the field and information obtained by farmers directly from the calendar of operations. The value of each indicator is added to obtain a global sustainability value which is composed of an environmental sustainability value, a social sustainability value and an economic sustainability value (Fig. 2). In the section on improving biodiversity, a new indicator has been added, the Shannon Biodiversity Index (Shannon and Weaver, 1949). This index is probably the most frequently used in community ecology. It is obtained using the number of individuals of each morphospecies. The Shannon index value is equal to 0 when the sample contains only one morphospecies and equals 1 when there is a great abundance of morphospecies and they are represented by the same number of individuals. Data collection was carried out in the 2014/2015 season and in the 2018/2019 season.

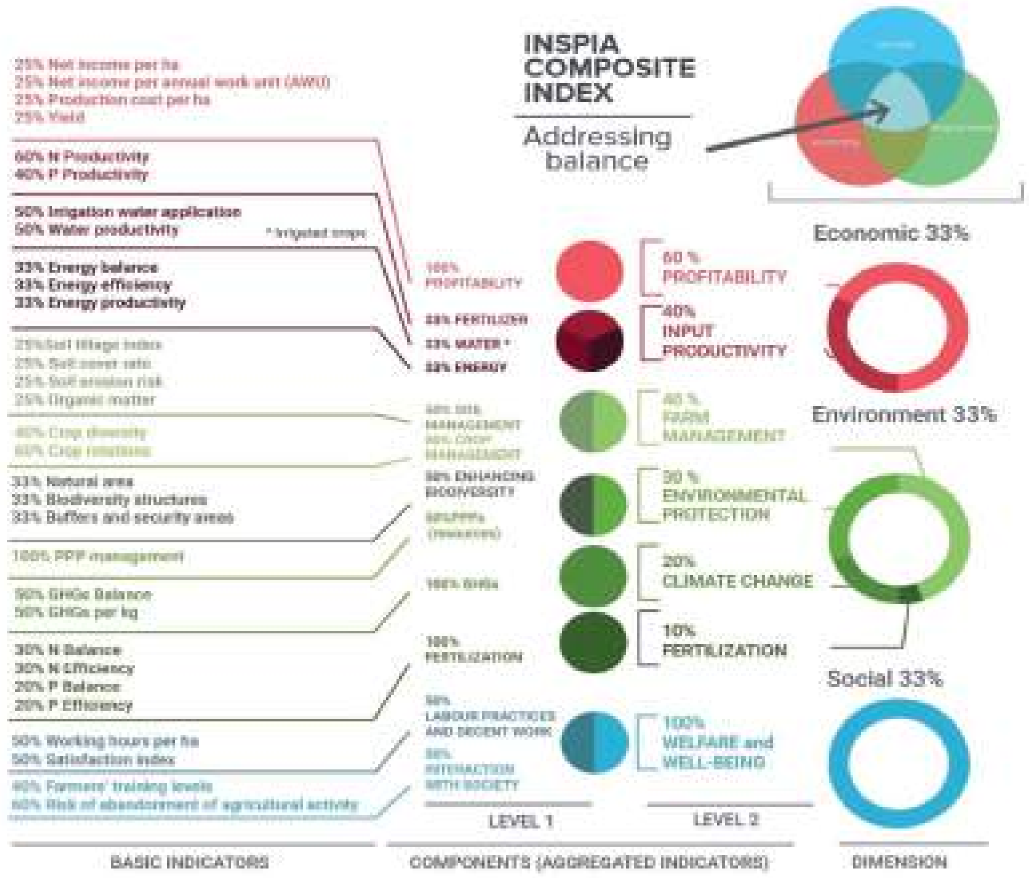

Fig 2. Indicators used in the evaluation of the sustainability of the demonstration farms. Source: Triviño-Tarradas et al 2019.

RESULTS

Conservation Agriculture vs Conventional Tillage

In all the analyzed farms, Conservation Agriculture practices have obtained higher global sustainability index values than Conventional Tillage practices. Thus, the cereal plots in No-till obtained sustainability index values of 62 and 71 out of a total of 100 in Farms 1.1 and 2.1 respectively, compared to the plots in conventional tillage of farms 1.2 and 2.2, which obtained values of 54 and 56 respectively. Regarding the olive grove plots, those with Groundcovers obtained sustainability index values of 71 and 68 in Farms 3.1 and 4.1 respectively, compared to the conventional tillage plots of Farms 3.2 and 4.2, which obtained values of 56 and 52 respectively.

Regarding the three studied sustainability areas, the one that most influenced the increase of the global sustainability value of the plots under Conservation Agriculture was environment, mainly due to soil improvements and the reduction of Greenhouse Gas emissions. It should be noted that in the economic sphere, in no case was the value of the associated indicator higher in the plots under conventional tillage, but rather the opposite, showing the highest values in the farms 2.1 of cereal and 1.1 of olive grove, both under Conservation Agriculture, the result of reducing variable costs and improving performance (Fig. 3).

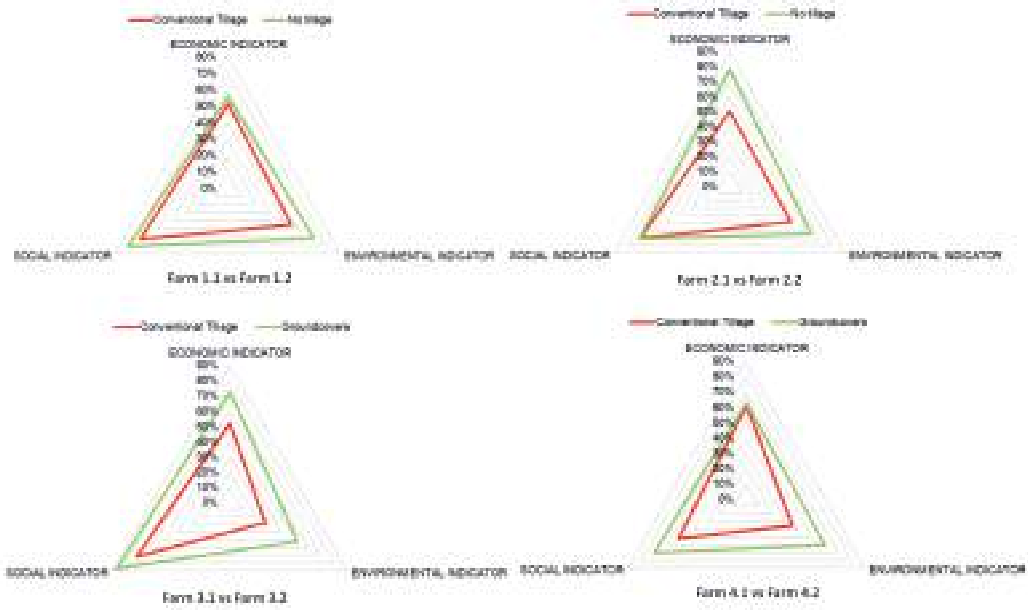

Fig. 3. Values of the added indicators by sustainability areas in the studied farms.

Temporal evolution of the indicators in the Conservation Agriculture plots

In all cases, a favorable evolution of the global sustainability indicator can be observed in the plots under Conservation Agriculture (Fig. 4). In the three out of the four studied cases, the continued practice of this management system has served to overcome the threshold through which the used methodology establishes the value from which the farm can be considered globally sustainable, because favorable values have been obtained in the three study areas. The increases of 10.7%, 24.6%, 17.5% and 13.3% for farms 1.1, 2.1, 3.1 and 4.1 respectively. With regard to cereal farms, the increases have been influenced by the progressive improvement of the environmental indicators, what shows that the benefits of No-till become more evident over time. The economic indicators have also improved over time, as yields and, above all, efficiency in the use of fertilizers have increased, what can show how the improvement of soil quality allows optimization of fertilization strategies, without decreasing productions. With regard to the olive grove plots, and as in the cereal plots, the environmental indicators have been those that have contributed to the general sustainability of the farms. In this case, the economic indicators have not been so decisive, taking into account the real behaviour of the olive tree and the low prices in the 2018/2019 season.

Fig. 3. Temporal evolution of the global sustainability indicator in the plots under Conservation Agriculture (the green line marks the threshold from which the farm is considered sustainable).

CONCLUSIONS

The achieved results have demonstrated the effectiveness of the practices included in operations 10.1.4 and 10.1.7, to meet the objectives for which the mentioned measures were designed.

Thus, it has been demonstrated that Conservation Agriculture, for agricultural ecosystems, is a more sustainable management system from all perspectives (environmental, economic and social) than conventional management based on tillage. It should be noted that soil indicators in Conservation Agriculture are a lot higher than those obtained in tilled plots. In the economic section, it stands out the fact that, in general, the plots in Conservation Agriculture have a higher profitability as a result of the lower agricultural operations costs, since there is no tillage. This fact also encourages energy indicators to be more favorable in Conservation Agriculture.

The carried out analysis has shown that the continued practice of Conservation Agriculture has improved the plots sustainability, after several seasons. Based on this, it can be stated that the implementation and development of this practice through multi-year programs can be a very effective measure in order to achieve objectives of the strategies proposed in Andalusian agriculture.

On the other hand, the evaluation methodology based on the use of indicators is shown as a useful, universal and practical tool not only to approach the monitoring of the operations contemplated in Measure 10, but also to make a diagnosis of the Andalusian agricultural sector sustainability, thanks to the universal nature of the used indicators.

In addition, and thanks to the methodology used in the sustainability audits carried out in the farms network established by the contract, based on the calculation of indicators designed with a solid technical and scientific basis, it has been possible to design measures which would protect the environment based on technical and scientific criteria.

AKNOWLEDGEMENTS

This paper has been possible thanks to the contract "Elaboración de un estudio relativo a la evaluación de los beneficios relativos a ciertas medidas Agroambientales" (CONTR 2019 553082) between the Secretaría General de Agricultura, Ganadería y Alimentación de la Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible (Regional Government of Andalusia) and the Asociación Española Agricultura de Conservación Suelos Vivos.

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SUBTHEME 4

PROMOTING CA-BASED KNOWLEDGE AND INNOVATION SYSTEMS AND INFORMATION SHARING AND COMMUNICATION

8th World Congress on Conservation Agriculture

The future of farming
Profitable and Sustainable Farming
with Conservation Agriculture

8WCCA
8th World Congress on
Conservation
Agriculture

Promoting CA-based knowledge and innovation systems and information sharing and communication

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Undoubtedly, the world is undergoing dramatic transition due to the confluence of 5 fundamental disruptive forces: climate change, demographics, communication/digitalization, data/technology, and rurality/urbanization. These forces are amplifying each other, intensifying land challenges in magnitude, scale, and influence, breaking the environmental and socio-economic trends. In addition, limited global land and biomass resources accompanied by growing demands for food, feed, fibers and fuels requires reshaping and transforming the agriculture and food sector. In fact, the shift to new paradigms and from these challenges has been maturing in science and society for years. Among pertinent transforming options, Conservation Agriculture (CA) was found to alleviate impacts of these forces. Worldwide CA is adopted in more than 180 million hectares in all continents and in most edaphic and social situations. In other terms, countries and their farming communities and institution should leverage on successful results to scale-up implementation towards sustainable food systems. However, still each of the CA principles poses different constraints and opportunities to farmers. Hence, for further expansion dynamics and producing monumental change in CA dissemination, it is necessary to improve comprehension, use and appropriation of CA principles and to ease knowledge and innovation access, acquisition, and development (Findlater et al., 2019). CA transition may be facilitated by several information sharing and research-based knowledge communication channels and initiatives (co-learning platforms, farmer networks) with support from private sector, civil society groups and other financial structures and incentive measures (e.g., price premiums, access to credit, regulation). Given the extensive heterogeneity of farms and societies around the world, stakeholders should use imaginative advancements to accomplish a genuinely necessary edge from CA systems.

Keywords: *Conservation Agriculture, Innovation and Knowledge Sharing Framework, Agricultural Information and Innovation System, Communication Pathways*

Abstract

Undoubtedly, the world is undergoing dramatic transition due to the confluence of 5 fundamental disruptive forces: climate change, demographics, communication/digitalization, data/technology, and rurality/urbanization. These forces are amplifying each other, intensifying land challenges in magnitude, scale, and influence, breaking the environmental and socio-economic trends. In addition, limited global land and biomass resources accompanied by growing demands for food, feed, fibers and fuels requires reshaping and transforming the agriculture and food sector. In fact, the shift to new paradigms and from these challenges has been maturing in science and society for years. Among pertinent transforming options, Conservation Agriculture (CA) was found to alleviate impacts of these forces. Worldwide CA is adopted in more than 180 million hectares in all continents and in most edaphic and social situations. In other terms, countries and their farming communities and institution should leverage on successful results to scale-up implementation towards sustainable food systems. However, still each of the CA principles poses different constraints and opportunities to farmers. Hence, for further expansion dynamics and producing monumental change in CA dissemination, it is necessary to improve comprehension, use and appropriation of CA principles and to ease knowledge and innovation access, acquisition, and development (Findlater et al., 2019). CA transition may be facilitated by several information sharing and research-based knowledge communication channels and initiatives (co-learning platforms, farmer networks) with support from private sector, civil society groups and other financial structures and incentive measures (e.g., price premiums, access to credit, regulation). Given the extensive heterogeneity of farms and societies around the world, stakeholders should use imaginative advancements to accomplish a genuinely necessary edge from CA systems.

1. Introduction

Climate risks such as climate suitability and variability through increasing temperatures, reduced precipitation, weather extremes, and the occurrence of abrupt climate shocks such as droughts and flash floods pose unprecedented risks to agricultural food production. Agricultural and food systems are further impacted by excessive land degradation, economic and political uncertainties, population growth, poverty and changes in food demands, consumption behaviours and diets. According to O'Neil et al. (2018) meeting sustainability goals is achievable but highly challenging with respect to sustainable natural resources use and preserving planetary processes. From a study by Seneviratne et al. (2018), policies to achieve the Paris Agreement goal will not necessarily remove the climate extreme risks and their impacts on ecosystems including agriculture. Though, these challenges need to be addressed and require different approaches than those currently applied. The last IPCC reports have stressed the need of immediate action to address such climate risks and associated food system and environmental degradation (IPCC, 2018, 2019). In response to the harms of these challenges, there has been a growing movement to shift towards climate smart agriculture (CSA) and especially Conservation Agriculture (CA). CA systems are proposed as promising regenerative framework for simultaneously mitigating and managing climate risks and transforming food production systems to be healthier and more sustainable (Kassam and Kassam, 2021). Niang et al. (2014) affirms with "high confidence" that CA has the potential to simultaneously increase food production and reduce climate change risks. In fact, with other related approach as agroecology and sustainable intensification, CA is being discussed at various levels. So far, a host of countries have contributed to world landmark 180 million hectares (Mha) of CA

(12 % of global arable lands) possibly reaching 533-1,130 Mha (38%–81% of global arable land) (Prestele et al., 2018).

CA is shown to enhance sustainability in its three dimensions without transgressing planetary boundaries. In other terms, CA improves the resilience, sustainability, inclusivity, and quality of food systems at global, regional, and national levels. However, CA is not a simple switch and there is a need to incentivize the transition for farmers. According to several authors, there is mounting evidence that CA is often inconsistently applied, which leads to lower yields and higher costs than expected (Brown et al., 2017; Yigezu et al., 2021).
For ensuring increased CA uptake, institutional innovation is required as well as actions promoting behavioral and attitudinal change by both farmers and the public. CA is known as intensive knowledge and science-based systems and hence ensuring universal access requires creative robust smart and upskilling channels. Some leader and emergent countries and national and international organizations are already making great strides to thrive in these resourceful areas, and such thrives and potential drawbacks should be analyzed and enlightened. Successful CA adoption necessitates to reduce or to bridge the connection gaps between science and farming actors through joint and transparent sharing and communication pathways mainly in situations of small holder and family farming.

2. Conservation Agriculture and Agricultural Transformation: unlocking benefits

The emergence of CA started in the1930s following the major environmental crisis (dust bowl) and since then knowledge and research findings are accumulating. The core principles of Conservation Agriculture include full residue retention, minimum soil disturbance, and diverse rotations (FAO, 2001). Therefore, CA cannot be a single technology but as a system or a package of technologies that functions best when the three principles are adequately and simultaneously applied and used (Jat et al., 2014). Consequently, CA is referred as a transformational change for a more environment-compliant and climate resilient agriculture. CA as a concept has gained notable traction over the last decades and has illuminated both strengths and weaknesses of food systems and sparked promising policy and technology innovations (Kassam et al., 2020). But still business and policy leaders should fully understand which technologies will matter to them and prepare accordingly and support farmers to look beyond long-established conventional production models.

CA was initially and primarily developed in response to excessive spread of land degradation mainly due to wind and water erosion. It was then extended for higher and stable crop production, enhanced resource use efficiency and increased farm's performances (Jat et al., 2014).

CA implementation strategies have shown considerable enhancement of crop production, improvement in soil functions and consequently better climate resilience and higher overall sustainability (Kassam, 2020a,b). CA systems enhance the amount of soil organic carbon and regenerate and build new soil providing numerous environmental and biodiversity benefits, such as drawing down carbon from the atmosphere, water retention, biodiversity conservation and enrichment and aquifer recharge—all of which lessen the impacts of floods, drought, and soil erosion. However, most of these benefits are left unaccounted for in farmers' trade-off considerations. It is urgently needed to lessen downstream effects and unlock benefits of CA at different scales and farm levels while instituting a shared understanding of concepts, practices, and perspectives for constructive interactions among stakeholders and agents of change. CA adoption studies and projects should be further motivated by a genuine desire to regenerate sustainable and healthy food production systems to face accumulated land challenges. Mechanisms to achieve such aspiration are context specific and dynamic, with no universally prescribed approach.

3. Communication and skill building for successful application of CA practices and systems

According to Corbeels et al. (2011), CA adoption requires a system thinking. It is conditioned by CA performances, subject to opportunities and trade-offs and constrained by different aspects of the context in which the farming operates including markets, institutional, socio-economic and policy conditions. The farming context is influenced by the environmental conditions and the level of the innovation and knowledge system including R&D consortium. Hence, for out scaling CA, in addition to improving livelihood goals (i.e., productivity and economic performance of the farming system), it is necessary to reduce risks, change the livelihood assets and strengthen policies and institutional processes. Henceforth, a system change should be employed when out scaling and upscaling CA. It is then required for research and extension institution to shift from technology transfer approach that is based on simple/single technologies or techniques to innovation system approach that is based upon system change.

For successful adoption of CA systems, strong capacity in problem solving from farmers and service providers is crucial. This related directly to level of education, knowledge, abilities and competences of farmers and other agents of change. To surmount such difficulties or gaps, it is imperative to mobilize co-innovation and information and capacity building through participatory learning for pull driving application of CA practices and their widespread.
CA systems were reported to alter the business and social landscapes and their benefits are robust evidence of agricultural transformation and transition to regenerative and sustainable food systems. However, CA adoption is still lacking behind due to various interacting barriers among which controversial attitudes and perception of CA and wide information and communication gaps. CA systems requires a high degree of social dynamics and bring a high level of innovation, knowledge, and skills to farmers but also to all value chain associates. Farmers and all stakeholders should decide if the shift or the change is worth the investment and the risk. Information and knowledge are very vital in Conservation Agriculture development and where they are poorly disseminated because of certain constraints, the adoption becomes highly impeded. Hence, for higher adoption, there a strong need to build-up skill and knowledge sharing, information brokerage, increase communication efficiency and improve decision-making abilities.

Widespread CA adoption entail large-scale changes in the traditional mixed farming-livestock systems. Many uncertainties shroud how to suit CA principles (mainly crop residue cover) to animal production. CA adoption should be designed to consider the values, knowledge and interests of all actors involved and the fair distribution of risks and benefits. Related information sharing should take in consideration the collective understanding of the ecological and economic underpinnings of the integration of CA and livestock.

Human and social factors are critical for the successful adoption and diffusion of CA practices and mainly when information and communication technologies and systems are used. Handling new knowledge and sophisticated technologies may be tedious and effort intensive for farmers with limited education and resources. It is then obligatory to transform CA knowledge, research results and science-based benefits to skills, curricula, awareness, and positive changes aligned with the anticipated needs of users.

Governmental support is of vital importance for CA knowledge improvement and communication implementation and its market penetration. It is necessary to implement long-term CA capacity development initiatives through high-standard educational platforms (Mrabet et al., 2021). In the New Digital Age, CA systems should be aligned with advanced technologies in artificial intelligence, digitalisation, high-tech communication and knowledge management tools, dynamic modelling, and precision agriculture for a deeper understanding of impacts to speed up uptake and improve science-based decisions by all users and practitioners and increase the scale of adoption across value chains.

4. Framework of CA knowledge and information sharing and communication

The linear knowledge transfer is outdated and mainly when dealing CA systems (Hermans et al., 2013). Considering the diverse range of stakeholders and associated socio-cultural and economic contexts, intensifying CA adoption warrant whole information exchange and communication system redesign and build-up. A systemic, dynamic, and holistic framework is necessary to capture, synthesize, analyse and make available relevant information to the users. It is a joint venture to promote mutual learning in order to either need, produce or exchange knowledge. Hence, with time the country's agricultural knowledge and innovation system (AKIS) should mature with more interaction among stakeholders and cross-fertilisation will further fuel innovation and impact. AKIS should be enforced and its capacities, infrastructure, institutions and funding mechanisms developed and upgraded in order to synergize and illuminate the communication and information initiatives and efforts to increase CA adoption and its impacts.

Leaders in both government, non-government organisations and business must not only know what is on the horizon but also start preparing for its impact. Most experiences reported that appropriate enabling conditions are critical to the achievement of wide uptake and impacts of CA.

The transition from conventional to CA systems requires an understanding of important determinants of social-ecological nexus to pursue changes over long periods. Plurality of farms and hence diversity of preferences and views from farmers on CA are important determinants to consider. In other words, an agricultural research consortium cannot provide the answers to all the societal concerns. Hence, it is of paramount importance to create strategic partnerships and platforms for shared learning and knowledge co-production and communication (Mrabet et al., 2021). Such platforms will help creating and strengthening connections and supporting knowledge flows for farmers and value chain actors in order to innovate, effectively solve problems and react to new opportunities for development.

The information system should consider co-creation and co-learning in exchanging and sharing knowledge related to CA systems. Such system will help to bridge the gap between science and practice and take full consideration of moving and changing social and political contexts and needs.

5. Channels & Innitiatives for fostering CA knowledge and innovation sharing and communication:

CA systems require supportive and enabling policies, institutional arrangements and inclusive governance to allow them to evolve in response to new challenges, drivers, and stressors. Formal and informal sharing frameworks and channels play a prime role in the dissemination and adoption of CA technologies.

For successful CA adoption supported by inclusive knowledge and innovation sharing system, it is critical to set engagement of farmers as equal partners in all activities. A growing body of literature has demonstrated the potential of participatory farmer to farmer (F2F) training to improve the uptake and maintenance of SLM technologies including CA (Kansanga et al., 2021). It is a cost-effective way to reach a wide range of smallholder farmers to promote the use of sustainable land management practices. It was also shown that farmer exposure to field-based learning alliances led to enhanced social interactions and increased opportunities for technological uptake and dissemination.

Systemic CA adoption and diffusion should involve all stakeholders – farmers, land managers, researchers, NGOs, businesses, decision-makers, communication media and consumers. Hence, transition to CA systems requires changes to technologies, policies, business, and lifestyles. It involves also an integrated and forward-looking analysis to identify key factors and barriers to CA uptake.

Communicative learning occurs and its efficiency improves when CA stakeholders exchange experiences and views and share opportunities and insights (Mashavave et al., 2013). In other terms, it is important to ameliorate information flow and connection strength to bridge the knowledge gaps and stimulate and ease CA adoption. Information processing and communication technologies play a critical role in this transformation process.

Transition to CA is a knowledge-intensive process (Caron et al., 2014). Hence, to be able to continue adoption and up/out scale of CA system, the science-policy gap should be filled, and even narrowed, and new arrangements and approaches should be investigated while strengthening the science-policy interface. Lifelong learning should be encouraged and supported among stakeholders and all value chain actors in order to face emerging issues, provide pathways for problem solving and deliver innovative and feasible solutions.

Publications, videos, blogs, and social media campaigns on CA systems and related benefits, impacts, trade-offs and success have been created by research centres, extension agencies, higher education, NGOs and international organisation, helping stakeholders from the world to make decisions based on science-based information. Applying emerging information and communication technologies (ICTs) in disseminating Conservation Agriculture information to farmers and farm communities should improve adoption and consequently contribute to ameliorate productivity and economic, social and environmental sustainability.

Farmers may need to solve their own problems and address specific or local challenges. Hence, farmer to farmer exchange and farmer centered knowledge sharing system should be encouraged and sustained. In this type of program, day-to-day, face-to-face, field labs and on-field demonstration activities are used to convince farmers on the CA benefits and ensure their motivation and support. Up-to-date information motivates farmers to expand their knowledge and get involved in the CA adoption process.

Various channels ranging from social media to networks were created for and by farmers to share and inform on CA systems. Such initiatives and many others were developed and implemented to increase awareness and communication of CA systems with varying degrees of success and feasibility, among which are:

- Farmer-driven knowledge networks including peer-to-peer learning and informal knowledge exchange amongst farmers;
- Farmer innovations and on-farm participatory research including field and living labs;
- Benchmarking and farmer-based learning alliances including learning center-based meetings, exchange visits, farmer field days;
- Genuine farmer initiatives including farmer working groups, farmer-to-farmer networks;
- Development of CA information services for farmers and their communities as well as agri-business managers;
- Invest in independent advisory services which encourage trust;
- Extension-facilitated meetings and interactive platforms;
- Regional study tours for cross-border knowledge and information sharing and capturing experiences and success case studies with support from media;
- Local to international agricultural shows and fairs;
- Communication through social media (for and by farmers);
- Knowledge and web-based interactive platforms;
- Improvement of information quality using farming media;
- Curricula development, on-line learning, and training resources.

For best and reliable flow of information and pertinent and effective knowledge sharing, integrated or combined use of these channels and options is mandatory. Relying on web-based communication tools will never replace contact exchange in the field and at the farm.

In other side for even greater efficacy, it is vital to take in account the impact of social influence on innovation and adoption of CA. Recurring interactions strengthen social coherence and trust within the group and among stakeholders. In addition, inclusion, and involvement of custodians of local laws and customs in the communication and sharing channels of CA is necessary to facilitate the adoption of CA (Nyathi et al., 2020). Such channels and social networking nurture stronger comprehension of key CA issues, advanced collaboration for better solutions, as well as publicize a market-oriented culture among farmers.

To shift away from top-down platforms, Innovation platforms (Pound and Posthumus, 2013) were used in several projects in order to out-scale CA systems while addressing obstacles and opportunities of the whole value chains and bringing together all stakeholders for advocacy, learning and exchange. They are challenge-driven platform to generate, refine, foster knowledge, and deliver results from CA implementation and dissemination.

The type of information sought by farmers to enhance resilience using CA are/can be diverse. Globally, market and crop advisory information are two of the main types sought. Improving farmer decision-making using mobile technology, climate information, early warning systems and monitoring information to forewarn farmers can further encourage the adoption and promotion of CA systems. To avoid inadequate collection of data and to ease access to information, appropriate platforms and mechanisms are needed to share, monitor and evaluate data, results, and experiences with involvement of a wider CA audience.

In order to make information and advisory accessible to farmers as well to other stakeholders including extension agents, trainers, students, business managers and even policy and opinion decision makers, additional initiatives are needed to enhance and develop capacities, competences and skills. Closing gender gap and empowering youth are critical reforms for CA uptake and information and innovation sharing. Another important issue in mainstreaming CA systems, governments are in the obligation for strengthening institutional systems of agricultural science and education. It is imperative to empower the linkages between research, education, and advisory services in order to develop CA innovation, knowledge and communication. Different networks and partnerships play a key role in cooperation for CA knowledge development and diffusion. In fact, many national, regional and international projects help countries share and create new knowledge and realize the potential for the development of CA systems.

- Creation and enforcement of CA centers of excellence, technology consortiums or competence centers;
- R&D and co-Innovation platforms (IP)
- Recognizing, administering and developing indigenous knowledge and coping strategies to support farmers and community uptake of CA systems;
- Implementing gender-aware based extension and capacity development initiatives as well reduction of gender-bias access to capital, markets and knowledge;
- Development of inclusive and innovative value chains that prioritize and mainstream CA products and technologies and promotion and facilitation of integrated linkages between input suppliers, producers and players;
- International and regional congresses and workshops for cross-border information sharing;
- Education and retraining programs focused on CA systems at universities and schools;
- Enforcing community and local voices to tailoring CA communication program needs and sustaining interest;
- Multi-channel information service Model including integrated use of ICTs (internet/mobile, on-line/web community, video/audio etc.);
- CA communities of practice for enhancing dialog and concerting actions with support from CA elites and champions;
- CA information and data gathering and communicating platforms with state of the art of reporting, monitoring and evaluation mechanisms;
- Building strong and durable coalitions and cooperation of multiple actors for increased CA outreach and funding.

Multidisciplinary teams of actors, including scientists, extension specialists, social scientists, information and communication specialists, and others, will be essential to move all these initiatives forward and for maximizing the effectiveness and efficiency. It is of prime important that such efforts use easily-understandable language, focus on real issues and concerns that farmers face and deliver concrete solutions for CA uptake.

6. Conclusion: implementing ca communication for transforming farm's life, business and economy

Conservation Agriculture is an appealing concept that integrates the promise of agricultural growth and economic prosperity with that of ecological stability. For inclusive and durable dissemination of CA systems, it is of priority to move from CA as projects to CA as innovation systems and processes. In other terms, it is required to shift from research driven project to a multi-actor learning and systemic approach where farmers are key innovator and endorsed by comprehensive M&E systems. By using such approach, it is possible to increase both the legitimacy and the recognition of CA and to achieve socially and societally desired outcomes from adoption process.

To cross the spectrum of potential drivers and impacts, information and knowledge management and sharing systems have multiple subsystems which include information gathering and management, learning and skill development and build-up, communication and sharing and inclusive decision-making process. However, despite the advances that have been made in communicating for CA adoption, there are still many areas that need additional investigation. CA adoption means changes in obligations and behaviour for a range of stakeholders (farmers and service providers), requiring innovation in the components of the food system in terms of 'software' (knowledge, information, skills and services), 'hardware' (equipment and material) and 'orgware' (institutions, linkages, logistics and policies). Hence, to provide value-added information and reliable services, multiple CA communication and information sharing initiatives and channels are used and under development.

Information sharing and innovation systems for CA adoption intensification require dynamic enabling environment, targeted research, social system development, legal frameworks, investment, and coordinated national policy guided by international agreement and financially supported.

CA adoption and upscaling are both knowledge and resource intensive, It is therefore critical that business and policy leaders further assist in CA communication and knowledge sharing to prepare for impacts and mitigate trade-offs. A proactive approach that combines promising technological, institutional and policy solutions aligned with robust and efficient communication and knowledge management and sharing schemes is the way forward to accelerating CA adoption and spread. In order to get sound impacts, It is an obligation to strengthen and develop the capacities of the country's agricultural knowledge and information system.

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The future of farming

Profitable and Sustainable Farming with Conservation Agriculture

8WCCA

8th World Congress on Conservation Agriculture

Next steps for Conservation Agriculture

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The greatest problems for expanding the adoption of CA principles worldwide are (i) lack of consistent policies or private programmes for payment of environmental services (PES), (ii) access to certification schemes that would qualify for PSE as in (i) above, (iii) lack of information on long term benefits, especially for cover crops, (iv) competition from new denominations that claim sustainability, but do not have a scientifically defined code of practice or independent verification. On PES, there is a forgotten enunciation in the Declaration of Madrid (First World Congress on Conservation Agriculture, Madrid, 2001 - FAO/ECAF), absolutely crucial to this debate: "….the conservation of natural resources is the co-responsibility, past, present and future, of all sectors of society, in the proportion that they consume products resulting from the exploitation of these resources", and concluded: "It follows that the environmental services provided by farmers practising Conservation Agriculture should be recognized and recompensed by society". This important section of the 1st. WCCA declaration was not emphasized in the subsequent promulgation of CA. Thus, there is an urgent need to link CA with PES. Today's CA concepts from the FAO website deal only with the agronomic definition of CA omit the social co-responsibility for conservation and need to be tightened and made uniform. In many countries, independent evaluation in certification is necessary to qualify for PES. The conundrum with certification is its rigidity and, consequently, it is difficult, and often initially costly, for farmers. Here, a stepwise approach to certification could resolve this, giving time for adjustments and dilution of investments over time. As an example, the Round Table on Responsible Soy (RTRS) has a widely respected, comprehensive, certification scheme, recognized by the European Commission, that includes zero de-forestation, best practices including CA, social and legal commitments. The drawback is that it is only for soya (and shortly maize). Extending this to a whole farm exercise, covering all farm products, would be much faster than to start from scratch. On competition from new denominations that, *de facto,* practice CA but with no scientific code of practice or independent verification, these would not normally qualify for PES. To encompass such new denominations, it would be necessary to obtain evidence that these are based on CA principles and additional social indicators, as required. This could qualify them for PES under such certification. On the technology side, the rapid growth of biological control for pests and diseases and mechanical, laser, or robotic weeders is attracting organic farmers to CA, since soil cultivation is not sustainable in terms of carbon balance. There is thus a need for a CA organic certification, or promulgation of a recommended code of practice for this mode. Overall, CA is contributing greatly to reducing global warming and responding to world population demand for ever more food. It is up to the technical sector to develop a simple and efficient whole farm certification tool that facilitates PES and consolidates CA. There is a trade-off between the risk of fraud and facility, or cost, of execution. This needs to be equated.

***Keywords**: CA principles, payment of environmental services, agricultural sustainability, biological control, organic agriculture, Round Table of Responsible Soy*

1. Introduction

The Conservation Agriculture movement was launched in the First World Congress on Conservation Agriculture (1WCCA) in Madrid, in 2001 (Vanelph and Benites, 2001). The three fundamental pillars of Conservation Agriculture (CA) had already been sacramented in USA (Phillips & Young, 1973) and Brazil (IAPAR, 1984). These were unified under a single definition, to implement the final plenary decision of WCCA1, embodied in the Declaration of Madrid (Vanelph and Benites, 2001). From then onwards, the European Conservation Agriculture Federation (ECAF) and the Food and Agriculture Organization of the United Nations (FAO), organizers of the WCCA1, took the lead and FAO launched a well-funded worldwide promotion campaign, so successful that the current adoption in the world is estimated at 180 million hectares (Kassam et al., 2015). Brazil and USA representing about 37% of this total. By land use intensification, Zero Tillage Conservation Agriculture (ZT/CA) is also responding to world population demand for ever more food.

The two fundamental recommendations of the Declaration of Madrid that have not been implemented to any impactful degree were:

> (i) "...the conservation of natural resources is the co-responsibility, past, present and future, of all sectors of society, in the proportion that they consume products resulting from the exploitation of these resources.
>
> (ii) "...it follows that the environmental services provided by farmers practising CA should be recognized and recompensed by society".

2. Discussion

The greatest problems for expanding the uptake of CA worldwide are: i. lack of consistent policies or private programmes for payment of environmental services (PES) to farmers; ii. access to certification schemes which would qualify for (i) above; iii. lack of information on long term benefits for cover crops; and, iv. competition from new denominations that claim sustainability, but do not have a scientifically defined code of practice or independent verification. The need for CA to embrace all sustainable and compatible technologies is emphasized in Landers et al. (2021b).

The above important dicta of the WCCA1 declaration were not emphasized in the subsequent promulgation of CA. Thus, there is an urgent need to link CA with payment of environmental services (PES). Concomitantly, a revision of ZT/CA principles is in order.

In the first place, a minimum of three crops for biodiversity is ambiguous, as the Brazilian crop succession soya/maize/grass cover crop repeated every year would qualify, whereas the adoption of the concept of a "pluri-annual rotation" where the same crop is not repeated in the same or succeeding year would be much more appropriate in terms of biodiversity. Secondly, "minimum soil disturbance" leads to the possible mis-interpretation that strip-till (ST), minimum tillage (MT) and even ridge till (RT) are CA, but, as shown by Reicosky (1997), soil cultivation has a negative carbon balance and it is axiomatic that cultivating a part of the land will proportionately affect the carbon balance of these and other partial cultivation systems, resulting in a carbon balance that is minimal or negative.

The use of tines for fertiliser and seed placement on some drills and planters makes it difficult to use the term "no soil inversion" to exclude these technologies, but soil disturbance limited to the planting line omits the effect of the fertilizer shank or disc about 10 cm from the line of planting, which will also disturb residue. Eccentric double discs or the inverted T-slot planter (Baker, 2007) are ideal as they disturb soil much less than tines, but it is alleged that discs are impractical on land with stones or with shallow compaction, as in pasture conversion. Thus, on a pragmatic basis, a better solution should be found for the actual FAO website wording on minimum soil disturbance. The minimum cover of 30% after drilling may be valid for narrow-spaced grain crops which would rapidly shade the inter-row, where implicitly, 70% of the soil could be without cover. But it is irrelevant for wider-spaced row crops (>50cm), where 70% cover after planting should be feasible (the minimum for adequate erosion control). Thus, soil cover after planting should have these two categories in order to avoid adopting the lowest common denominator that would leave the soil more susceptible to erosion.

Certification and tracking of the origin and socio-environmental responsibility of agricultural products is well established. In most certified labels, to qualify for bonuses (effectively PES), independent evaluation is practiced and necessary. The conundrum with certification is its rigidity; consequently, it is difficult, and often initially costly, for farmers. Here, a stepwise approach to certification could resolve this, giving time for adjustments and dilution of investments over time. As an example, the Round Table on Responsible Soy Association (RTRS, 2020) has a widely respected, comprehensive, certification scheme that includes zero de-forestation and zero conversion of natural habitats, best agronomic practices that recognise CA, plus social and legal commitments. RTRS certification has been approved for biofuels by the European Commission. The drawback is that it is only for soya and, in the future, possibly maize. Extending this to a whole farm exercise, covering all farm products as a qualification for PES, would be much faster and cheaper than to start from scratch. In addition, the RTRS already has a functional international sales platform operating for over ten years, negotiating 4.7 million tons of soya a in 2020.

On competition from new denominations that, de facto, practice CA but rarely recognise the CA principles, which they practice. These would not normally qualify for PES via certification, for lack of a code of practice. To encompass such new denominations, it would be necessary for them to provide evidence that they are based on CA principles and additional social indicators, as required. This could qualify them for PES under such certification recognised by governments or other organisations remunerating PES (Prado et al., 2016).

On the technology side, the rapid growth of biological controls for pests and diseases and mechanical, electric, laser or robotic weeding is attracting organic farmers to CA, since soil cultivation for weed control is not sustainable in terms of carbon balance (Reicosky, 1997). There is thus a need for a CA organic certification, or promulgation of a recommended code of practice for this mode as done for organic farming on the FAO website. Overall, CA is contributing greatly to reducing global warming via several mechanisms: i. Carbon sequestration in soils (Lal, 2004); ii. Reduced fuel consumption (Akbarnia and Farhani, 2014); iii. Land use intensification (higher yields mitigating the demand for de-forestation (Landers et al., 2020); and, iv. Increased albedo of surface residue, reflecting more of the sun's rays back to space, thus reducing the amount of sun's energy absorbed by the earth's surface) (Davin et al. 2014).

As agricultural science evolves, so must our philosophy: to conduct the symphony of soil biology we must no longer "think like a root" (F.Shaxson, personal communication, 1985), we must now think like a rhizosphere. Walker et al. (2003) describe the varied functions of root exudates that activate rhizosphere organisms according to the plant's needs. Francis Shaxson (personal communication, 2021) alerts to a negative correlation between compaction and water availability to roots, due to the increase of surface tension in smaller soil pores. We also need to emphasize more the aboveground fundamentals of pluri-annual crop rotations for biodiversity, crop scouting and spot applications with drones, GPS to reduce soil compaction; overlapping or the opposite in applying inputs, especially with controlled traffic farming; and rotation of phytosanitary products to avoid resistance in target organisms. Precision farming is a combination of several information technologies (ITs), like yield mapping and variable rate fertilization, or modern soil sampling probes and monitors on combine harvesters with immediate recording of results, all enhancing good farm management, but far from being universal and only applicable for small farmers via associations, co-operatives, NGOs or government i.e., little uptake to date.

We are only at the dawn of managing the plethora of beneficial soil organisms (antagonic fungi) controlling soil and seed-borne diseases, bacterial control of diseases and pests, fungal controls of insects and nematodes, enzymes and organic acids which solubilize soil nutrients (Mendes et al., 2013, Walker et al., 2003). Novel agricultural practices, compatible with CA (Landers et al. 2021b), need to be recognised, be they farmer innovations or discovered by research. They also need to be elucidated and, when validated, disseminated. Examples could be: i. inoculation with specific microorganisms at planting, e.g. Trichoderma spp., common in Brazil (Parra, 2014), to control root diseases; ii. use of efficient P-solubilizing bacteria to release P fixed in the soil or to be applied as biofertilizer (Batista et al., 2018); iii. the use of locally produced stone meals as soil conditioners and, for some specific stone meals, substitute costly fertilizer imports in stable ZT/CA areas (Landers et al., 2021a; Manning, 2012); iv. undiscovered micronutrients necessary for soil microbiota as cobalt is for Rhizobium spp. (Riley & Dilworth, 1985); v. new biological controls for pests, diseases (Parra, 2014) and even weeds (farm scale “bokashi” anaerobic compost fertilizer extract - Planet Natural, 2021); vi. legume interplanting (association) to supply N, to suppress nematodes (Crotalaria spp. and other species) (Bunch, Berkelaar and Motis, 2019), or to advance planting time for the second crop and capture more rainfall. Multiple cover crop mixes (Bunch, Berkelaar and Motis, 2019) combine many functions, amongst the most important are: i. generation of biomass to add carbon to the system and sequester this element in improved soil organic matter (SOM) levels; ii. cover crop N supply for the system to reduce fertilizer cost and boost yields (Bunch, Berkelaar and Motis, 2019); iii. increasing SOM also increases the soil cation exchange and water-holding capacities, retrieving leached nutrients and depositing them at the surface in residue; iv. smothering of weeds (smother crops); v. off-season grazing; vi. formation of soil aggregates by root exudates; vii. penetrating compacted soil layers for crop roots to follow; viii. preventing rainfall runoff and water erosion; ix. nematode control; and, x. cover crop legumes for free N supply.

On the fundamental importance of the soil biota in ZT/CA soils, Yang et al. (2020) cite the following anthropogenic impacts on soil biota communities: 1. increasing crop diversification in rotations could bring positive impacts, such as continuous wheat cropping could negatively impact soil health by enhancing activities of host specific pathogens; 2. physical agronomic practices such as tillage can alter soil microbial communities by shifting microclimate conditions; 3. mineral nitrogen fertilizer use, a leading nutrient input, may have exceeded the planetary boundary of N cycling, and is causing soil acidification and decreasing microbial biomass; and, 4. synthetic chemicals... are often toxic to non-target soil microorganisms, while biofungicides and biofertilizers—a more sustainable approach—carry significant risks to trigger succession of the native soil microbial community, thus impacting on soil health.

The importance of crop biodiversity has been enshrined in ZT/CA since its inception. Mendes (2018) have introduced a soil health analysis based on enzymes in rot exudates and implanted this in Brazilian commercial laboratories, an excellent example to be disseminated worldwide.

3. Conclusions

Effective PES with payments direct to farmers are vital to resource conservation and preservation; "a farmer in the red cannot look after the green". Thus, the co-responsibility principle enunciated in WCCA I means that consumers should pay this cost. Whole farm certification would greatly assist PES. Finally, for technology innovations to prosper, there must be open and enquiring minds, with community spirit.

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Soil protection and carbon sequestration through seeded groundcovers, spontaneous vegetation and pruning remains mulch in olive orchard

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Olive orchard is well-adapted to Mediterranean conditions so this crop has economic, social and environmental importance in this area. Woody crops are considered lands with scarce soil protection as canopies provide less than 30% of soil cover and, in many cases, olive trees are placed in marginal areas with steep slope what eases erosion processes. In addition, some agricultural practices like intense tillage or bare soil favour soil loss. Groundcovers have been proven to be efficient controlling erosion in olive orchard, furthermore, they have the ability to fix atmospheric carbon and improve soil organic carbon (SOC). Among different types of groundcovers are found spontaneous, seeded or pruning remains mulch.

A four-season study with four experimental fields was performed to assess the protection provided and the carbon sequestration potential of seeded species from different families of plants and the spontaneous vegetation of the area. The seeded groundcovers were a grass (*Brachypodium distachyon*), a crucifer (*Sinapis alba*) and a legume, hairy vetch (*Vicia villosa*), each of them was sown in a different field and compared with the specific natural flora. In the fourth field, mulching system with scattered pruning remains from olive trees were tested and compared to the natural vegetation of the area. The dose of pruning remains was established from the average of pruning weight obtained per tree, the distance between two trees and a strip of 2 m (chopping machine width). Soil coverage during the decomposition period and carbon fixation in soil were measured in all types of groundcover considered. The seeded groundcovers showed higher soil cover than spontaneous vegetation throughout the study period. Brachypodium was the species that provided a higher and long-lasting protection level with values over 75% at the end of the decomposition period of the four seasons. In all fields, the seeded specie was more protecting than spontaneous. The pruning remains mulch maintained the soil cover quite high until the fourth season where the value was lower of 30% at the end of the season since there was not a new application of pruning remains during four years.

Regarding carbon sequestration, pruning remains reached the greatest annual rate of 3.5 Mg C ha^{-1}. However, it covered lower (2 m) strip surface than living groundcovers (3.5-4 m). Brachypodium increased SOC 1.9 Mg C ha^{-1} annually in the field with the highest clay content. Sinapis obtained an average fixation of 1.8 Mg C ha^{-1} per season and vetch improved SOC 1.1 Mg C ha^{-1} y^{-1}. Instead, spontaneous vegetation provided lower sequestration rate in the four fields, the values ranged between -0.2 and 1.7 Mg C ha^{-1} y^{-1}. Among the experimental fields, those where the soil clay content was higher and initial SOC was lower gave better increments.

The use of groundcovers in olive orchard is highly recommendable because they can protect the soil and mitigate climate change through SOC sequestration. The treatments where farmers had a role, such as seeded groundcovers and pruning remains, worked better than spontaneous vegetation, which is the most used groundcover.

Keywords: *Groundcovers; Brachypodium distachyon; Sinapis alba; Vicia villosa; Pruning remains; Olive orchard*

Abstract

Olive orchard is well-adapted to Mediterranean conditions so this crop has economic, social and environmental importance in this area. Woody crops are considered lands with scarce soil protection as canopies provide less than 30% of soil cover and, in many cases, olive trees are placed in marginal areas with steep slope what eases erosion processes. In addition, some agricultural practices like intense tillage or bare soil favour soil loss. Groundcovers have been proven to be efficient controlling erosion in olive orchard, furthermore, they have the ability to fix atmospheric carbon and improve soil organic carbon (SOC). Among different types of groundcovers are found spontaneous, seeded or pruning remains mulch.
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The seeded groundcovers showed higher soil cover than spontaneous vegetation throughout the study period. Brachypodium was the species that provided a higher and long-lasting protection level with values over 75% at the end of the decomposition period of the four seasons. In all fields, the seeded specie was more protecting than spontaneous. The pruning remains mulch maintained the soil cover quite high until the fourth season where the value was lower of 30% at the end of the season since there was not a new application of pruning remains during four years.
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The use of groundcovers in olive orchard is highly recommendable because they can protect the soil and mitigate climate change through SOC sequestration. The treatments where farmers had a role, such as seeded groundcovers and pruning remains, worked better than spontaneous vegetation, which is the most used groundcover.

1. Introduction

Mediterranean basin accounts for 95% of the global surface area of olive trees (FAO, 2019). Spain encompasses more than 2.7 Mha (MAPA, 2019) being the country with the greatest surface and production. Thus, the olive tree best represents the Mediterranean area because of its economic, social and environmental importance (Ortega et al., 2020).

Currently, two of the biggest problems of olive groves are the high rate of erosion (Durán-Zuazo et al., 2020) and soil organic carbon (SOC) loss due to conventional agricultural practices such as intensive ploughing and the removal of herbaceous cover (Repullo-Ruibérriz de Torres et al. 2018a). In addition, olive trees canopies provide scarce soil coverage sometimes lower than 30% (Miranda-Fuentes et al, 2015) and they have been traditionally cultivated in marginal areas of low fertility and shallow soils located on hills. According to Vanwalleghem et al. (2011), the average soil erosion for the widely spaced olive trees on the slopes in southern Spain range from 29 to 47 Mg ha^{-1} $year^{-1}$. The soil loss, due to erosive processes, implies economic and environmental losses.

The use of groundcovers (GC) in the inter-rows of olive orchards is a good agricultural practice that is being adopted by farmers to curb soil and SOC losses. Despite GC consume water and nutrients, they provide several ecosystem services: soil loss reduction (Espejo-Pérez et al., 2013), diffuse pollution limit (Ordóñez-Fernández et al., 2007), nutrient storage during the dormant season and release when olive trees are actives (Repullo-Ruibérriz de Torres et al., 2021), N fertilization mainly through legumes (Ordóñez-Fernández et al., 2018), biological activity enhancement and diseases control (Abawi & Widmer, 2000) and C sequestration (Repullo-Ruibérriz de Torres et al. 2018b), among others.

Soil organic carbon is considered an indicator of soil health. Furthermore, SOC improvement in croplands is mainly due to carbon fixation through photosynthesis and an appropriated soil management. Thus, agricultural soils play a significant role in regulating carbon dioxide (CO_2) from atmosphere, being SOC one of the most important carbon sink (Lal, 2018). In this regard, '4perMille 'initiative was launched at the 21st Conference of the Parties (COP21), held in Paris, with the aim of increasing global SOC stock by 0.4 % per year as a compensation for the global greenhouse gases emissions by anthropogenic sources (Minasny et al., 2017). Using GC is one of the best management practices that contribute to increase SOC stock and fulfil the 4perMille initiative objective (Francaviglia et al., 2019).

Different types of groundcovers can be used by farmers. GC can be composed by seeded species. Among them, Gramineae, Leguminosae and Cruciferae should be highlight as the main families. However, the most preferred option as GC is the spontaneous vegetation due to economic advantages. Conversely, spontaneous vegetation has some drawbacks such as more competitive species for water and nutrients and lower soil protection when there is scarce seed bank, what is usual when the previous soil management consisted of intense tillage or the weed control was conducted by pre-emergence herbicide. In addition, the continuous use of spontaneous flora might end up producing soil compaction and species of more difficult control.

A non-competitive alternative is the use of pruning remains as mulch. The periodic pruning of woody crops generates a by-product that can be used as mulch after chipping. In addition, this practice is a sustainable alternative to the burning that provides a long-lasting soil cover.

The aim of this research was to assess soil protection capacity and the carbon sequestration potential of different GC comparing the spontaneous vegetation in each area with 3 seeded species from the main families and pruning remains used as mulch.

2. Materials & Methods

Four different olive orchards represented the experimental fields where the soil protection and the carbon sequestration potential by seeded species from different families of plants and the spontaneous vegetation of each field were assessed. The seeded GC were a grass (*Brachypodium distachyon*), a crucifer (*Sinapis alba*) and a legume, hairy vetch (*Vicia villosa*), each of them was sown in a different field and compared with the specific natural flora during 4 seasons. In the fourth field, mulching system with chipped pruning remains from olive trees were tested instead of a seeded species. Some soil properties of the four fields are shown in table 1.

Table 1. Some soil properties of the experimental fields. (OM: organic matter; CEC: Cation exchange capacity; BD: bulk density)

Field	Depth (cm)	OM (%)	CEC (mol_c/kg)	$CaCO_3$ (%)	BD (Mg/m^3)	Sand (%)	Silt (%)	Clay (%)	Textural class
1	0-20	0.87	0.23	29.2	1.32	7.9	41.4	50.7	Silty clay
	20-40	0.66	0.22	31.8	1.43	8.4	41.7	49.9	Silty clay
	40-60	0.58	0.22	33.1	1.44	8.8	41.8	49.4	Silty clay
2	0-20	1.12	0.34	1.5	1.42	35.4	25.4	39.2	Clayey loam
	20-40	1.10	0.39	1.5	1.47	31.7	24.8	43.5	Clayey
	40-60	0.75	0.39	2.6	1.47	29.3	23.0	47.6	Clayey
3	0-20	2.18	0.14	15.7	1.30	57.4	26.7	15.8	Sandy loam
	20-40	2.07	0.13	15.4	1.40	56.2	28.2	15.5	Sandy loam
	40-60	1.37	0.13	20.9	1.41	62.6	25.3	12.0	Sandy loam
4	0-20	1.96	0.20	16.4	1.48	42.5	39.9	17.6	Loamy
	20-40	1.29	0.19	20.4	1.49	44.3	37.6	18.1	Loamy
	40-60	1.03	0.17	20.9	1.50	45.1	38.6	16.3	Loamy

The field 1 was sown with Brachypodium at a rate of 30 kg/ha following the commercial recommendations. In the field 2, the spontaneous vegetation was compared with Sinapis seeded at 10 kg/ha. The legume in the field 3 was seeded to a high dose (200 kg/ha) as it was used as green manure in an organic olive orchard. In the field 4, the dose of pruning remains was established from the average of pruning weight obtained per tree, the distance between two trees and a strip of 2 m (chipping machine width). In total 15.67 Mg/ha (dry matter) of pruning remains were applied and left on ground during 4 seasons. All doses were calculated as dry matter per hectare of GC. In the field 1 and 2, Brachypodium and Sinapis had a strip width of 4 m. The legume in field 3 was seeded in a 3.5 m wide strip. Soil coverage during the decomposition period was estimated through the subjective evaluation per sectors method of Agrela (Moreno-García et al., 2018). Carbon sequestration in soil was measured in all GC as the increment of SOC between the end of the 4-season study period and the beginning of the experiment to a depth of 20 cm.

3. Results & Discussion

3.1. Soil coverage

The maintenance of surface vegetative coverage is an effective way to protect the soil against erosion (Espejo-Pérez et al., 2013). Soil coverage was usually higher in seeded GC than spontaneous vegetation. Sometimes with averages statistically significant. A critical point is the end of the decomposition period (Rodríguez-Lizana et al., 2018), when most of residue biomass has been decomposed especially in case of plant material with low C/N ratio (Repullo-

Ruibérriz de Torres et al., 2018b). The table 3 shows the percentage of soil cover at the end of the decomposition period (October) in each season.

Table 2. Soil cover provided by the groundcovers residues at the end of the decomposition season. (BRA: *Brachypodium distachyon*; SIN: *Sinapis alba*; VIC: *Vicia villosa*; PRM: Pruning remains mulch; SV_: Spontaneous vegetation in each field. *significant differences; ns: non-significant differences with SV according to LSD test at $p \leq 0.05$)

Season	Field 1			Field 2			Field 3			Field 4		
	BRA		SV1	SIN		SV2	VIC		SV3	PRM		SV4
1	84.1	*	36.8	34.5	ns	29.0	30.4	ns	25.0	85.3	*	49.9
2	99.3	*	78.1	41.3	ns	39.0	58.0	*	28.0	62.5	*	39.2
3	79.0	ns	66.0	48.3	ns	41.5	62.8	*	22.0	34.8	*	60.3
4	90.0	*	58.9	51.8	ns	39.8	44.2	ns	42.2	22.3	*	72.6

The results show the high potential for soil protection of the grass Brachypodium with soil coverage higher than 75% at the end of the decomposition period of all seasons. In case of legume (field 3), lower protection is maintained at the critical point as the decomposition is faster (Ordóñez-Fernández et al., 2018). Sinapis always provided higher soil cover values than spontaneous vegetation of that field but non-significant differences were obtained.

All seeded GC maintained the soil cover upper than 30%, threshold in Conservation Agriculture (González-Sánchez et al., 2015). Spontaneous flora did not protect the soil at the end of the decomposition period in all seasons and fields.

In case of pruning remains, a biennial pruning can be expected in the olive orchard; thus, in four years, there should be a new application of pruning remains on the soil. However, the decomposition of pruning remains applied once was studied in this research. On the other hand, spontaneous vegetation may appear while those are decomposing so that it would also provide soil protection.

3.2. Carbon sequestration

The main factors that affect C sequestration are clay content, water holding capacity, nutrient reserves, landscape position and the antecedent SOC stock (Lal, 2018). Furthermore, a positive soil C budget is created by increasing the input of biomass-C and reducing SOC losses by erosion and mineralization (Lal, 2018).
The C input provided by GC decomposition each season is shown in table 3. In total, the vetch was the GC that provided the higher C input since it was sown at a higher rate and the decomposition and C release was faster due to its high C/N ratio. Brachypodium had greater residue biomass than Sinapis and the spontaneous vegetation from the four fields, in fact, it obtained the highest soil cover values. However, Brachypodium had a slower C release than vetch.

Table 3. C release (kg/ha) from groundcovers residues (above-ground) during the decomposition period in each season and field. (BRA: *Brachypodium distachyon*; SIN: *Sinapis alba*; VIC: *Vicia villosa*; PRM: Pruning remains mulch; SV_: Spontaneous vegetation in each field).

Season	Field 1		Field 2		Field 3		Field 4	
	BRA	SV1	SIN	SV2	VIC	SV3	PRM	SV4
1	2994.2	901.8	831.8	633.6	2602.4	559.7	4295.7	925.8
2	4602.2	2786.3	876.6	1338.9	3443.3	995.1	983.9	810.0
3	1550.5	2294.8	569.2	542.6	4455.9	1055.6	1257.0	1058.3
4	712.4	523.2	543.2	604.3	1778.6	1935.5	412.5	1411.0
Sum	9859.3	6506.0	2820.8	3119.3	12280.2	4545.9	6949.1	4205.1

The C sequestration during the four-year study period and annual average are shown in table 4. Brachypodium was the seeded species that showed the most favourable results, increasing more SOC at 0-20 depth than the other GC. Nevertheless, pruning remains provided higher C sequestration than herbaceous GC as greater amount (15.67 Mg/ha) was applied at the beginning of the experiment. It should be highlighted the high rates of Sinapis despite the released C by above-ground biomass was not very significant. The below-ground biomass means an extra C input, especially in crucifers due to the strong taproot system, which has not been taken into account for C release calculation.

In general terms, those soils with higher clay content increased SOC stock such as soils of fields 1 and 2. In addition, those soils were poorer in OM at the beginning of the experiment what encourages high SOC increments when a GC is established. In the field 3, the high initial OM and the low clay content decreased the SOC with spontaneous flora as the C input was no enough to improve the soil.

Table 4. C sequestration (Mg/ha) obtained through GC at 0-20 cm depth during the 4-season study period in each field; annual C sequestration rate (Mg/ha/year) and 4perMille rate (annual rate/baseline C stock×1000). (BRA: *Brachypodium distachyon*; SIN: *Sinapis alba*; VIC: *Vicia villosa*; PRM: Pruning remains mulch; SV_: Spontaneous vegetation in each field).

Season	Field 1		Field 2		Field 3		Field 4	
	BRA	SV1	SIN	SV2	VIC	SV3	PRM	**SV4**
C sequest. (4 seasons)	7.64	6.96	7.11	1.29	4.33	-0.77	14.13	2.96
Annual C sequest. rate	1.91	1.74	1.78	0.32	1.08	-0.19	3.53	0.74
4perMille rate	146.4	129.1	77.1	14.0	47.4	-8.4	102.8	21.5

All type of GC fulfilled thoroughly the 4perMille initiative goal, except spontaneous flora in field 3 that reduce its SOC. According to Francaviglia et al. (2019), woody crops show greater potential to increase SOC stocks than annual crops. Those authors obtained 4perMille rate of 80‰ on average for woody crops, which is in agreement with our results.

Conclusions

The use of GC in the inter-rows of olive orchards is recommendable to protect the soil, reducing SOC loss while mitigate climate change through SOC sequestration. The treatments where farmers had a role, such as seeded GC and pruning remains mulch, worked better in all experimental fields than spontaneous vegetation, which is the most used GC. Agricultural Policies should foster the use of GC as a sustainable practice with several benefits, especially the potential for climate change mitigation.

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Enabling smallholder farmers to sustainably improve their food, energy and water nexus while achieving environmental and economic benefits in the EGP: Conservation Agriculture-based sustainable intensification for smallholder systems

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Traditional rice-based crop production in the Eastern Gangetic Plains (EGP) region of South Asia are energy, water and labor intensive and inefficient, with relatively low productivity and profitability. Additionally, crop management in these systems typically does not consider the emission of CO_2-equivalent greenhouse gases, which is often relatively high. The EGP is currently a highly impoverished region, but it has natural resources sufficient to become a leading food-producing region in South Asia. Conservation Agriculture-based sustainable intensification (CASI) crop management practices improve crop productivity and profitability while reducing energy, water and labor requirements, and greenhouse gas emissions. The introduction of CASI practices within villages and districts of the EGP provides opportunities for farming households to sustainably diversify and/or intensify their crop production. it also enables the micro-entrepreneurship and employment opportunities within rural communities.

In over 400 on-farm experiments we compared the performance of traditional and improved management practices in rice-based cropping systems. We found that CASI management practices improved crop grain yields by up to 10%, reduced labor demand by up to 50%, while increasing water productivity (up to 19%) and energy productivity (up to 26%). Combined, these results reduced the cost of crop production under CASI by up to 22% compared to traditional practice, and increased gross margins in general by 12% to 32%. Concurrently, CO_2-equivalent emissions from CASI management were lower than those from traditional management by between 10% to 17%.

The method of implementing and testing CASI management practices was important: this participatory research was embedded within existing farmer support groups, which served as hubs to support collaborative participatory research and to connect farmers and researchers with other important stakeholders as needed. An actively enabling policy environment was necessary to support CASI uptake and to facilitate outscaling at scale outside research areas.

Keywords: *economic benefits, environmental benefits, greenhouse gas emission reduction, productivity benefits, profitability benefits*

1. Abstract

In extensive field trials across the Eastern Gangetic Plains in South Asia, we engaged with over 400 farmers and conducted participatory research trials to examine the effects of introducing Conservation Agriculture-based sustainable intensification crop management practices to rice-based cropping seasons in a) the wet season, b) the dry season, or c) both seasons. Experimental trials were analysed at the cropping system level in terms of grain productivity; water usage and water productivity; energy usage and energy productivity; CO_2-equivalent emissions; labour requirements; cost of production and gross margins. Our results demonstrate that for a range of agro-environments across the Eastern Gangetic Plains, Conservation Agriculture-based sustainable intensification management practices improve smallholder farmers' food, energy and water nexuses. While the benefits of these improved management practices are apparent at the single-crop level, they are enhanced when improved management is applied to all crops in the cropping system.

2. Introduction

Traditional rice-based cropping systems in the Eastern Gangetic Plains (EGP) region of South Asia are energy, water and labor intensive and inefficient, with relatively low productivity and profitability (Ladha et al., 2015). Farmers managing crops in these systems do not consider the emission of CO_2-equivalent greenhouse gases; there is potential here to increase the efficiency of these production systems, in terms of the greenhouse gases emitted per ton of crop product generated (Ladha et al., 2015; Padre et al., 2016). The EGP is a highly impoverished region, but it has natural resources sufficient to become a leading food-producing region in South Asia (Ericksen et al., 2011). Conservation Agriculture-based sustainable intensification (CASI) crop management practices improve crop productivity and profitability while reducing energy, water and labor requirements, and greenhouse gas emissions. The introduction of CASI practices within villages and districts of the EGP provides opportunities for farming households to sustainably diversify and/or intensify their crop production while facilitating micro-entrepreneurship and employment opportunities within rural communities (Islam et al., 2019).
In over 400 on-farm experiments we compared the performance of traditional and improved management practices in rice-based cropping systems. We found that CASI management practices improved crop grain yields by up to 10%, reduced labor demand by up to 50%, while increasing water productivity (up to 19%) and energy productivity (up to 26%). Combined, these results reduced the cost of crop production under CASI by up to 22% compared to traditional practice, and increased gross margins in general by 12% to 32%. Concurrently, CO_2-equivalent emissions from CASI management were lower than those from traditional management by between 10% to 17%.
The method of implementing and testing CASI management practices was important: this participatory research was embedded within existing farmer support groups, which served as hubs to support collaborative participatory research and to connect farmers and researchers with other important stakeholders. An actively enabling policy environment was fundamental to support CASI uptake and to facilitate outscaling at scale beyond research areas. Chowdhury et al. (2021) provide more details on outscaling in West Bengal, India.

3. Experimental trials

Experimental trials were conducted in over 400 farmers' fields for three years, from 2015 to 2017 inclusive. These experimental fields were located in eight districts spanning the EGP: Sunsari and Dhanusha in the Nepali Terai; Madhubani and Purnea in Bihar, India; Coochbehar and Malda in West Bengal, India; and Rajshahi and Rangpur in north-western Bangladesh. Before the trials commenced all fields had been cultivated using traditional methods. Approximately 50 farmers in each of the eight districts participated in the experimental trials. The first experimental year was used to upskill farmers in new agronomic techniques and ensure methodological consistency. Data from the second two years of the trial were used in analysis. Fertiliser, irrigation water and pesticides were applied according to local university or state agronomic best practice guidelines. Additional field trial information, including the weather, soil and hydrological characteristics of all eight districts in which trials were conducted and further methodological details, are detailed in Islam et al. (2019).

At all sites, a rice-based cropping system under traditional cultivation (CT) was the baseline treatment, with rice grown in the wet season followed by an irrigated cereal crop (primarily wheat) grown in the dry season. In this system, the soil was repeatedly tilled prior to establishing each crop. In the rice crop, seedlings were established in a 'nursery' field before being manually transplanted at approximately four weeks' age into the tilled field which had a compacted (or puddled) soil layer at about 20cm depth and which was surrounded by bunds approximately 20cm high.

Weeds were controlled through both standing water retained by the bunds and through manual weed removal. Crop residues were removed to feed animals or were burned to facilitate the establishment of the succeeding wheat crop. In the wheat crop, seed was manually broadcast into tilled fields, weeds were controlled manually, and crop residues were removed for animal feed or other alternative use. Rice was predominantly grown in rainfed conditions, while the dry season crop was irrigated.

There were three experimental treatments to examine the effects of Conservation Agriculture-based sustainable intensification (CASI). In the first of these, partial CASI practice (p-CASI), rice was established and grown as in the CT baseline treatment. The dry season crop was mechanically established without prior tillage and weeds were controlled using herbicides. Previous wet season (rice) crop residues were retained *in situ* at seeding. There were two full-CASI experimental treatments: in one, CASI-DSR, rice seed was mechanically sown into the main fields and in the other, CASI-UPTR, rice seedlings were mechanically transplanted into the main fields at approximately four weeks' age. In both full-CASI treatments and for both crops there was no tillage or puddling prior to crop establishment, weeds were controlled with herbicides, and residues were retained in the field.

The four experimental treatments were compared in terms of the annual cropping system (a) rice-equivalent yield (REY), calculated according to Eq. (1); (b) irrigation water usage (IWU), the total amount of irrigation water used to produce both crops in the cropping system; (c) water productivity (WP), the amount of grain per cubic meter of water received by the crops, calculated according to Eq. (2); (d) energy usage (EU), the amount of energy required to produce both crops; (e) energy productivity (EP), the amount of grain per megajoule of energy used to produce the crops; (f) CO_2-equivalent (CO_2-eq) emissions produced in the management of the crops (excluding emissions from the crops themselves) and calculated according to Eq. (3); (g) labor required to produce the crops (LR); (h) cost of producing both crops (COP); and (i) gross margins (GM), calculated according to Eq. (4). All economic data were converted to USD to facilitate comparison across countries.

REY = (grain yield of the component crop x price of the component crop)/ (price of rice) (1)

WP = (grain yield)/(irrigation water received by the crop + in-crop rainfall) (2)

CO_2-eq = [(total fuel energy required to produce a crop x CO_2-eq) + (total fertilizer energy required to produce a crop x CO_2-eq) + (total agrochemical energy to produce a crop x CO_2-eq)], for CO_2-eq conversion factors shown in Gathala et al., 2020a (3)

GM = (grain yield x grain sale price) – cost of production (4)

Statistical analyses, including analyses of variance (ANOVA) of the field trial data were conducted according to the methodology described in Islam et al. (2019).

4. Results and Discussion

Fig. 1 illustrates the relative results of the four experimental treatments across all nine comparison metrics. These are examined in more detail below.

4.1. Rice-equivalent yields

There was no significant difference in average rice-equivalent yields (REY) between p-CASI (8.84 t ha^{-1}), CASI-DSR (8.87 t ha^{-1}), and CASI-UPTR (8.95 t ha^{-1}), however these yields were significantly greater than REY for the baseline CT system (8.61 t ha^{-1}). This study observed yield increases in dry-season irrigated crops under CASI practice relative to these crops under CT practice: this result is similar to previous studies short-term studies in comparable agro-ecologies (e.g. Chakraborty et al., 2017). We did not observe differences in rice yields between crop management treatments. Jat et al. (2014) reported that the yield benefits of CASI in rice production are unlikely to be observed in the short term but were present after seven years' of CASI crop management.

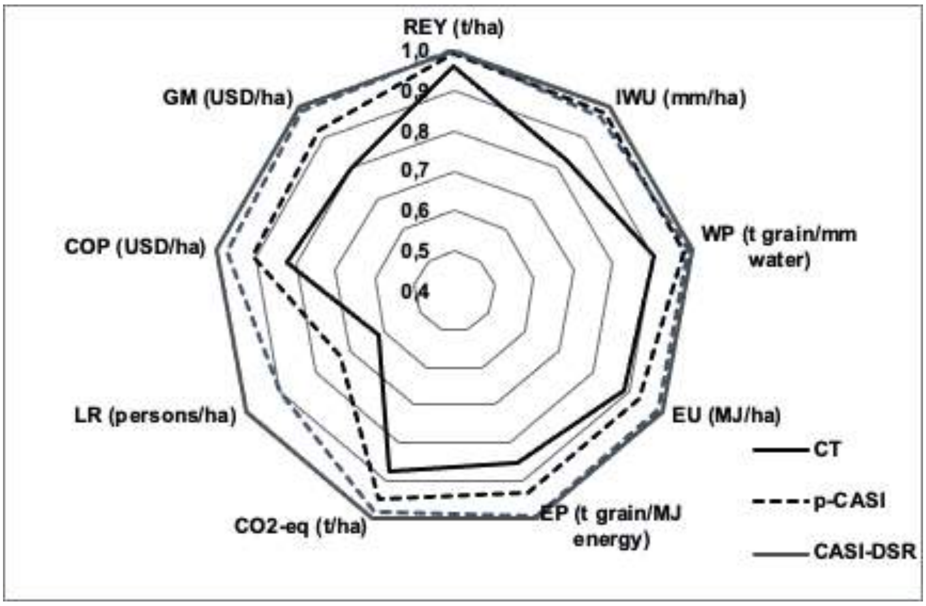

Fig. 1: multi-criteria evaluation of rice-based cropping systems under conventional tillage (CT, black line); partial CASI (p-CASI, dotted black line); full CASI with mechanised direct-sown rice (CASI-DSR, grey line); and full CASI with mechanised unpuddled transplanted rice (CASI-UPTR, grey dotted line) across all research districts. For this multi-sectorial comparison each metric has been normalized and scaled between 0 and 1; a higher value indicates a more desirable outcome

4.2. Water usage and productivity

Similarly to REY, there were no significant differences in average irrigation water used (IWU) in each cropping system or average cropping system water productivity (WP) between the three CASI treatments, however IWU was lower in all instances than the CT baseline and WP higher. Other studies in South Asia have reported reduced water usage in rice grown under DSR or UPTR relative to rice grown under traditional CT management (e.g., Kumar et al., 2018; Laik et al., 2014).

Irrigation water savings for dry season crops under CASI management was in part a consequence of slower flow of the water over the soil surface at the start of an irrigation event under CASI, as the soil was smoother and friction greater under CT (post ploughing and without retained residues). This effect was most pronounced during the first irrigation event of each crop. The higher yields under CASI combined with lower irrigation requirements resulted in increased water productivity in the CASI and partial CASI treatments: this result has also been reported elsewhere (e.g., Laik et al., 2014; Jat et al., 2014).

4.3. Energy usage and productivity

The cropping system under partial CASI management used 6.4% less energy than the system under CT management, while the treatments under full CASI management used 13.2% (CASI-DSR) and 10.4% (CASI-UPTR) less energy than the baseline system. Crop cultivation under CT management is energy intensive as diesel fuel is burned to power tractors for tilling, land preparation and to pump irrigation water (additional water is required in CT treatments). While CASI treatments required higher energy inputs for agro-chemicals (e.g., herbicides and pesticides) than CT treatments, overall these inputs were significantly lower than the additional diesel inputs required in CT crop cultivation (Gathala et al., 2020a). Similar results were observed elsewhere in South Asia (e.g., Laik et al., 2014). Of all the sub-components of the energy budget, inorganic fertilizers comprised over half (51-65%) of all cropping system energy usage (Gathala et al., 2020b). This result indicates how critical it is for farmers to have the knowledge to maximise their fertiliser-use efficiency and ensure wastage is minimised, both to improve farm household budgets and to minimise negative environmental impacts.
As a result of the higher cropping system yields under CASI practice and the reduced energy required to produce both crops, energy productivity was significantly higher in both cropping systems under full CASI practice than the systems under partial CASI or CT management. This result is consistent with other research elsewhere in South Asia (e.g. Ladha et al., 2015; Kumar et al., 2018).

4.4. CO_2-equivalent emissions

Average CO_2-equivalent emissions at the cropping system were significantly higher under CT treatment (1.55 Mg ha^{-1}) than they were in the p-CASI treatment (1.42 Mg ha^{-1}). Emissions from the p-CASI treatment were higher than those from the CASI-UPTR treatment (1.36 Mg ha^{-1}) and significantly higher than those from the CASI-DSR treatment (1.30 Mg ha^{-1}). For all wet and dry season crops, emissions were higher under CT than under CASI practice, across all experimental treatments. Higher CO_2-eq emissions in CT cropping systems result from greater tractor use and irrigation water application, particularly in rice crops. While higher emissions from agrochemical use were observed in CASI than in CT treatments, these were relatively small and did not offset the greater emissions from diesel consumption under CT treatments. Similar results have been observed elsewhere in South Asia (e.g., Kumar et al., 2018; Ladha et al., 2015).

4.5. Required labor

Average labor use was highest in the experimental treatments under CT management, significantly lower in those under partial CASI, and significantly lowest in those under full CASI management, where the CASI-DSR experimental treatment required 77 person-days ha^{-1} and the CASI-UPTR 86 person-days ha^{-1}. In contrast, the p-CASI treatment required an average of 112 person-days ha^{-1} and the CT treatment 131 person-days ha^{-1}. This reduction in labour required for agronomic-related activities was achieved while maintaining or increasing cropping system productivity. CASI management eliminates labour required for land tillage and preparation prior to sowing, and also the labour required for manual transplanting of rice. As crops are mechanically sown or transplanted in lines (instead of being broadcast, as wheat conventionally is) manual weeding is easier. Additionally, CASI practice encourages the use of targeted and appropriate herbicides to control weeds, which reduce the labor required still further. These results of lower labour in cropping systems without tillage have been observed elsewhere in South Asia, primarily on research stations and smaller on-farm trials (e.g., Aryal et al., 2014; Keil et al., 2015). Increasing mechanisation may result in loss of employment opportunities for landless agricultural laborers, however it is also the case than in many districts in South Asia farmers are presently unable to hire labor due to rural ex-migration (Gathala et al., 2021).

4.6. Cost of production and gross margins

Average production costs were \$1,045 USD ha^{-1} in the conventional CT cropping system, \$949 USD ha^{-1} in the p-CASI system, \$843 USD ha^{-1} in the CASI-DSR and \$871 USD ha^{-1} in the CASI-UPTR systems. There were significant differences in costs of production between the CT and p-CASI systems and between the p-CASI and both full CASI treatments. In the CT system, the costs of labor (\$375 USD ha^{-1}), machinery (\$292 USD ha^{-1}) and all crop inputs (\$379 USD ha^{-1}) accounted for approximately a third each of the total production cost. In contrast, in the CASI-DSR system, labour (\$222 USD ha^{-1}) and machinery (\$197 USD ha^{-1}) accounted for a quarter or less of the total production costs each, and all crop inputs (\$422 USD ha^{-1}) were more than half of the total cost of production. Under CASI-UPTR labour costs were slightly higher (\$244 USD ha^{-1}) than in the CASI-DSR system, but still significantly less than those of the CT and p-CASI treatments. Lower production costs under zero tillage and conservation agricultural management more generally have been observed elsewhere in South Asia (e.g., Aryal et al., 2014; Keil et al., 2015; Kumar et al., 2018). Under full CASI, average gross margins (\$1,143 USD ha^{-1} for CASI-DSR and \$1,126 USD ha^{-1} for CASI-UPTR) were significantly higher than under partial CASI (\$1,021 USD ha^{-1}) or under CT management (\$896 USD ha^{-1}). These data reflect the lower costs of production and equivalent or higher cropping system yields under CASI than under partial CASI or under CT and concur with similar results reported elsewhere in South Asia (e.g., Aryal et al., 2014; Keil et al., 2015; Kumar et al., 2018).

4.7. Effective methods to test CASI practices on farmers' fields

The large-scale, widespread and participatory nature of these field trials was fundamental to their success, and to the interest and enthusiasm for CASI practices which remains in, and extends beyond, the research districts following the cessation of formal research activities. In particular, a multi-stakeholder approach which was tested in West Bengal (India) and extended to Bihar (India) and north-western Bangladesh, was a particularly effective means of engaging with local farming communities in a manner which built mutual trust and respect. The research team engaged with under-used in-village institutional frameworks (such as farmer groups or cooperatives) to promote skill development and knowledge transfer. These farmer groups were hubs for CASI training and outscaling activities, and were the point through which on-farm CASI experiments were demonstrated within villages and districts. Once momentum for the new practices had been established, we engaged with critical local and state stakeholders to supplement the bottom-up approach with top-down policy and institutional support. More detail on this outscaling approach in West Bengal, India, is provided in Chowdhury et al. (2021).

5. Conclusion

Conservation Agriculture-based sustainable intensification management practices are effective tools to help farmers reduce their labour, water, and energy usage while reducing CO_2-equivalent emissions and maintaining or improving cropping system yields. This research, conducted using participatory engagement approaches, has demonstrated the efficacy and value of CASI practices across the Eastern Gangetic Plains. For farmers who are initially unwilling to commit to complete CASI crop management, partial CASI (i.e., in the dry season only) is a useful interim step.

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The development of straw retention technology for Conservation Agriculture in China

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Conservation Agriculture is the effective technology to help address challenges of feeding a growing and more demanding population and soil degradation in the world. Crop straw retention technology is one of three principles of Conservation Agriculture (no-till, crop rotation and crop straw retention), which can reduce soil bulk density, increase soil organic matter, improve the large diameter size content of aggregate and structure and fertility of soil, provided the good soil environment for crop yield increase and prevented open burning of crop straw. The crop straw retention machine is the main agricultural machinery equipment to accomplish crop straw retention process. In the operating process, crop straw is firstly chopped and collected by high-speed rotation chopping knives. Then, the chopped straw is inhaled by negative pressure occurred in the machine inlet by high-speed rotation chopping knives. Further, by multiple comprehensive effects, such as chopped, teared and rubbed, the crop straw is chopped, of which length is satisfied the quality criterion. Finally, the chopped straw is spread to field by the airflow and centrifugal force. The straw chopping quality and spreading uniformity are important factors to evaluate operating performance of straw retention, and directly affect the no-tillage or reduce till seeding quality, seed germination and growth, thus impacting crop yield. According to the power provided source, the retention machine is divided to powered by tractor and combined harvester. Furtermore, to reduce straw plugging in no-till or reduce-till planting process, straw chopping device combined with no-tii / reduce-till seeder; to increased the decomposition of straw, straw retention machine combines with tillage and cultivation machine to form straw mixed or buried machine. However, because of poor straw chopping quality, bad spreading uniformity and high energy consumption, widespread application of crop straw retention machine is limited. In the future, the chopped straw simulation model, specific air flow field distribution in chopper room, and the effect of machine parameter on straw chopping and spreading quality should be the main research points to address above limited factors of crop straw retention technology.

Keywords: *Conservation Agriculture, crop straw retention, crop yield, chopping quality, spreading uniformity*

Abstract

Conservation Agriculture is the effective technology to help address challenges of feeding a growing and more demanding population and soil degradation in the world. Crop straw retention technology is one of three principles of Conservation Agriculture (no-till, crop rotation and crop straw retention), which can reduce soil bulk density, increase soil organic matter, improve the large diameter size content of aggregate and structure and fertility of soil, provided the good soil environment for crop yield increase and prevented open burning of crop straw. The crop straw retention machine is the main agricultural machinery equipment to accomplish crop straw retention process. In the operating process, crop straw is firstly chopped and collected by high-speed rotation chopping knives. Then, the chopped straw is inhaled by negative pressure occurred in the machine inlet by high-speed rotation chopping knives. Further, by multiple comprehensive effects, such as chopped, teared and rubbed, the crop straw is chopped, of which length is satisfied the quality criterion. Finally, the chopped straw is spread to field by the airflow and centrifugal force. The straw chopping quality and spreading uniformity are important factors to evaluate operating performance of straw retention, and directly affect the no-tillage or reduce till seeding quality, seed germination and growth, thus impacting crop yield. According to the power provided source, the retention machine is divided to powered by tractor and combined harvester. Furthermore, to reduce straw plugging in no-till or reduce-till planting process, straw chopping device combined with no-till or reduce-till seeder; to increase the decomposition of straw, straw retention machine combines with tillage and cultivation machine to form straw mixed or buried machine. However, because of poor straw chopping quality, bad spreading uniformity and high energy consumption, widespread application of crop straw retention machine is limited. In the future, the chopped straw simulation model, specific air flow field distribution in chopper room, and the effect of machine parameter on straw chopping quality and spreading uniformity should be the main research points to address above limited factors of crop straw retention technology.

1. Introduction

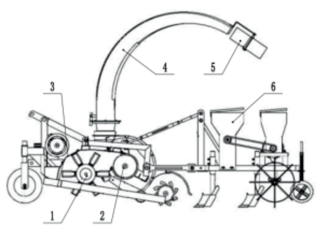
Crop straw, by-product of agricultural production, has abundant elements (carbon, nitrogen, phosphorus and potassium, etc.) to help the next crop growth and improvement of soil structure and fertility. However, because a mass of crop straw after harvest covers on the field surface, the planting operation of next crop will be seriously plugged to affect crop germination and growth of next crop. To solve the problem, farmers always opening burns the crop straw after harvest in the field (Jin et al., 2017). The severe air pollution is generated because of opening burn of crop straw. To increase the utilization efficiency and methods of crop straw, many researches focused on used as fertilizer, fodder, industrial raw material, biofuel and edible fungus base material. In summary, the crop straw as fertilizer (crop straw retention in the field) is simpler than other methods, which can reduce the soil bulk density, water and wind erosion and improve the content of soil organic carbon and soil aggregate and finally increase the crop yield (Zhang et al., 2015; Wen et al., 2017; Liu et al., 2019).

Straw mechanized retention is the main operation of crop straw retention in the field. Its executor is the crop straw retention machine. In the operation, the crop straw is picked, chopped and spread. Finally, the fibriform crop straw is generated to increase the pass-ability of planter. The chopping quality and spreading uniformity of crop straw are the main parameters to measure the operating performance of straw retention machine. In this paper, the variety of crop straw retention machine was divided to powered by harvest or tractor. Furthermore, the crop straw retention machine powered by tractor was also divided to the machine combined with no-tillage or reduce-tillage planter, crop straw chopping machine, chopped crop straw burying machine. Finally, the research focused points were proposed.

2. Main structure of crop straw retention machine

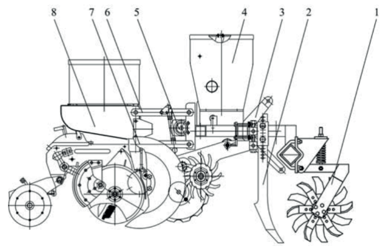
2.1 Machine combined with no-tillage or reduce-tillage planter

In the planting process, because of a mass of crop straw covering on the field, the blockage of no-tillage or reduce-tillage planter was occurred. Therefore, the crop straw retention machine was installed in front of no-tillage or reduce-tillage planter to cut and chop the crop straw in the field surface and thus improving the pass ability of no-tillage or reduce-tillage planter. Sidhu et al. (2007) developed a no-tillage seeder by which straw was chopped and spread behind the seeder along the airway under inertial force. Gu et al. 2016 designed a straw-chopping and back-spreading device to shred and spread straw to reduce seeder blockage (Fig.1). Jia et al. 2017 deigned a gear-tooth stalk cutting device for no-tillage seeder, which can cut and remove straw in the seeding row to avoid the straw blockage in the seeding process (Fig.2).



1. Straw chopping device **2.** Straw collecting device **3.** Main frame **4.** Straw transmission pipelines
5. Scatters device **6.** No-till seeder

Fig.1. Structure of no-till planter under coverage of wheat straw.



1. Stalk cutting mechanism **2.** Fertilizer opener **3.** Rack **4.** Fertilizer box
5. Transmission **6.** Parallel link mechanism
7. Land wheel **8.** Seeder unit

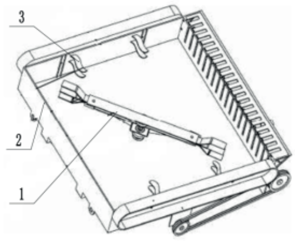
Fig.2. Structure diagram of the no-tillage planter combined with straw cutting mechanism

2.2. Straw chopping machine

The straw chopping machine is the main machine to achieve crop straw mechanization retention. According to the drive powered mode, the machine is divided into the tractor or harvester powered straw chopping and spreading machine.

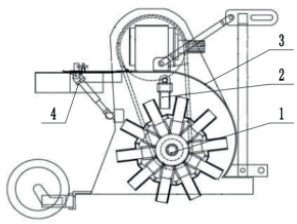
2.2.1. Straw chopping machine powered by tractor

The straw chopping and spreading machine powered the tractor mainly included chopping knives, chopping knife roller and chopper room. In the world, a series of straw chopping and spreading machines were designed and developed by many companies, such as the Maschio, (UK), Kverneland (Norse land), and YTO Group Corporation (China). Many researches were executed in order to improve straw chopping quality and spreading uniformity. Gan et al. (2014) designed a banana stalk chopper for high moisture and thick banana stalk (Fig. 3). The banana stalks were firstly chopped by high rotational speed chopped knives, and secondly chopped by fixed knives installed in both sides of machine shell. Zhang et al. (2017) designed a straw chopping and spreading machine with adjustable spreading device, which can adjust straw spreading uniformity and width (Fig. 4). Importantly, the shape of machine frame was designed by logarithmic spiral to improve the air flow speed in the chopping room. Due to long stubble remained in farmland after harvesting, Qiu et al. (2015) designed a rice straw chopping and spreading device, which can collect, chop and evenly spread the crop straw in the seeding row. The straw chopping and spreading machine combined with tractor has been widely used in the world. However, because of those problems, like low operation efficiency, high power consumption and low chopping quality, the operation property of the machine need further improvement.



1. Chopped knife **2.** Main frame **3.** Fixed knife

Fig. 3. Structure of banana stalk chopper.

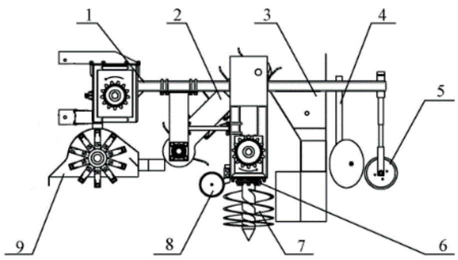


1. Chopped knife **2.** Fixed knife **3.** Main frame **4.** Adjustable device

Fig. 4. Structure of straw chopper and spreader with adjustable spreading device.

2.2.2. Straw chopping and mixing/burying machine

In many regions, especially in North China, large amount of straw would affect seed emergence rate, the subsequent seeding operations and straw decomposition velocity (Yang et al., 2016; Guo et al., 2016). Therefore, the crop straw buried or mixed in the soil was researched to solve those problems. Lin et al. (2018) designed a 1JH-2 style straw deep burying and returning machine to achieve straw deep burial (Fig.7). Wang et al. (2014) developed an integrated machine which can deeply bury 90% straw in the surface into 10 cm below the surface. Zheng et al. 2017 designed a straw pickup-chopping and ditch-burying integrated machine, which can bury 20%-50% straw in the surface into the 15 cm below the surface. Ju et al. (2020) designed a straw chopping machine. In the operation, part of the straw was mixed with soil and another chopped straw was covered in the ground. The chopped straw was buried or mixed by the machine, which can improve decomposition efficiency and create a clean seeding row. However, there are occurred some problems of the buried or mixed machine, such as high power consumption, poor consistency of ditched height and lower straw spreading uniformity, to affect promotion and application of the machine.

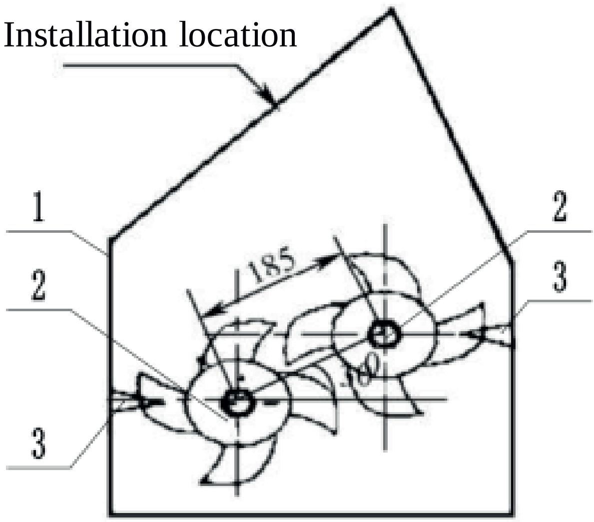


1. Frame **2.** Conveying device **3.** Hopper device **4.** Covering device **5.** Pressing device **6.** Post-position transmission case **7.** Spiral type opener **8.** Disk opener **9.** Straw crushing device

Fig.7. 1JHL-2 type straw deep bury and returning machine.

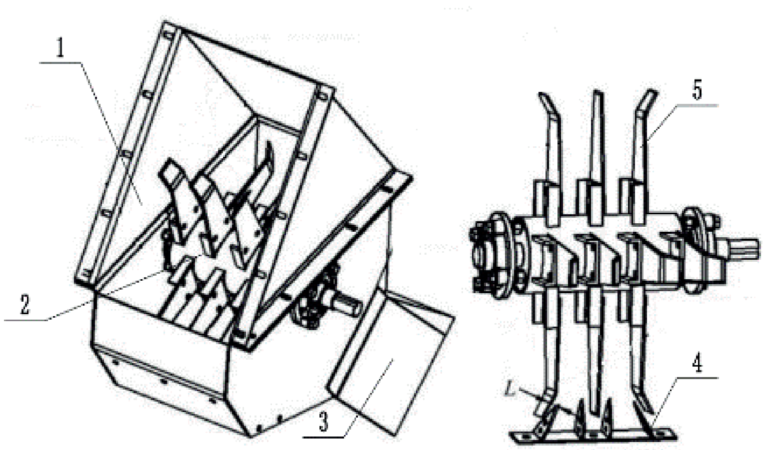
2.2.3. Straw chopping machine powered by harvester

The straw chopping and spreading machine is always installed in central or behind harvester. Many researches were carried out to improve the straw chopping quality and spreading uniformity. Schillinger, Smith, and Schafer (2008) build a high-volume air system to increase straw spreading uniformity. Chen et al. (2011) designed 1JHSX-34 straw chopper for combine harvester, which completed the multiple chopping of straw (Fig. 8). Wang et al (2018) designed a straw chopping device for rice/wheat combined harvester to improve the straw chopping quality and spreading uniformity (Fig.9). The machine usually takes up most of the power provided by the harvester, which results in decreasing the harvesting performance. Therefore, how to adjust the power radio between harvester and chopping and spreading machine is a key point.



1. Frame **2.** Chopping knife **3.** Fixed knife

Fig.8. Structure of 1JHSX-34 type double-shaft straw crusher.



1. Frame **2.** Chopping device **3.** Discharge baffle **4.** Fixed knife group **5.** Chopping knife

Fig.9. Structure of straw chopping device.

3. Future research focused points

Many researches were executed to improve operative quality of straw retention machine by field experiment, but few studies focused on the change principle of machine parameters on the straw chopping quality and spreading uniformity, which limited the high-quality development of crop straw chopping and spreading machine. The future research focused points of straw chopping machine are as follows:

(1) Build the chopped straw simulation model. At present, the simulation model of crop straw always was as rigid, which cannot provide help for the change principle of force and energy consumption in the straw chopping and spreading process. Therefore, a flexible simulation model of chopped straw needs to be built to improve the simulation precision.

(2) Specific air flow field distribution in chopper room. In the operation, high speed air flow had a significant effect on spreading uniformity of chopped straw. Therefore, specific interaction of chopped straw and air flow in the straw chopping process is conductive to improve the straw chopping quality by simulation and field test.

(3) Research the effect of machine parameter on straw chopping quality and spreading uniformity. Machine parameters, such as the shape, number and arrangement of straw chopped blade, the rotational speed of chopped blade, the shape of chopped room, operating velocity, and air flow field distribution are the crucial factors to influence the straw chopping and spreading quality. However, how these above-mentioned parameters affect the crop straw chopping and spreading quality is not clear. Therefore, greater efforts are needed to specific those effects, which are conductive to the design and develop of straw chopping and spreading machine.

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The future of farming
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Conservation Agriculture adoption in Central Asia: present and future prospects

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The development of agriculture sector is one of the government priorities because the Central Asia region is suitable for production of a large variety of crops. Cotton and cereals are the main crops. Kazakhstan is a major producer and exporter of wheat, while Uzbekistan is a major global producer of cotton. Since 1990s, there has been a considerable expansion of areas under wheat in Turkmenistan and Uzbekistan, and substantial reduction in Kazakhstan (over 2 M ha). Over the past three decades, diversification of crops was limited in Central Asia because of the prevailing mono-cropping practices in the agricultural sector. Legumes (alfalfa and beans), maize and vegetable production decreased sharply. Despite some successes in the expansion of the area under fruit tree crops, there are still shortages of fruits and grapes.

Sustainable crop production is constrained by variable and uncertain rainfall, cold winters, hot dry summers and soil salinity in many parts of the world including Central Asia. Soil degradation continues in conventional production systems, largely due to tillage and poor biomass management but also because of poor understanding about how to secure ecological sustainability. Thus, to achieve the future needs of increased and sustainable agricultural production in Central Asia, it is necessary to understand and apply Conservation Agriculture (CA) practices, such as no-till, crop biomass retention as soil mulch cover, crop diversification, in combination with other good agricultural practices of integrated crop, soil, nutrient, water, pest and energy management. Research on soil-climatic conditions and biological properties of varieties is an important part of integrated crop management for the development of good quality CA systems in the region for irrigated as well as rainfed conditions. The latest agricultural policies in Central Asian countries are becoming increasingly aligned to the promotion of sustainable and environment friendly crop production systems based on CA. The extended abstract will elaborate on the present status of adoption and spread of CA systems in Central Asia, and the future prospects for mainstreaming CA.

Keywords: *Degradation, no-till, crop biomass, crop diversification*

Abstract

The development of agriculture sector is one of the government priorities because the Central Asia region is suitable for production of a large variety of crops. Cotton and cereals are the main crops. Kazakhstan is a major producer and exporter of wheat, while Uzbekistan is a major global producer of cotton. Since 1990s, there has been a considerable expansion of areas under wheat in Turkmenistan and Uzbekistan, and substantial reduction in Kazakhstan (over 2 M ha). Over the past three decades, diversification of crops was limited in Central Asia because of the prevailing mono-cropping practices in the agricultural sector. Legumes (alfalfa and beans), maize and vegetable production decreased sharply. Despite some successes in the expansion of the area under fruit tree crops, there are still shortages of fruits and grapes.

Sustainable crop production is constrained by variable and uncertain rainfall, cold winters, hot dry summers and soil salinity in many parts of the world including Central Asia. Soil degradation continues in conventional production systems, largely due to tillage and poor biomass management but also because of poor understanding about how to secure ecological sustainability. Thus, to achieve the future needs of increased and sustainable agricultural production in Central Asia, it is necessary to understand and apply Conservation Agriculture (CA) practices, such as no-till, crop biomass retention as soil mulch cover, crop diversification, in combination with other good agricultural practices of integrated crop, soil, nutrient, water, pest and energy management. Research on soil-climatic conditions and biological properties of varieties is an important part of integrated crop management for the development of good quality CA systems in the region for irrigated as well as rainfed conditions. The latest agricultural policies in Central Asian countries are becoming increasingly aligned to the promotion of sustainable and environment friendly crop production systems based on CA. The extended abstract will elaborate on the present status of adoption and spread of CA systems in Central Asia, and the future prospects for mainstreaming CA.

1. Adoption of ca in the region

In 2018, CA practices in Central Asia extended to 3.13 M hectares (Table 1), of which about 2.9 M hectares are located in Kazakhstan. While the other countries altogether have adopted 0.23 M ha. Also, more than 11.41 M hectare of cropland is under minimum tillage technology in the region. Kazakhstan is leading the adoption of this farming system in Central Asia. In addition, there are perennial fruit trees and grapes with permanent cover crops about 0.70 M hectares and highest area of 0.37 M ha is located in Uzbekistan. Adoption of CA practices in the region except for Kazakhstan has been relatively slow compared to other regions in the world, especially in the irrigated lands. Permanent fruit tree orchards and plantations of grapevines with vegetative ground cover can be also be added as the CA area in the region (Table 1). Total area of permanent fruit tree orchards and plantation of grapevines with vegetative cover is about 0.70 M hectares across Central Asia, making the total area of CA practices in the region equal 3.83 M ha.

In the Republic of Kazakhstan, the state policy is oriented towards expanding the area under CA. Moreover, in national agricultural research, the priority area of study is the improvement of CA practices. Main research topics to be addressed in the future are: weed control; crop rotations; fertilization strategies; training and awareness. In the crop sector, the government support scheme is biased toward wheat production since the scheme applies no ecological or any kind of sustainability criteria. This, it turns, leads to the proliferation of large-scale monoculture crop production.

In Kyrgyzstan, the adoption of CA practices such as no-till, crop residue and crop diversification remain limited. This is because there is limited access to no-till seeders and other production inputs, lack of accessible long-term credit, and inadequate training available for farmers. In Kyrgyzstan, there are now several organizations, research institutions, and international organizations which support sustainable land management practices including CA practices.

Government of Uzbekistan adopted the Presidential Decree # 5742 dated on 17 June 2019 on measures for efficient use of land and water resources in agriculture (Lex.uz, 2019). As per the decree, land users have the right to independently organize land use plans involving no-till methods. This creates new opportunities for pursuing crop diversification for forage crops such as barley, rye, maize, sorghum and sudan grass so that farmers produce more fodder for winter period which will strengthen the animal production sector. There is also an opportunity to introduce forage pea and pear millet production under no-till to the existing crop production system.

In Tajikistan, some basic principles of CA were introduced through an ICARDA and IFAD, and FAO led projects. No-till and permanent bed planting systems have been tested for food and feed crops such as wheat, barley, safflower, sunflower, mung bean, soybean, kidney bean, maize, forage pea, common vetch and sainfoin in Tajikistan. Production risks due to reduced soil fertility and crop diseases are being addressed through the introduction of CA-based technology including no-till, cereal-legume rotations and integrated crop management.

Turkmenistan adopted its National Programme of Social and Economic Development until 2030. The programme takes into account measures aimed at resource saving technologies including minimum soil disturbance through no-tillage and introduction of crop diversification.

The adoption of CA practices in the region should be carried out through close integration of breeders, farmers, technologists, machine builders and scientists. Only the creation of favorable institutional conditions for the integrated adoption of CA systems and methods and the intensification of the economic activities of agricultural enterprises will allow the region to sustain CA-based crop production systems in the region.

2. Prospects for crop diversification under conservation agriculture

There are a number of factors that determine the prospects of diversification of agricultural crops under CA in the countries of Central Asia.

Natural factors. First, limitation of water resources and frequent droughts (Aitekeyeva et al., 2020) necessitate the production of crops that require less water - cotton is not such a crop. This is of special importance to Uzbekistan and Turkmenistan, as in these countries more than 90% of the water resources come from outside their territories, highlighting the importance of transboundary management of water resources (Yu et al., 2018). Second, the level of soil fertility in the countries of Central Asia has declined to the extent that further monoculture production without diversification can lead to dire consequences. Recently, the authorities of the countries of the region have realized this situation, and more and more attempts are being made to limit monoculture production of cotton and wheat. Natural-climatic conditions of Central Asian allow the production of various kinds of crops, and in some cases the production of two or even three crop per year, which occasionally can lead to saturation of domestic markets. In some irrigated areas (especially Southern parts of Uzbekistan and Tajikistan), three crops per year can be grown under CA practices. At the same time, in other countries of the Commonwealth of Independent States (CIS) there exists a growing demand for agricultural products such as grapes, melons, early vegetables, and onions, which give more profit than cotton and use less labour and inputs.

Out migration: Increasing out migration of the agricultural population to cities is observed in the region. Though this does not strongly influence the production of agricultural products at present, there will come a time when there will be shortage of labour in agriculture, in particular in cotton production, and in some regions of Central Asia, this trend can already be observed. This will gradually force agricultural producers to change crops. Most likely this tendency will be observed principally in those regions where there are large cities and, therefore, steady growth in demand for agricultural products (vegetables, fruits, potatoes, meat, oilseeds). Filling this demand will require sustainable perennial cropping system diversification, moving away from unsustainable production of wheat and other annual crops. This can include CA-based mixed cropping systems, rangeland seeding and re-seeding, no-till seeding of legumes and grasses (e.g., alfalfa, sainfoin, sorghum, Sudan grass, and ryegrass) between trees as alley crops, as well as integrated pest and disease management (e.g., entomophagous, biological plant protection), maximum snow retention, salt and drought tolerant fodder systems, and enhanced food and seed storage capacities.

3. Constraints and challenges

The social and economic benefits of annual and perennial CA systems are clear and they should be regarded as the preferred systems able to address the interlinked problems of food insecurity and the degradation of natural resources in a changing climate.

Despite the progress of CA and soil conservation technologies in the region, there are several persistent technological, institutional and policy-related challenges for the wider adoption of CA systems and practices in the region (Kienzler et al., 2012). In the near future Central Asian governments and their institutions and international research and development organizations should join efforts to address the following objectives in the field with CA:

Weed control (infestation management) remains one of the major tasks problems of CA management and needs to be addressed through further scientific research. It is important to develop efficient methods to combat weeds, especially for the early stages of introduction of no-till technologies. Selection of herbicide types, identification of efficient combinations, concentrations and application schedule depending on the weed species present is the main objective of this research. Research is expected to provide recommendations on the most efficient and cost-effective measures to combat weeds under CA conditions. Experience shows that after the initial years, CA helps to reduce herbicide application level and weed infestation significantly. However, as indicated above, in the initial stages of CA introduction, weed control is a serious technical and management task. Biological methods of weed management also merit more research including cover crops and mixtures, crop associations including inter-cropping and alley cropping, and allelopathy.

A major constraint to CA in many Central Asian countries is the poor access to good quality no-till seeders in order to accelerate the adoption of CA. Local no-till seeder development is absolutely essential for up-scaling. However, for introducing the concept of CA and for demonstrating CA systems, imported seeders can and are being used. However, ultimately, locally or regionally manufactured or assembled seeders are important for affordable seeders to be readily available.

- *Challenges in Kazakhstan:* In the north, readjust incentive policies to improve the quality of CA and include smaller farmers; in the south, provide similar support for uptake of CA for the diversified, irrigated and smaller scale cropping systems (i.e., permanent bed planting technologies).

- *Challenges, Kyrgyzstan:* Crop diversification by small farmers; knowledge about CA systems among extension and technical staff; knowledge about CA at all levels; availability of equipment; and access to finance, high interest rate and short repayment period. Limited access to finance, driven by high interest rates and short repayment periods.

- *Challenges, Tajikistan:* Knowledge about CA systems among extension and technical staff; practical experience for farmers in pilot areas with CA – proof of concept; knowledge about CA at all levels; availability of equipment; and accessible and affordable credit.

- *Challenges, Turkmenistan:* Knowledge about CA systems among extension and technical staff; availability of equipment; permission for kolxozs'[1] to decide on diversified crop rotations.

- *Challenges, Uzbekistan:* Small-scale farmer adoption of CA; knowledge about CA systems among extension and technical staff; availability of equipment; permission for farmers to decide on diversified crop rotations.

4. Conclusions

It is clear that soil and water management is very important for sustainable agriculture in Central Asia. Much work has been done to improve soil and water related aspects. However, it has been observed that policy support for the uptake of new efficient systems and practices such as CA are required as well as technology transfer mechanisms for small-scale farmers so that they are empowered to take full benefit and increase their productivity and profitability. In this context, international agricultural research centers as well as international development organizations have been able to work with national institutions and scientists in formulating and testing locally adapted CA practices, especially suited to small and marginal farmers in Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan as well as the large-scale farmers in Kazakhstan. These CA practices need to be promoted further for large-scale adoption and desired impact on farmers' fields across the region.

1 Kolxoz – collective farm

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Table 1: Area of agricultural crops land under different tillage methods in Central Asia[2]. 000 ha (2002-2018)[3]

Country	Technology and crops	2002	2005	2010	2015	2018	Operations
Kazakhstan	Conventional	19000	15200	11600	7700	5600	Multiple tillage methods with blades and sweeps, (mostly monocropping system)
	Minimum tillage	0	3400	6200	9300	10500	Direct seeding with V-shaped openers or with narrow chisels regularly combined with shallow harrowing/ cultivation, (few diversification)
	Perennial crops	13	14	14	15	16	Perennial fruit trees and plantation of grapevines with vegetative cover
	No-till	0	400	1200	2000	3000	Direct seeding with narrow chisels or double discs openers (diversification)
	No-till and perennial crops	13	540	1350	2150	3060	Perennial fruit trees and plantation of grapevines with vegetative cover and no-till
Kyrgyzstan	Conventional	1150	1160	1150	1200	1180	Multiple tillage methods with blades and sweeps, (mostly monocropping system)
	Minimum tillage	0	0	0	30	60	Direct seeding with chisels with shallow harrowing/cultivation and planting wheat on standing cotton, (few diversification)
	Perennial crops	50	50	50	50	50	Perennial fruit trees and plantation of grapevines with vegetative cover
	No-till	0	0	0	70	70	Direct seeding with narrow chisels or double discs openers (diversification)
	No-till and perennial crops	50	50	50	120	110	Perennial fruit trees and plantation of grapevines with vegetative cover and no-till
Tajikistan	Conventional	90	90	84	87	64	Multiple tillage methods with blades and sweeps, (mostly monocropping system)
	Minimum tillage	30	30	50	80	20	Direct seeding with chisels combined harrowing/cultivation and planting wheat on standing cotton, (diversification)
	Perennial crops	89	100	110	120	120	Perennial fruit trees and plantation of grapevines with vegetative cover
	No-till	0	0	0	0	50	Direct seeding with narrow chisels or double discs openers (diversification)
	No-till and perennial crops	90	10	110	120	170	Perennial fruit trees and plantation of grapevines with vegetative cover and no-till
Uzbekistan	Conventional	3500	3410	3410	3310	3210	Multiple tillage methods with blades and sweeps, (mostly monocropping system)
	Minimum tillage	450	540	620	630	650	Direct seeding chisels regularly combined harrowing/cultivation and planting wheat on standing cotton, (diversification)
	Perennial crops	320	340	310	360	370	Perennial fruit trees and plantation of grapevines with vegetative cover
	No-till	0	0	0	30	120	No-till including alley cropping
	No-till and perennial crops	320	340	310	390	490	Perennial fruit trees and plantation of grapevines with vegetative cover and no-till

2 Data for Turkmenistan is not available

3 Source: Statistical committee/Agency of Kazakhstan (https://stat.gov.kz/), Kyrgyzstan (http://www.stat.kg/), Tajikistan (https://www.stat.tj), Turkmenistan (http://www.stat.gov.tm/) and Uzbekistan (https://stat.uz/), 2018.

The future of farming
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The role of farmers implementing and disseminating sustainable soils management systems: challenges and drivers, view of farmers associations

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For a long time, many scientific studies and several initiatives of intergovernmental /governmental agencies (GSP = Global Soil Partnership) of FAO, the 4per1000 Initiative, the Climate Smart Agriculture, are well documenting:

- Status and threats on soils: erosion, compaction, loss of SOM and biodiversity,
- Technical solutions to improve practices and farming systems.

Conservation Agriculture (CA) systems are more and more known by farmers, experts, decision-makers and stakeholders. Their positive impacts are well documented and more and more recognized internationally, on food security, climate, biodiversity, water management (i.e., all Ecosystem Services).

Awareness is raising globally about the urgency of action, often in link with climate emergency, soil degradation, and loss of biodiversity.Beyond the growing general acceptation of the principles of CA by the “international scientific community”, in principle, two questions remain unanswered by experts and stakeholders, in first-line policymakers:

- the technical question: how to implement, in practice, the on-farm transition to CA while continuing to produce in a viable way and enable farmers to live and produce,
- the sociological question: how to engage farmers to change their practices into CA is still a mystery for most no-farmers persons.

Several studies led by sociologists tried to get an answer. Without results: innovative farmers are a minority, thus not easy to identify, they are reluctant to be treated as objects of study. They do not trust unknown persons, especially when having faced criticism about CA.However, policymakers need to understand the sociological aspects of farmers decision processes, their reaction to challenges, drivers and policies.These questions of obstacles and drivers to adoption are also vital for farmers associations who want to disseminate and grow.

Several CA farmers associations have got success in the technical implementation of CA on farms, and on dissemination, especially when they benefit from the support of expert scientists in the subject. They are leading the change of their colleagues on their farms, locally, but also around the world, thanks to modern ways of communication and the globalization of knowledge and know-how.Many CA associations have formed the Global Conservation Agriculture Network (GCAN) to advocate for CA in Climate Conferences, starting in COP21 in Paris Dec. 2015. GCAN is supported by the experts and scientists of the CA global community, led by the CA-COP of FAO (CA Community of Practices).

Several of them around the world have mutualized their experiences and made interesting findings concerning:

- understanding challenges farmers are facing
- their drivers for changes
- the keys to success

They propose a method to their colleagues and partners of the CA global community, a joint venture to scientists, official bodies and the private sector. The objective is to accelerate CA implementation by farmers on the ground, to make rapidly agriculture the essential part of the solutions to the multiple challenges the global society is now facing.

Farmers are not a problem for anyone, but the essential actors of the solution.

Keywords: *farmers associations, sociology of change, Sustainable Soil Management, Conservation Agriculture, policies, ecosystem management, food security, carbon sequestration*

Summary

Since a long time, many scientific studies and several initiatives of intergovernmental / governmental agencies (GSP = Global Soil Partnership) of FAO, the 4per1000 Initiative, the Climate Smart Agriculture, are well documenting:

- status and threats on soils: erosion, compaction, loss of SOM and biodiversity,
- technical solutions to improve practices and farming systems.

Conservation Agriculture (CA) systems are more and more known by farmers, experts, decision makers and stakeholders. Their positive impacts are well documented and more and more recognized internationally, on food security, climate, biodiversity, water management (i.e., all Ecosystem Services). Awareness is raising globally about urgency of action, often in link with climate urgency, soil degradation, and loss of biodiversity.

Beyond the growing general acceptation of the principles of CA by the "international scientific community" in principle, two questions remain now unanswered by experts and stakeholders, in first line policy makers:

- the technical question: how to implement practically on farm transition to CA while continuing to produce in a viable way and enable farmers to live and produce,
- the sociological question: how to engage farmers to change their practices into CA is still a mystery for most of no-farmers persons.

Several studies led by sociologists try to get an answer. Without results: innovative farmers are a minority, thus not easy to identify, they reluctant to be treated as objects of study. They do not trust unknown persons, especially when having faced criticism about CA. However, policy makers need to understand sociological aspects of farmers decision processes, their reaction to challenges and drivers, and to policies. These questions of obstacles and drivers to adoption are also vital for farmers associations who want to disseminate and grow. Several CA farmers associations have got success in technical implementation of CA on farms, and on dissemination, especially when they benefit from support of expert scientists in the subject. They are leading the change of their colleagues on their farms, locally, but also around the world, thanks to modern ways of communication and to globalization of knowledge and know-how.

Many CA associations has formed the Global Conservation Agriculture Network (GCAN) to advocate for CA in Climate Conferences, starting in COP21 in Paris dec 2015. GCAN is supported by the experts and scientists of CA global community, led by the CA-COP of FAO (CA Community of Practices), by ECAF, the Federation of CA European Associations, by ACT Network of Africa. Several of them around the world have mutualized their experiences and made interesting findings about:

- understanding challenges farmers are facing
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They propose a method to their colleagues and partners of the CA global community, a joint venture bridging farmers associations, scientists, official bodies and private sector. The objective is to accelerate CA implementation by farmers on the ground, to make rapidly agriculture the essential part of the solutions to the multiple challenges the global society is now facing. Farmers are not a problem for anyone, but the essential actors of the solution.

The Global Conservation Agriculture Network:
Situation of innovative farmers and their associations Realizations and limits

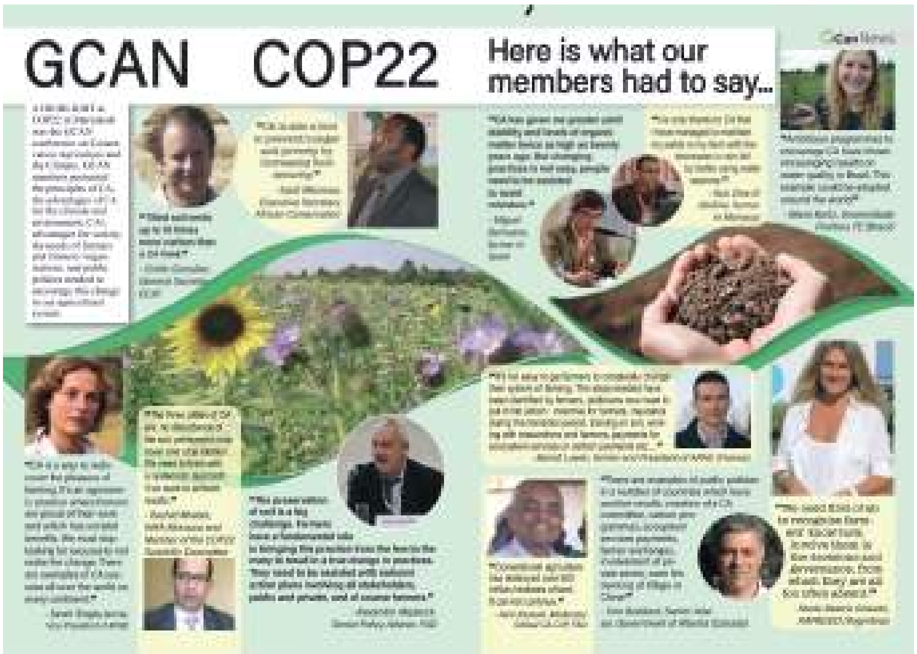
Farmers are diverse, their situations also. Modern agriculture has been dominated during last decades by technologies, and many modern farmers have learnt in school how to become specialists. They dream that technologies will make the necessary changes. But without changing the approach of their systems, taking into account the soil and the ecosystem functions, they will not succeed.

Farmers in "developing" world, with no or limited access to technologies and no money to pay them, have no choice than survive adapting to the ecosystems. In the best case, they can attain a degree of welfare enabling them to survive with their family. This subsistence agriculture has a limited social function. In some countries this accounts for 80 % of farmers. But their populations in growing cities cannot expect from them to produce enough for them, and their governments have no choice that importing. When they can pay with the hopefully rest of productive economy. In all cases, the key is in improving dramatically the capacity of farmers to make their job in ways which are as well viable (for them) as sustainable for the rest of the population and for the ecosystems.

Without farmers in capacity of driving and managing farming ecosystems in a sustainable way, there will be no future for mankind or the planet. This means that collectively, all societies and the globalized society have no other choice than meet farmers needs. Starting listening to them, and accepting the legitimacy of their voice.

This analysis of the needs of farmers associations and of the benefits of networking has been made by learning and understanding the reasons of success of CA in leading countries of the Americas, especially AAPRESID case in Argentina, with the personal support of Rolf Derpsch, the international expert having supported and backed the historical development of CA in South America from its beginning to today.

This partaken analysis with other associations of other continents has been the starting point of the creation of the GCAN (the Global Conservation Agriculture Network), to give a more structured and organized approach to a global informal movement, historically mainly driven by scientists and researchers, full of potential, but focusing mainly on advocacy and technical exchanges between experts.



Farmers associations have started and will continue to exchange between themselves, and progress as they can, with or without support. They have not waited for approval to realize what they have done until today. On the contrary they have operated and developed in many cases despite others. However, their progresses, by counting on themselves and their network only, are limited and slow. If mankind had the time, no problem, changes have always been slow in the past. But it seems that current situation drives urgency of action: demography is still increasing fast, thus also the demand for food, energy, welfare, space...Global climate does not seem improving, neither biodiversity status, nor energy sources, nor the general status of available resources and environment. In brief, needs are growing much faster than solutions are being implemented.

CA farmers do an excellent job:

- Technical transformation of their agro-ecosystems
- Dissemination to their colleagues

They need some action from other stakeholders, to enable them to accelerate implementation.

Expectations from other stakeholders

Policy makers:

The best would be facilitating policies for farmers to make a better job and accelerate their transformation and dissemination to their colleagues. If this is too complicated, the best is to stop policies and give freedom to farmers. A good start would be to cancel inadequate policies. Farmers know what is inadequate or facilitating. Ask them. Promote a fair governance, with equity to all stakeholders, each one in its legitimate place. There must be no privilege. Give farmers their legitimate place of key actors in production systems. Do not let other influence you against farmers. Give a real role of co-production of public policies to innovative farmers. Decisions must be based on reality, facts and science. Not on opinions, believing, influence or manipulation of public opinion. Take care of public expenses. Too many business models are based on chasing public funds. Publicly funded actions must be monitored and evaluated according to their results.

Scientists, experts, private sector, NGO's, medias:

Let farmers speak for themselves, dot not by-pass them to influence policies. Farmers are the only ones producing material goods and services, when all other produce words, reports, knowledge, but without impacting directly the real material world of production.
You depend more on farmers than farmers depend on you. If you damage farmers work, you will all be in trouble. More than farmers themselves.

Appropriate and fair governance

Is essential for efficacy of the society: The common good is made in common, by all stakeholders, each one in its legitimate place. A claim of a group of interest is legitimate for what it is: just a group of interest. Not beyond. No stakeholder can pretend to talk for other ones, represent "the civil society" alone, or know better than others what is good for all.

Assessment of economic impacts of Conservation Agriculture and precision agriculture technologies on a winter wheat crop

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The adoption of sustainable cultivation practices in modern agriculture such as Conservation Agriculture (CA) and Precision agriculture (PA) is absolutely necessary not only for sustaining crop productivity but also for reducing costs and ensuring economic viability of the farms. The scope of the present study was to compare the economic impacts when integrating CA and PA techniques on a winter wheat crop. During the 2017-18 winter growing period, a pilot field was established on a farmer's field in central Greece testing No-tillage (NT), Sustainable rotation with legumes (SR) and Variable rate fertilization (VRF) and comparing them with traditional practices including ploughing, rotation with maize and constant rate fertilization. Three treatments including different levels of implementation of the sustainable practices: "NT", "NT+SR", "NT+SR+VRF" were compared with a reference method "R" containing all the traditional practices.

All field operations and inputs were recorded analytically in timesheets. Final yield was measured with a combine harvester provided with a yield monitor. The data were analysed for estimation of production costs, gross and net profits for each treatment. The investment cost of the equipment was also taken into account. For that scope, the FarmEcon tool (Cavalaris et al., 2015), a computational model giving the opportunity for a holistic economic analysis of agricultural farms was used.

Two alternative scenarios were examined. The first one was considering the actual farm size of the collaborating farmer, which was 20ha and which is representative of the small farms in Greece and the second one, an hypothetical large farm of 300ha but with the same crops and structure.

The results shown that no-tillage had a clear positive effect on winter wheat yield. The average yield in the traditional R plot was 3.38t/ha while NT yielded 3.73t/ha. The combination of no-tillage with a legume rotation in the NT+SR method provided a further yield increase at 4.26t/ha. The best results were obtained with the combination of all the three sustainable practices in the NT+SR+VFR method which gave 4.37t/ha.

The economic analysis revealed important margins for cost reduction for both the small size, 20ha farm as also for the large 300ha farm when sustainable methods are implemented. Compared with R, cost reduction for NT and NT+SR was 170€/ha for the small farm and 195€/ha for the large. The cost reduction comes from abolishing soil tillage and from the lower depreciation of the machinery (only for the big farm). The addition of VRF at NT+SR+VRF method provided a further reduction of 15€/ha and 31€/ha for the small and big farm respectively, coming from savings at the fertilizer use.

The net income is estimated negative for all the cases of the small farm and positive for the sustainable methods at the big farm (still negative for R). The negative result is owed to the high depreciation costs of the farm equipment, a factor that is often dismissed by the farmers. For the big farm, the net income was -85€/ha for the reference method R, 191€/ha for NT, 338€/ha for NT+SR and 346€/ha for NT+SR+VFR.

Keywords: *Conservation Agriculture, Precision agriculture, no-tillage, economic analysis*

1. Introduction

In the frame of a highly competitive global agricultural environment, economic viability of agricultural enterprises passes through the adoption of novel but also well established sustainable schemes like Conservation Agriculture (CA) and Precision Agriculture (PA). CA is performed for many years all over the world (Kassam et al., 2019) and lately is envisaged as an essential tool to comply with global environmental strategies such as the Paris Agreement for reductions on greenhouse emissions and the 4p1000 commitment to capitalize on the increase of soil carbon (Minasny et al., 2017) and combat climate change (Delgado et al, 2013). CA is based in three basic principles namely, minimum soil disturbance, permanent soil cover and crop rotations. It is a system with a respectful long term recognition for its multiple benefits delivered through improving and stabilizing crop productivity, conserving the soil and water, increasing soil biota and improving soil fertility, reducing energy use, fuels and crop production costs and its potential for mitigation and adaptation to climate change (Kassam et al., 2009; Gonzalez-Sanchez et al., 2018). Compared to CA, PA is a rather younger approach that is taking advantage on the rapid developments in information and communication technologies (Cisternas et al., 2020). Among its important benefits is the reduction in external inputs such as fertilizers, pesticides etc, the rational use of irrigation water, the reduction of soil compaction, the reduction of GHGs emissions and elimination of soil and water pollution (Medici et al., 2021). Both methods are widely adopted and well recognized for their profits. Their combined implementation is an indispensable step forward not only for sustaining crop productivity but also for reducing costs and ensuring economic viability of the farms (Palm et al., 2014; Balafoutis et al., 2017, Jat et al., 2018). The scope of the present study was to compare the economic impacts when integrating CA and PA techniques under real farmer's conditions.

2. Material and methods

2.1. Pilot field setup

A pilot field was established in 2018 in the region of Perivlepto, central Greece to test the performance of three sustainable agricultural practices namely No-tillage (NT), Sustainable rotation with legumes (SR) and Variable rate fertilization (VRF) over a winter wheat crop. The pilot field was 8ha and was divided into four plots including a scaling-up combination of the above sustainable practices as also, a traditional farmer practice treatment, served as a control. The three sustainable treatments were:

- **No-tillage (NT)** (Integration level I). The treatment was established on a part of the field that included maize as a previous crop. Direct drilling of winter wheat was performed with a Kuhn SD Liner 3000 no-till planter over the shredded mulch of maize.

- **No tillage and sustainable rotation (NT+SR) (**Integration level II). One part of the farmer's field included a legume (beans) as a previous crop. Direct drilling was applied again over the bean's mulch without any disturbance of the soil. No glyphosate application was considered necessary to control weeds in neither of the no-till previous methods.

- **No tillage, sustainable rotation and variable rate fertilization (NT+SR+VRF). (**Integration level III). As before, direct drilling was performed after the legume rotation but also nitrogen was applied at a variable rate using the Eye-Q system developed by Augmenta (www.augmenta.org).

A fourth, **Conventional treatment (CT)** based on the farmer practices was established as a control. The treatment included all the farmer's traditional practices involving soil ploughing and secondary cultivation with a tine cultivator. The method was allocated on the part of the field containing maize as a previous crop. Sowing was performed with the farmer's conventional drill. Nitrogen fertilization was applied at a flat rate at usual doses used by the farmer.

All the rest farming practices (basic fertilization, sowing date, seed rate, crop protection were similar among the treatments according to the farmer usual practices.

Harvest was done with a combine harvester with a yield mapping system providing the chance to estimate average crop yield among the treatments as well as to perform a statistical analysis to compare the results.

2.2. Economic analysis

A systematic register of all the applied field tasks, the agricultural inputs and their prices were kept during the whole growing period. These registrations along with the final yields and current grain prices were entered into the FarmEcon platform (Cavalaris et al., 2015), a computational model giving the opportunity for a comprehensive economic analysis of agricultural enterprises. The platform is able to estimate both variable and fixed production costs and provides the user the chance to select the kind of inputs to be encountered in the computations. Variable costs refer to the expenses made by the farmers usually annually during the growing period, directly related to a specific crop and therefore clearly anticipated by the farmers (e.g. seeds, fertilizers, pesticides, fuels, labor, equipment repairs and maintenance and other direct payments). Fixed costs refer to institutional capital investments in the form of machinery, equipment and facilities that are necessary for the production process but are made once or rarely, and therefore they are usually neglected by the farmers. They are also known as hidden costs and may comprise a significant part to the whole production cost especially in small scale enterprises which is the usual case in Greece and most of the European countries. Fixed costs include capital spending and relative interests, fees and taxes and cost of storage. In the present study, both cases were examined. In addition, two alternative scenarios were encountered. The first one was considering the actual farm size of the collaborating farmer, which was 20ha and which is representative of the small farms in Greece and the second one, a hypothetical large farm of 300ha but with the same crops. For the small enterprise, the actual farmer's machinery comprising of two tractors (a medium 130hp and a small one, 65hp) were taken into account. The large farm was assumed to utilize also two tractors but of a larger size 170hp and 110hp. An investment to a no-till planter was considered necessary when transitioning from conventional to no-till as also buying a system for variable rate fertilization when up-scaling in VRF. Shifting to a smaller tractor and abolishing all the tillage implements were some additional assumptions for no-till in order to reveal the whole potential profits.

2.3. Results and discusion

The stepwise addition of sustainable practices improved winter wheat production in a similar scalar mode. As shown in Tables 1 and 2, the transition from traditional plough tillage to a no-tillage system improved yield by 10.4%. The combination of no-tillage with a sustainable rotation scheme involving a legume, provided an additional improvement in yield by 16%. It is worth to mention that no-tillage and appropriate crop rotations comprise the two of the three basic pillars for Conservation Agriculture. Finally, the introduction of variable rate fertilization as another sustainable practice to upgrade the previous treatments, improved further the crop yield by 3.1%. The overall improvement from conventional CT method to the fully implemented NT+SR+VRF was 29.5%. From the three integrated sustainable practices the most important for yield was the crop rotation followed by the tillage technique and finally, the variable rate fertilization.

Table 1. Variable costs, total costs (fixed and variable), net income and cost of production for a small farm of 20ha. CT = Conventional treatment, NT = No-tillage, NT+SR = No tillage and Sustainable rotation, NT+SR+VRF = No-tillage and Sustainable rotation and Variable rate fertilization.

	Variable costs				Variable & fixed costs			
20ha enterprise	**CT**	**NT**	**NT SR**	**NT SR VRF**	**CT**	**NT**	**NT SR**	**NT SR VRF**
Expenses (€/ha)								
Tractor depreciation					334	334	334	334
Soil tillage	168	0	0	0	243	0	0	0
Fertilization	213	212	212	180	223	222	222	207
Sowing	137	135	135	135	168	242	242	242
Spraying	56	55	55	55	74	73	73	73
Irrigation	106	106	106	106	124	124	124	124
Harvest	101	101	101	101	101	101	101	101
Transportations	1	0	0	0	19	18	18	18
TOTAL	781	610	610	578	1286	1115	1115	1100
Yield (kg/ha)	3370	3720	4260	4360	3370	3720	4260	4360
Production cost (€/kg)	0.23	0.16	0.14	0.13	0.38	0.30	0.26	0.26
Gross income (€/ha)	775	856	980	1003	775	856	980	1003
Net income (€/ha)	-6.2	245	369	425	-511	-260	-135	-98

Improving crop yields is of course an invaluable benefit for the farmers but the sustainable practices under consideration have the potential to reduce also production costs. Indeed, no-tillage eliminated the variable and fixed costs of tillage by 170€/ha in the small farm and by 195€/ha in the large one (Tables 1 & 2). An extra reduction of 23,4€/ha was encountered for the large farm by shifting to smaller tractors with no-till. Nevertheless, there was an increase at the cost of sowing for NT due to the investment to a no-till drill This increase were at the order of 10.4€/ha for the large farm but was escalated to 74€/ha for the small farm deriving mainly from intensive capital spending and interests. Fixed costs are extremely high for the small farm because the limited annual use of machinery and equipment result to an extremely high hourly cost. Farmers usually neglect this but if they do consider, it may reverse their perception for the profitability of their farms by encountering a negative net income. This was the case for all the treatments in the small scale farm as also for the CT treatment in the large farm. It is also worth mentioning that the small farm resulted on a negative income for CT method, even if just the variable costs were taken into account.

Table 2. Variable costs, total costs (fixed and variable), net income and cost of production for a large farm of 300ha. CT = Conventional treatment, NT = No-tillage, NT+SR = No tillage and Sustainable rotation, NT+SR+VRF = No-tillage and Sustainable rotation and Variable rate fertilization.

	Variable costs				Variable & fixed costs			
300ha enterprise	**CT**	**NT**	**NT SR**	**NT SR VRF**	**CT**	**NT**	**NT SR**	**NT SR VRF**
Expenses (€/ha)								
Tractor depreciation					36	12	12	12
Soil tillage	167	0	0	0	192	0	0	0
Fertilization	214	214	214	182	216	216	216	185
Sowing	139	150	150	150	142	163	163	163
Spraying	55	55	55	55	59	59	59	59
Irrigation	103	103	103	103	112	112	112	112
Harvest	101	101	101	101	101	101	101	101
Transportations	0.4	0.1	0.1	0.1	1.6	1.3	1.3	1.3
TOTAL	779	624	624	592	860	665	665	634
Yield (kg/ha)	3370	3720	4260	4360	3370	3720	4260	4360
Production cost (€/kg)	0.23	0.17	0.15	0.14	0.26	0.18	0.16	0.15
Gross income (€/ha)	775	856	980	1003	775	856	980	1003
Net income (€/ha)	-4.2	232	356	411	-85	191	315	369

Legume rotations are well established for their potential to improve soil fertility and reducing the needs for nitrogen fertilization. In the present case however, it was decided not to use less nitrogen fertilizer because no-tillage was firstly introduced so keeping a balanced C:N ratio is essential for also fulfilling the demands of the mulch decomposing microorganisms (Jat et al., 2018). Variable rate fertilization however reduced the total amount of nitrogen fertilizer by 18% in the NT+SR+VRF method. It also spatial redistributed the rate resulting in improved nitrogen use efficiency. VRF requires though the investment to appropriate variable rate equipment.

Considering both the effects on yields and production costs it is estimated that NT method was capable to improve the net income by 251€/ha in the small-scale farm and by 276€/ha in the large farm. The net income however, remains still negative for the small farm, when both variable and fixed costs are taken into account, but hopefully turns to positive (by 191€/ha) for the large farm. The introduction of the legume rotation increased further the net income in NT+SR by 124€/ha both in the small and the large-scale farm. The overall profit raised to 375€/ha and 400€/ha respectively compared to the CT method. Finally, the introduction of VRF at the NT+SR+VRF method improved profitability by further 38€/ha for the small farm and by 54€/ha for the large farm resulting on an improved overall profit of 413€/ha and 454€/ha respectively compared to CT.

The selling price of durum wheat during the studied year was 0.23€/kg. Considering the production costs per kg of grain it is realized that for the small-scale farm there is no chance to cover the expenses with the conventional farmer practice method even if only variable costs were taken into consideration. The farmers therefore rely on the extra income from the associated EU subsidies (which are not encountered on the present study). The integration of sustainable farming practices may provide the opportunity to obtain a positive income but only if fixed costs are neglected. The only way to sustain a real profit is by integrating sustainable practices in large scale farming schemes. In that case, the integration of all three sustainable practices in NT+SR+VRF method, provided a margin of 0.08€/kg for a farmer profit.

Conclusions

In the present study, Conservation Agriculture and precision agriculture practices were evaluated for their economic profitability under real farmer conditions on a pilot field. No-tillage, sustainable legume rotation and variable rate fertilization were added on a scaling-up pattern of treatments. From the three practices, no-tillage was the method that boosted most the profit per ha and per kg of grain by improving crop yield by 10.4% and at the same time, reducing production costs by 23%. The combination of no-till with a legume rotation improved the yield by a further 16%. Additional implementation of variable rate fertilization provided a further reduction of 4% in the production costs and also improved yield by 3.1%. On a descending order the profitability of the tested methods were evaluated as: no-tillage > sustainable rotation > variable rate fertilization. The analysis revealed also the importance of the farm size showcasing that a real farmer profit can be obtained only by intensive annual use of agricultural equipment (either on single large farms or in collaborative schemes of common use) in order to suppress the fixed costs of the investments.

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Fine-tuning nitrogen fertiliser norms for wheat under Conservation Agriculture in South Africa

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Current N norms for wheat are derived from N response trials under conventional tillage and wheat monoculture, as well as adoption from research that originated mainly from Western Australia. Development of scientifically sound N norms for wheat the Western Cape is required. The aim of this study was to evaluate N requirement for wheat and to determine optimal N top dress rates under CA.

Cropping systems included were dryland wheat (*Triticum aestivum* L.) after canola (*Brassica napus* L.), medics (*Medicago spp*) or lupine (*Lupinus spp*) or after lucerne (*Medicago sativa*). Randomised block design with eight N top dress rates and four replicates. The N top dress treatments comprised of different N rates (0, 25, 50, 75, 105, 135 and 165 kg N ha^{-1}). Grain yield and quality were recorded. Linear and segmented linear models were fitted to normalised data.

At Darling (medium deep sandy soil) the control yield was 1282 kg ha^{-1} for the canola-wheat rotation and 1347 kg ha^{-1} for medics-wheat. Yields increased by 0.87% kg^{-1} of N applied between N rates of 0 and 34.56 kg ha^{-1}, thereafter slowed to 0.11% kg^{-1} of N applied. At Porterville (deep reddish coloured clay loam soil) the yield of the control was 1997 kg ha^{-1} for canola-wheat and 2591 kg ha^{-1} for medics-wheat. Yield increased at a rate of 0.16% kg^{-1} of N applied between N rates of 0 and 72.92 kg ha^{-1}, thereafter the yield declined at a rate of 0.07% kg^{-1} of N applied. At Tygerhoek (shallow sandy loam shale derived soil) the control yield was 3060 kg ha^{-1}. Yield increased at a rate of 0.55% kg^{-1} of N applied between N application rates of 0 and 59.72 kg ha^{-1}, thereafter yield declined with a rate of 0.05% kg^{-1} of N applied.

Results shows that biologically optimum yields can be reached at lower total N application rates than currently prescribed. Determining site specific economically optimum N application rates are in process.

Keywords: *Conservation Agriculture, fertiliser, nitrogen, wheat*

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1. Introduction

Current N norms for wheat derived mainly from N response trials under conventional tillage and wheat monoculture, as well as adoption from local experience and research that originated mainly from Western Australia. Very useful information regarding fertilizer N requirements is also available from the Fertilizer Association of Southern Africa (Anon 2016). Adoption of conservation agricultural practices will also positively influence soil physical, chemical and biological properties and will, amongst others, influence nitrogen relations and N mineralization in the topsoil. Development of scientifically sound N norms for wheat the Western Cape is required. The aim of this study was to evaluate N requirement for wheat and to determine optimal N fertilization rates under Conservation Agriculture in the Western Cape grain producing areas.

2. Materials and methods

The research was conducted during the 2016-2020 growing seasons and included localities in both the Swartland and southern Cape sub-regions of the grain producing areas of the Western Cape Province of South Africa. Six different sites were included Riversdale (34º9'38"S,21º9'6"E), Riviersonderend (34°08'56.5"S,19°54'09.9"E), Caledon (34°12'03" S,19°16'12"E), Moorreesburg (33°16'34.8"S,18°42'15.3"E), Darling (33°17'04.9"S,18°21'04.0"E) and Porterville (32°54'49.2"S,18°55'58.9"E). Cropping systems included were dryland wheat (*Triticum aestivum* L.) after canola (*Brassica napus* L.), medics (*Medicago* spp) or lupine (*Lupinus* spp) or after lucerne (*Medicago sativa*). Randomised block design with eight N top dress rates and four replicates. For the purpose of this presentation, only the wheat after canola sites will be covered. The N treatments comprised of different N rates (0, 25, 50, 75, 100, 130, 160 and 190 kg N ha-1). Grain yield and quality were recorded. It was concluded that quadratic functions fitted the data best and were of better practical value than other models tested initially.

3. Results

At most sites a positive response to increased fertilizer N rates were observed within the 0 – 50 kg N ha^{-1} application rates for the wheat after canola systems. To minimize the year effect, relative yield (yield expressed as a percentage of maximum yield recorded for a specific year and site) was calculated for all sites and years (Fig. 1). Relative yield was plotted against N application rate and the quadratic function used to calculate the grain yield at 90% of maximum biological yield (Table 1). This was done for all sites and cropping systems included in the study. For the purpose of this abstract, only the Tygerhoek site will be included as an example.

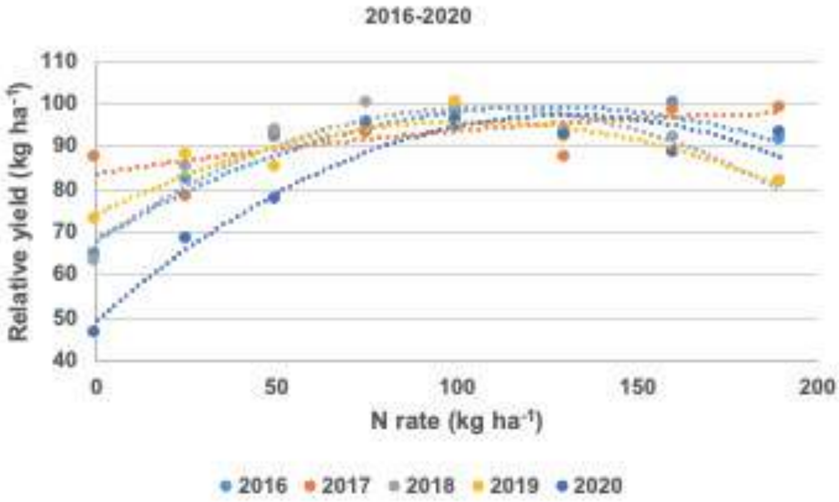

Fig. 1. Relative yield of wheat after canola at Tygerhoek Research Farm (Riviersonderend) in response to fertilizer N application rate 2016-2020.

Year	Quadratic function	R^2	P value	Yield al 90% (kg ha⁻¹)	Kg N at 90% (kg ha⁻¹)	Protein %
2016	y= -0.002291971x2 + 0.56856x + 64.9467	0.9071	0.0026	4072	57N	10.9
2017	y= -0.000292747x2 + 0.13183x + 83.533	0.4813	0.1938	4467	56N	11.9
2018	y= -0.00275668x2 + 0.58837x + 67.6719	0.8699	0.0061	5372	49N	11.2
2019	y= -0.002003626x2 + 0.41415x + 74.4652	0.8414	0.0099	2775	49N	12.4
2020	y= -0.002807959x2 + 0.73609x + 49.2435	0.9296	0.0013	4901	80N	*

Table 1. Quadratic functions, R^2-value, P-value, yield at 90% of maximum (kg ha^{-1}), nitrogen applied to achieve 90% of maximum yield (kg ha^{-1}) and protein content (%) at Riviersonderend wheat after canola 2016-2020.

Summary and conclusion

Interpretation of data collected over the 5-year period shows great potential to reduce the recommended N application rate but still obtain high wheat grain yields of acceptable quality.

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The future of farming

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Perceptions on soil macrofauna in the agricultural field

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Soil is responsible for one quarter of the biodiversity on our planet. The soil fauna is divided in groups according body size: microfauna, mesofauna and macrofauna, and each contribute to soil functions and the soil food web. Soil management directly the soil fauna, and knowledge of the role of these animals in soils is important for their proper conservation and for sustainable agriculture. In the present study, we evaluated the social perceptions concerning soil macrofauna among farmers and professionals working in agriculture. A questionnaire was applied in the years of 2008 and 2018 in the National No-Tillage Meetings in Brazil. A total of 12 questions identified the profile of those interviewed, soil management practices and their perceptions regarding soil macrofauna. A total of 171 people answered the questionnaire (87 in 2008 and 84 in 2018), including 33% farmers in 2008 and 31% in 2018. From the list of nine organisms (Oligochaeta – earthworms, Hemiptera – stinkbugs, Formicidae – ants, Diplopoda – centipedes, Araneae – spiders, Isoptera – termites, Coleoptera – beetles, Chilopoda – millipedes and Gastropoda – slugs) only earthworms, spiders and centipedes were not generally considered pests. When asked if they observed an increase in pest incidence, 61% of the interviewees noticed an increase in 2008 and 73% in 2018. This increase was related mostly to the excessive use of pesticides and monocultures in both years, though the number of people relating these practices increased in 2018 (31% and 52%, respectively). Most respondents considered earthworms (93-100%) and spiders (45-64%), to be beneficial animals. The management practices considered to enhance soil biodiversity were mainly green manures, crop rotation, integrated pest management and the use of no-tillage (all >65% in 2008), although the number of responses including these practices decreased slightly 10 years later. In both years <29% of the respondents considered that maintaining native vegetation fragments was important to improve soil biodiversity. When asked about soil health indicators, >80% mentioned the presence of many organisms (although most animals had been considered by many respondents to be pests earlier!), while roughly half mentioned the presence of many earthworms and soil aggregation. The fact that the number of responses mentioning increases in pest incidence increased, and the responses mentioning for good practices decreased after 10 years is worrisome, and highlights the need to further capacity building and dissemination of information regarding the importance and function of soil biodiversity and soil animals to society.

Keywords: *Bioindicators, soil quality, soil macrofauna*

Abstract

Soil is responsible for one quarter of the biodiversity on our planet. The soil fauna is divided in groups according body size: microfauna, mesofauna and macrofauna, and each contribute to soil functions and the soil food web. Soil management directly the soil fauna, and knowledge of the role of these animals in soils is important for their proper conservation and for sustainable agriculture. In the present study, we evaluated the social perceptions concerning soil macrofauna among farmers and professionals working in agriculture. A questionnaire was applied in the years of 2008 and 2018 in the National No-Tillage Meetings in Brazil. A total of 12 questions identified the profile of those interviewed, soil management practices and their perceptions regarding soil macrofauna. A total of 171 people answered the questionnaire (87 in 2008 and 84 in 2018), including 33% farmers in 2008 and 31% in 2018. From the list of nine organisms (Oligochaeta – earthworms, Hemiptera – stinkbugs, Formicidae – ants, Diplopoda – centipedes, Araneae – spiders, Isoptera – termites, Coleoptera – beetles, Chilopoda – millipedes and Gastropoda – slugs) only earthworms, spiders and centipedes were not generally considered pests. When asked if they observed an increase in pest incidence, 61% of the interviewees noticed an increase in 2008 and 73% in 2018. This increase was related mostly to the excessive use of pesticides and monocultures in both years, though the number of people relating these practices increased in 2018 (31% and 52%, respectively). Most respondents considered earthworms (93-100%) and spiders (45-64%), to be beneficial animals. The management practices considered to enhance soil biodiversity were mainly green manures, crop rotation, integrated pest management and the use of no-tillage (all >65% in 2008), although the number of responses including these practices decreased slightly 10 years later. In both years <29% of the respondents considered that maintaining native vegetation fragments was important to improve soil biodiversity. When asked about soil health indicators, >80% mentioned the presence of many organisms (although most animals had been considered by many respondents to be pests earlier!), while roughly half mentioned the presence of many earthworms and soil aggregation. The fact that the number of responses mentioning increases in pest incidence increased, and the responses mentioning for good practices decreased after 10 years is worrisome, and highlights the need to further capacity building and dissemination of information regarding the importance and function of soil biodiversity and soil animals to society.

1. Introduction

Soil is the habitat for several organism and holds one quarter of the world biodiversity, considered by many to function as a living organism (Harshberger, 1911, Decaëns et al., 2006). The soil fauna can be divided into well-defined groups according to body size: microfauna, mesofauna and macrofauna, each providing a unique contribute to soil functioning, in particular to the food web (Swift et al., 1979, Lavelle et al., 1996). The activity of these organisms is tightly associated with the set of ecosystem services provided, not only by directly impacting nutrient cycling, organic matter breakdown, the soil structure and water retention, but also their unique role on soil trophic webs (Lavelle et al., 1997). The feedbacks between soil management and the functioning of soil biota are profoundly important to promote appropriate conservation measure and stimulate a sustainable agriculture (Wolters, 2001).

Many organisms of the soil fauna are bioindicators of the environment quality and their presence/absence is directly related with how the environment and the soil are managed by man (Bianchi et al., 2007; Santos et al., 2019). Farmers and who work directly with soil have considered some organisms as beneficial to soil and know hey assist in the agriculture productivity (Schiedeck et al., 2009). Considering these associations several studies have been focusing on understanding how human action affects soil fauna and whether this information, in particular related to preservation and conservation, is disseminated to the entire society (Pulleman et al.,2005; Lima et al., 2016). Moreover, in assessments that aim people's perception on soil fauna, it is important to emphasize that the main idea is not evaluate people's knowledge, but to understand their points of view in relation to the subject (de Bruyn et al., 2003).

The aim of this study was evaluated the social perceptions concerning soil macrofauna among farmers and other stakeholders working in an agricultural context mainly in Brazil.

2. Methodology

A survey composed by 12 questions was applied in two different moments, first in 2008 at the 11th National Meeting of No-Tillage on the Straw, held in Londrina, Paraná, Brazil, and the second was conducted in 2018 at the 16th National Meeting of No-Tillage on the Straw, held in Sorriso, Mato Grosso, Brazil. The questionnaire was available for those at the events and was answered by whoever wanted.

The questions were multiple-choice and most of them with an open-ended question to complement the answers and the interviewed could choose more than one answer. It was asked profession activity, educational background and geographical. Was also included questions about management practices (major crops produced, livestock, soil management and crop waste residues – straw), soil macrofauna perception (organisms considered pests, trends in pest incidence, causes of the pest increase, but also focused on which organisms are considered beneficial to the soil and which management practices suggest increase in soil biological activity) and how the people assess the health of the soil.

3. Results

In 2008, the National No-Tillage on the Straw Meeting had 600 participants and 87 answered the questionnaire, and in 2018 had 570 participants and 84 answered, about 20% of the participants in both events, totaling 171 answered questionnaires. In 2008, 33% of the interviewees were farmers, 20% technical assistance. In 2008, 36% of the interviewees managed an area larger than 2001 ha and 21% areas 101 to 500 ha. In 2018, farmers were the larger proportion of interviewees (31%). Regarding the size of the exploration area, 51% had managed areas larger than 2000 ha (Table 1).

Table1. Profile of the interviewees.

Question 2008 n=87		Responses (%) 2018 n=84	
Education	Agronomist	61	50
	Other formation	11	13
	Agricultural technician	7	20
	Collage	11	14
	High School	7	8
	Middle School	2	1
Profession[1]	Farmer	33	31
	Researcher	14	11
	Professor	2	8
	Autonomous/Consultant	4	11
	Extensionist	9	0
	Technical Assistance	20	14
	Other	18	24
Country of origin	Brazil	93	100
	Paraguay	7	0
Region of origin in Brazil[2]	North	1	10
	Northeast	0	4
	Midwest	20	78
	Southeast	19	8
	South	60	0
Size of the management area[3]	< 20 ha	13	8
	21 to 50 ha	9	0
	51 to 100 ha	5	4
	101 to 500 ha	28	10
	501 to 1000 ha	6	10
	1001 to 2000 ha	3	7
	> 2001 ha	36	61

[1] Various interviewees answered more than one option; [2] n=78 for both years; n=64 in 2008 and n=71 in 2018.

From the list of nine organisms (Oligochaeta – earthworms, Hemiptera – stinkbugs, Formicidae – ants, Diplopoda – centipedes, Araneae – spiders, Isoptera – termites, Coleoptera – beetles, Chilopoda – millipedes and Gastropoda – slugs), only earthworms, spiders and centipedes were, generally not considered pests (Table 2). When asked if they observed an increase in pest incidence, 61% of the interviewees noticed an increase in 2008 and 73% in 2018. This increase was related mostly to the excessive use of pesticides (25%) and monocultures (38%) for both years, though the number of people relating these practices increased in 2018 (31% and 52%, respectively). When asked what kind of management was used for pest control, the chemical, mechanical and fallow practices were the most cited in both years, but the fallow decreased almost the half and other options, like biological and alternative managements and the Integrated Pest Management (IMP) increased from 0 to 3% in 2008 to 17% to 32% in 2018 (Table 2).

Table 2. Responses about organisms considered to be pests, their control and management practices.

Question **2008** **n=87**		**Responses (%)** **2018** **n=84**	
Organisms considered pests	Oligochaeta	1	2
	Hemiptera	52	62
	Formicidae	41	33
	Diplopoda	33	14
	Araneae	2	7
	Isoptera	55	38
	Coleoptera	62	43
	Chilopoda	6	8
	Gastropoda	37	38
	Others	17	20
Increase in plagues/pests	Yes	61	73
	No	39	27
Reason for the increase of plagues/ pests	Pesticides	25	31
	Monocultures	38	52
	Pest/plague resistance	21	13
	Other	16	3
Management used for pest control	Chemical[1]	40	49
	Biological[2]	0	17
	Mechanical[3]	33	39
	Alternatives[4]	3	17
	IPM[5]	3	32
	Fallow	94	48
	Nothing	3	4

[1] Use of traditional pesticides; [2] Use of viruses, bacteria, parasites, etc.; [3] plowing, harrowing, etc.; [4] Homeopathy, herbal medicine, etc.; [5] Integrated pest management.

Most respondents considered earthworms (93-100%) and spiders (45-64%), to be beneficial animals. The management practices considered to enhance soil biodiversity were mainly green manures, crop rotation, integrated pest management and the use of no-tillage (all >65% in 2008), although the number of responses including these practices decreased slightly 10 years later. In 2008 <40% of the respondents considered that maintaining native vegetation fragments was important to improve soil biodiversity, but in 2018 only 29% considered this option. When asked about soil health indicators, >80% mentioned the presence of many organisms (although most animals had been considered by many respondents to be pests earlier), while roughly half mentioned the presence of increased number of earthworms and soil aggregation.

Table 3. Responses on soil macrofauna as beneficial organisms, good management practices and soil health.

Question 2008 n=87		Responses (%) 2018 n=84	
Organisms considered beneficial	Oligochaeta	93	100
	Hemiptera	7	7
	Formicidae	22	23
	Diplopoda	18	23
	Araneae	64	45
	Isoptera	10	15
	Coleoptera	26	18
	Chilopoda	17	13
	Gastropoda	5	10
	Others	7	5
Management to favor soil biodiversity	Green manure	90	77
	Crop rotation	91	89
	Native forest fragments	40	29
	IPM	15	65
	Terracing	22	19
	Subsoilong[1]	5	6
	No-Tillage System	90	82
	Minimum tillage	11	17
	Other	3	0
Destination of the straw on soil	Left on the soil	93	88
	Burned	2	0
	Incorporated in soil	7	11
	Animal feeding	6	7
	Silage	1	4
	Other	3	1
How assess soil health	Many organisms	80	85
	Many earthworms	51	45
	Soil color	20	37
	Texture	15	45
	Soil aggregation	49	46
	Plants as indicator	21	0
	Other	22	0

[1] Mechanical practice using equipment (subsoiler or rippers) to break up soil compacted layers (30 to 50 cm depth).

4. Discussion

The social perception, especially from farmers and other stakeholders working in agriculture, concerning the functions, importance and benefits promoted by soil macrofauna, is still lacking. Generally, farmers recognize that organisms are capable of modify soil structure, the dynamic of organic matter and nutrients and balance of the food web, but few are aware about how these activities can assist water infiltration, aeration, improve soil fertility and plant growth, reflecting directly the soil health.

A review was conducted by Pauli et al. (2016) on the studies performed and the knowledge of farmers regarding the use of soil macrofauna. Across continents, the authors observed that most of the studies are focused mainly in one taxonomic group and this inclination happens according to the location and the importance or how strong negative impacts were observed (Pauli et al., 2016).

In Brazil, throughout the different regions, is possible to observe some knowledge regarding the benefits of the macrofauna for the soil, mostly for earthworms, as several farmers emphasize that a soil with earthworms is a healthy soil with better fertility and helping with crop production (Schiedeck et al., 2009; Van Groenigen et al., 2014; Schiavon et al., 2015). In some regions, where the dissemination of information is more difficult and most farmers use agriculture for subsistence, there is almost nothing regarding the knowledge about soil macrofauna or how to classify a healthy soil (Lima et al., 2016).

Talking directly to farmers in situ and enquiring about their actions towards a sudden increased amount of organisms (insects, bugs, millipedes, crickets, etc.) in their crop fields, they spontaneously answered: "I apply pesticides!" (personal observation M.L.C. Bartz). There is a major misunderstanding concerning the function and importance of the soil biodiversity that embodies the perceptions of farmers, technical workers and other professionals linked to agriculture. We suggest that these patterns are associated with market and consumer perceptions, especially shaped by the ones that sell products for farming, and that are not well prepared to work with a biodiverse environment. Moreover, in Brazil and probably elsewhere, there is a profound gap between the academic community with those that directly work in agriculture.

5. Conclusions

In this study, the fact that most soil macrofauna were not perceived as beneficial and that the number of responses showed an increase in pest, together a decreasing trend in the application of good practices after 10 years is worrisome, and highlights the need to foster capacity building and to stimulate dissemination of evidence regarding the importance and function of soil biodiversity to society.

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The first twenty years-the development and adoption of a climate smart grain production system for the Swartland region of the Western Cape Province, South Africa

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A long-term crop rotation trial was launched by the Western Cape Department of Agriculture at Langgewens Research Farm (33.276821552S 18.703171288E) near Moorreesburg in the Swartland region of the Western Cape, in 1996. The aim was to determine the short- and long-term effects of eight of the most feasible crop and crop/pasture rotation systems identified for the Swartland on: crop yields, weed control, disease suppression, soil production potential, sheep production, and economically sustainable land-use in the Swartland. The initial project continued for 20 years and was terminated in its original form, in 2015, as planned. An integral part of this research was also the development of Canola as an alternative crop for the Western Cape. After 20 years, an impact study was undertaken by an independent company to investigate the impact (social and economic) this trial has had on the greater Swartland region at the end of the 20 years.

The effects of crop rotation on wheat yield over the 20-year period shows that wheat monoculture, being the norm at the time of inception of the trial, has become inefficient as part of an efficient production system, with the lowest wheat yield over the period. A general trend was that the systems including the legume pasture, Medic (primarily a mixture of *Medicago truncatula* and *Medicago polymorpha)* showed the highest wheat yields and biggest percentage improvement in overall wheat yield. Implementing crop rotation had an overall 30% improvement on average wheat yield over the period when compared to a wheat monoculture system. Wheat yield data showed that there was a 15% overall improvement in wheat yield with the implementation of no-tillage. Carbon percentage increased over the range, from a low of 18% to the highest of 34%. The pasture cropping systems showed a slightly higher improvement of 2% Carbon over the cash cropping systems. These results where a major driving force in convincing farmers to convert to crop rotation systems. The trial has also built capacity in terms of postgraduate students, a comprehensive Conservation Agriculture (CA) research programme was initiated over other regions and this has lead to climate change resilience in production systems over the province.

The Conservation Agriculture (CA) research programme is seen as one of the game changing initiatives of the Western Cape Department of Agriculture. It has shown how starting out with a long-term multidisciplinary crop rotation research project in 1996, has led to the development of a small grain industry norm and practice, resulting in farmers being competitive, resource smart and climate smart.

***Keywords**: grain, systems, adaptation, sustainability, resilience*

1. Introduction

The Conservation Agriculture (CA) research programme has shown how starting out with a long term multidisciplinary crop rotation research project in 1996, has led to the development of a small grain industry norm and practice, resulting in farmers being competitive, resource smart and climate smart.

1.1. Long Term Crop Rotation Trial

A long term crop rotation trial was launched at Langgewens Research Farm near Moorreesburg in the Swartland region of the Western Cape, in 1996. The aim of this study was to determine the short- and long-term effects of eight of the most feasible crop and crop/pasture rotation systems identified for the Swartland on: crop yields, weed control, disease suppression, soil production potential, sheep production, and economically sustainable land-use in the Swartland. The research project has led to several long term research projects incorporating CA principles. The initial project continued for 20 years and was terminated in its original form, in 2015, as planned.

1.2. Capacity building through component trials

Various component research projects were executed on this crop rotation trial over the years, investigating a range of production factors. An integral part of this research drive was also the development of Canola as an alternative crop for the Western Cape.

Industry partners have contributed funding for this project. Producers' interest followed, which has led to the success of this long term trial.

Capacity building started out with the project team being trained and using some of the data for their postgraduate studies Postgraduate students from universities were contracted to execute specific component projects. This escalated the profile of the project.

1.3. Impact studies

Two economic impact studies were also conducted to assess the impact of CA and specifically the role research played in the adoption of the CA in rain-fed production in the province, and another study, as part of its monitoring and evaluation programme, was undertaken by an independent company in 2015. The aim was to investigate the impact the crop rotation trial on Langgewens has had on the greater Swartland region at the end of the 20 years, and also to provide recommendations for the future.

1.4. Conservation Agriculture and Climate Change

The crop rotation trial has also lead to the establishment of the association "Conservation Agriculture Western Cape "and also the development of an extended research programme on CA practices. This crop rotation trial, together with the CA research programme, was subsequently also one of the case studies for "Smart Agriculture for Climate Resilience" (SmartAgri Case Study #2, 2016) a framework and implementation climate change response plan developed for the Western Cape Government, with the vision "Leading the way to a climate-resilient agricultural future for the Western Cape with a coordinated sector plan". The plan presents the "road map" for the agricultural sector to travel towards a more productive and sustainable future, despite the uncertainties around specific climate projections.

1.5. Technology transfer

The demand for data from this trial grew to such an extent that an annual information day was not sufficient and it was expanded with "walks & talks", invitations to speak at study groups and various other agricultural meetings. Consequently technical advisors of agri-businesses and also manufacturers of planters became involved in the trial. They became part of the research, with the result that developments in the trial, as well as the greater CA programme, escalated because of their involvement and contribution.

2. Materials and methods

2.1. Long Term Crop Rotation Trial

Langgewens Research Farm is situated in one of the most important areas for wheat production in South Africa. It experiences a Mediterranean climate with hot and dry summers, and cool winters with winter rainfall. The long term average annual precipitation is 398.2 mm with around 80% of the rainfall falling during winter (April to September). The aim of the crop rotation trial was to determine the short- and long-term effects of eight of the most feasible crop (4) and crop/pasture (4) rotation systems identified for the Swartland on: crop yields, weed control, disease suppression, soil production potential, sheep production, and economically sustainable land-use in the Swartland. The four crop rotations were: WWWW (Wheat:wheat:wheat:wheat); CWWW (Canola:wheat:wheat:wheat); CWLW (Canola:wheat:lupin:wheat); LCWW (Lupin:canola:wheat:wheat).

The four crop/pasture rotations were: MWMW (Medic:wheat:medic:wheat); MCMW (Medic:canola:medic:wheat); McWMcW-(Medic/clover:wheat:medic/clover:wheat); McWMcW-2(Medic/clover(+shrub*):wheat:medic/clover(+shrub):wheat). * Shrub refer to the additional availability of salt bush within this system to allow for sufficient initial growth of the medic/clover pasture.

The experimental area was 50 ha with two replications of each crop sequence and rotation system. The trial lay-out ensured that, in any given year, all the phases of each rotation were represented.

A record of all activities was kept for each replicate of each treatment to facilitate the calculation of input costs to each crop rotation system. Data collection included the following: soil data, planting data, weed seedbank data, sheep data (including carcass data), pasture and crop data, disease control data, wheat and canola quality, economic analyses for each of the 48 camps, and climatic data.

2.2. Capacity building through component trials

Component trials formed part of the crop rotation trials and were executed by other researchers. These component trials focused on a range of aspects including economic studies, soil nitrogen dynamics, monitoring seedbanks, monitoring plant diseases, soil arbuscular mycorrhiza and wheat quality and baking characteristics. The component trials were suitable for postgraduate studies and developed capacity building and collaboration.

2.3. Impact studies

An impact assessment was done on the role research played in the adoption of CA in rain-fed wheat production in the province. The aim was to evaluate the impact

of the long-term crop rotation trials on (1) the shift from monoculture cropping to crop rotation in the Swartland and (2) of the sustainability of farming systems in the grain producing areas and (3) the effect that the research had on the adoption rate of CA and (4) the production value of wheat within the new production methods.
An internal monitoring and evaluation study was executed on the impact of the long term crop rotation trial on the greater Swartland region. This evaluation focused on determining the short and long-term effects of the 8 rotation systems in terms of the following aspects: crop yields; weed control; disease suppression; soil production; sheep production; and economically sustainable land-use in the Swartland. This was done through interviews.

2.4. Conservation Agriculture and Climate Change

The long term crop rotation trial addressed certain CA principles, but a study tour to Argentina escalated the need for more research and awareness regarding no-till cropping and proposing the active promotion and implementation of CA.
The Western Cape Department of Agriculture then coordinated an inaugural meeting and supplied the secretariat for the association Conservation Agriculture Western Cape – CAWC, undertaking to render support until the farmers in the province were organised and sufficiently capacitated to operate the association independently.

This long term crop rotation trial was also one of the case studies for the SmartAgri Plan for the Western Cape. The study started with an assessment of climate change responses in agriculture in the province. It also engaged in the assessment of risk and impacts of commodities within agro-climatic zones to provide an understanding of the response gaps, needs and opportunities.

2.5. Technology transfer

Technology transfer has progressed from an initial annual farmer's day and various publications. As a result, farmers became more involved and the demand for information grew. "Green Tours" (Walk-and-Talks within the growing season) and "Brown Tours" (Walk-and-Talks during the dry season when there are no crops growing) were initiated where scientists, technical advisors, extension officers and farmers could share ideas and experiences towards enhancing Conservation Agricultural practices in the province.

3. Results and discussion

3.1. Long Term Crop Rotation Trial

The main findings from the 20 year crop rotation trial at Langgewens include the crop data (as seen in Table 1) and ryegrass weed seedbank data.

Table 1: The average wheat yield per crop sequence over the 20 year period. (W=wheat; C=canola; L=lupin; M=medic; Mc=medic/clover pasture)

Crop sequence	Yield in (kg/ha)	% Improvement in overall wheat yield due to crop sequence
WWW**W**	2570	-
C**W**	3166	23
CW**W**	2950	15
CWW**W**	2658	4
L**W**	3347	30
M**W**	3510	37
Mc**W**	3422	33

From Table 1, the effects of crop rotation on wheat yield over the 20 year period shows that wheat monoculture, being the norm at the time of inception of the trial, has become inefficient as part of an efficient production system, with the lowest wheat yield over the period. Evident from the yield data is that the systems including the legume pasture, Medic (mixture of *Medicago truncatula* and *Medicago polymorpha*), showed the highest wheat yields and biggest percentage improvement in overall wheat yield. This is generally ascribed to the fact that Medic is a legume, thus binding Nitrogen in the soil benefitting the follow-on crop (in this case, wheat) and also the fact that Medic is a broad-leafed crop and that the main weed species (Ryegrass) can be relatively successfully controlled during the broadleaf crop phase of the sequence, prior to the wheat year.

Focusing on the sequences with multiple years of wheat following on canola (CW, CWW and CWWW), the data shows clearly that the wheat yield decreased with an increase of wheat cropping phases following on the canola phase. This result shows the negative effect of wheat following on wheat, on the wheat yield within a system. Thus, during the third year of wheat after a canola year, the effect is almost reaching what one see within a wheat monoculture, with the main challenges being progressively inefficient weed management of *Ryegrass* weed within the successive wheat phases over the next three years.

Crop rotation had an overall 30% improvement on average wheat yield over the period when compared to a wheat monoculture system.

From 1996 to 2001, minimum tillage was implemented, while no-till was implemented from 2002 until the end of the trial period in 2015. Wheat yield data showed a 15% overall improvement in wheat yield with the implementation of no-tillage. When comparing no-till monoculture wheat to no-till crop rotation, data showed an improvement over monoculture for all crop rotation sequences. This confirmed that even under a no-till regime, wheat monoculture was not sustainable and that crop rotation is key to changing the efficiency and sustainability of the farming systems in the Swartland.

Results from the *Ryegrass* weed seedbank studies revealed that the effect of the same crop, year on year, had an influence on weed management. An example is the sequence CWWW, where *Ryegrass* seedling numbers per square meter increased with the number of wheat phases following on each other. Within the MCMW sequence, the number of *Ryegrass* seedlings per square meter decreased over the four year period of the sequence. This data showed the magnitude of the change that crop rotation has brought and is strengthened by the findings that showed the decrease in herbicide inputs reported by farmers after implementing crop rotation.

Since 2001, when no-till practices were implemented in the trial, the percentage Carbon in the soil was also recorded. Carbon percentage increased over the range, from a low of 18% to the highest of 34% with the pasture cropping systems showing a higher improvement of 2% Carbon over the cash cropping systems.

As evident from Table 2, the income for farmers could be increased dramatically with the implementation of crop rotation. With the inclusion of pastures in these systems, an increase in the gross margin, above monoculture, of up to 87% was shown. These results where a major driving force in convincing farmers to convert to crop rotation systems. (Hardy, M.B., Strauss, J.A., Laubscher, S.J.A., 2011).

Table 2: The average gross margin per crop rotation system from 2002 to 2012. (W=wheat; C=canola; L=lupin; M=medic pastures; Mc = Medic/clover pastures)

System	Average Gross Margin per system (Rand per hectare)	% Increase when compared to monoculture wheat
WWWW	1865	-
CWWW	2697	45
CWWL	2670	43
WCWL	2999	61
MCMW	2961	59
MWMW	3309	77
McWMcW	3489	87

3.2. Capacity building through component trials

Component trials addressed the effects of crop rotation on various production factors. From this trial alone, a B.Tech degree, MSc degrees and a PhD were successfully completed.

3.3. Impact studies

The survey to assess the impact of the role research played in the adoption of CA in rain-fed wheat production in the province showed promising results. It was determined that there was a R 341 million benefit from the introduction of CA in the Western Cape since it started out in 2005 with a 5% application to 60% application in 2010. It was found to cost 16.5% more to fertilise using conventional methods and up to 46 times more herbicides were required with conventional farming. Although mechanisation has always been regarded as an expensive part of CA, 64% of farmers had at that stage recently bought specialised equipment to reduce tillage. On farm level CA has brought about up to 70% decreases in labour costs.

Interviews showed that 81% of farmers said CA was easy to apply and 94% of the farmers reported an increase in total income per hectare. It was found that, to produce 3 tons of wheat per hectare, it costed R 444/ha under conventional methods, while with CA methods it costed R 2 387/ha. Apart from the amount of fuel used, the improvement of soil quality and the consequent water conservation and retention in the soil were some of their key factors for converting to CA. Water conservation in the soil may become a key requirement for sustainable grain production in future, as part of the proposed mitigation for climate change. (ARC, 2014)

The impact assessment of the crop rotation trial on the greater Swartland region also showed positive results. The main findings indicated that 98.8% of farmers are implementing crop rotation, since it has had a positive impact on farming in the area as indicated by reduced disease and weed infestation and associated increases in farm incomes. Crop rotation has had a positive effect on crop yields, soil, farm income, weed control and a decrease in mechanisation costs. (Yohane, C., 2015)

3.4. Conservation Agriculture and Climate Change

The long term crop rotation trial with its no-till and zero-till practices have shown lower inputs and a higher, as well as more stable production in wheat. Productivity was essentially improved through improving soil health, which was the result of increased soil moisture retention, decreased soil temperature, increased micro-organisms and decrease compaction of the soil. The CA initiative of the Department has become a prominent feature in the grain industry and was elected a case study in the research and compilation of the Western Cape Climate Change Response Framework and Implementation Plan for the Agricultural Sector. (SmartAgri Plan, 2016)

3.5. Technology transfer

The positive results from the long term crop rotation trial at Langgewens caused more farmers to convert to CA. Also, CA has been identified to catalyse the early adoption of important climate change response interventions with high impact which will fast track climate change resilience of the agricultural sector in the Western Cape. (SmartAgri Case Study #2, 2016)

4. Conclusion

Conventional winter grain practices heavily rely on regular tillage, monoculture wheat and the application of agro-chemicals, such as herbicides. These practices cause soil degradation and carbon and nutrient depletion. This conventional system has become uneconomical and ecologically not viable. The CA principles that were adopted in this long term trial yielded results showing that this was the way towards sustainable grain production, both ecologically and economically.
Future climate change risks for the province suggest heat and water stress, thus the effect of conventional agriculture and climate change on the productivity and profitability of the Western Cape grain sector, and national food security, could be severe. (SmartAgri Case study #2: Conservation Agriculture, 2016).
CA has been identified as an important adaptation to respond to climate change by potentially decreasing the impacts of changes in temperature and rainfall on yields by improving soil water retention and soil fertility. (SmartAgri Case study #2: Conservation Agriculture, 2016).

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The influence of Conservation Agriculture on topsoil stratification in the Western Cape of South Africa

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Over the last years Western Cape grain farmers have adopted one or more principles of Conservation Agriculture (CA) namely: minimal mechanical soil disturbance, permanent soil cover with crop residue and/or cover crop and crop rotation. This change from conventional winter wheat production to CA-principle has led to changes in topsoil nutrient distribution.

Stratification refers to the accumulation of soil nutrients in certain areas more than in others. Stratification may influence availability of nutrients in various soil depths of the root zone, especially during prolonged dry spells in the growing season. This study determines if stratification has occurred after a 12 year period under CA on an existing project at Tygerhoek Research Farm (34˚29'32" S, 19˚54'30").

Four tillage treatments, namely: (1)zero-till(ZT) – soil left undisturbed (weeds controlled with only herbicide) and planted with a star-wheel planter, (2)no-till (NT) – soil left undisturbed until planting and then planted with a tined planter, (3)minimum till (MT)– soil scarified March/April to depth of ± 100-150 mm in late March/early April and then planted with a no-till planter, and (4)conventional tillage (CT)– soil scarified late March/early April to a depth of ± 100 - 150 mm, then disked to a depth of ± 200 mm before planting with a no-till planter, was studied in combination with four crop rotations, namely: monoculture wheat, wheat/medics/wheat/medics, medics/wheat/medics/wheat and lupine/wheat/canola/wheat.

The soils are all shallow and have a high stone content (soil forms Entisols and Alfisols). Soil samples were collected using a 40 mm diameter steel tube in 0-5, 5-10, 10-15, 15-20 and 20-30 cm depth increments. Ten subsamples per plot were bulked to give a composite sample. The soil was dried, passed through a 2 mm sieve and analysed chemically.

Crop rotation had no significant effect on nutrient stratification; however the degree of soil disturbance had an effect. The pH in the 0-5 cm soil layer of ZT and NT were significantly ($P<0.05$) higher than the other depths (pH (KCl) 6.15 and 6.21 respectively). CT was more evenly distributed. P decreased with depth for all the tillage treatments. The P content in the 0-5 cm depth was the highest in ZT and NT and the lowest in MT and CT. Potassium followed the same trend as P. Carbon stratification was clearly visible in the 0-5 cm layer under ZT with significantly higher ($P<0.05$) C content compared to the 5-15 cm layer.

We need to understand the unique conditions in CA that influence nutrient behaviour. Changes in soil pH are important for determining P and micronutrient availability, root growth and microbial activity. Producers should consider taking soil sample under conservation tillage at depth increments for a better understanding of the nutrient status, to optimize fertilizer and lime recommendations. The traditional 0-30 cm soil sampling procedure may not detect the deficiencies at lower depths.

Keywords: *stratification, Conservation Agriculture, soil depth*

Abstract

Over the last years Western Cape grain farmers have adopted one or more principles of Conservation Agriculture (CA) namely: minimal mechanical soil disturbance, permanent soil cover with crop residue and/or cover crop and crop rotation. This change from conventional winter wheat production to CA-principle has led to changes in topsoil nutrient distribution.

Stratification refers to the accumulation of soil nutrients in certain areas more than in others. Stratification may influence availability of nutrients in various soil depths of the root zone, especially during prolonged dry spells in the growing season. This study determines if stratification has occurred after a 12 year period under CA on an existing project at Langgewens Research Farm (33˚16'34" S, 18˚45'51" E; altitiude191 m).

Four tillage treatments, namely: (1)zero-till(ZT) – soil left undisturbed (weeds controlled with only herbicide) and planted with a star-wheel planter, (2)no-till (NT) – soil left undisturbed until planting and then planted with a tined planter, (3)minimum till (MT)– soil scarified March/April to depth of ± 100-150 mm in late March/ early April and then planted with a no-till planter, and (4)conventional tillage (CT)– soil scarified late March/ early April to a depth of ± 100 - 150 mm, then disked to a depth of ± 200 mm before planting with a no-till planter, was studied in combination with four crop rotations, namely: monoculture wheat, wheat/medics/ wheat/medics, medics/wheat/medics/wheat and lupine/wheat/canola/wheat.

The soils are all shallow and have a high stone content (soil forms Entisols and Alfisols). Soil samples were collected using a 40 mm diameter steel tube in 0-5, 5-10, 10-15, 15-20 and 20-30 cm depth increments. Ten subsamples per plot were bulked to give a composite sample. The soil was dried, passed through a 2 mm sieve and analysed chemically.

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We need to understand the unique conditions in CA that influence nutrient behaviour. Changes in soil pH are important for determining P and micronutrient availability, root growth and microbial activity. Producers should consider taking soil sample under conservation tillage at depth increments for a better understanding of the nutrient status, to optimize fertilizer and lime recommendations. The traditional 0-30 cm soil sampling procedure may not detect the deficiencies at lower depths.

1. Introduction

The Western Cape is an important grain producing regions in South Africa and the regions' economy has long been based on wheat production. The wheat industry is vital to ensure food security and rural development of the Western Cape Province. Most of the arable land in this region is cultivated, producing wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*) and canola (*Brassica napus*) under dryland conditions, as well as legume pastures (medics, clover and lucerne).

Traditional tillage in the winter rainfall areas of the Western Cape was a primary tillage operation with a disk, mouldboard or chisel plough followed by a secondary action with a disk or tine for weeding and seedbed preparation before planting. Tillage has long been used by farmers to loosen soil, make a seedbed and control weeds. Tillage or conventional tillage generally refers to inversion ploughing to at least 20 cm or more (Kassam, A). Conventional tillage has deteriorated soil fertility due to a loss of soil organic matter and the increase of water and wind erosion.

Increased input costs (particularly diesel and agro-chemicals), exposure to international commodity prices, as well as variable rainfall combined with a low level of economic support from government, stimulated the adoption of Conservation Agriculture. Conservation Agriculture (CA) is defined by the FAO as minimal soil disturbance, maintaining crop residue on the soil surface combined with crop rotation with different species including legumes. According to Findlater, K the winter rainfall regions of the Western Cape are the most successful in South Africa with an adoption rate of around 80% for CA. Differences in the frequency and intensity of tillage can strongly influence the distribution and availability of the soil nutrients. Conventional tillage incorporates crop residues throughout the upper soil layers. In contrast, CA do not incorporate the crop residues, resulting in higher concentration of soil nutrients and soil organic carbon (SOC) in the soil surface, before decreasing sharply with depth (Vu,D). Nutrient stratification is a common occurrence and can potentially reduce the ability of crops to access soil nutrients and as a result reduce grain production.

Nutrient stratification is where nutrients such as phosphorus (P), potassium (K) and sulphur (S) occur naturally as layers or bands through the soil profile as a result of pedological processes or through anthropogenic (man-made) processes (Wheaton, R).The concern about nutrient stratification is driven by the idea that crops may not be able to access nutrients concentrated in the surface layer of soils because this is the first layer to dry out and plant roots can not extract nutrients from dry soil. Therefore, it is important to characterize nutrient stratification for producers to make appropriate fertilizer management decisions (Lupwayi, N).

Farmers in most developing countries remove crop residues for use as fodder and/or bedding for animals, building material or fuel, resulting in great nutrient exports from agro-ecosystems (Bhupinderpal-Singh). According to Scott, B stubble retention implies standing stubble or surface-applied stubble or mulch. Retention of plant residue has been found to have many long-term benefits like decreased soil erosion, increased soil water content and increase in soil biological activity. Soil water increase is due to greater rate of infiltration and decreased soil water evaporation (Li, J).

Nutrient cycling in the soil-plant ecosystem is an essential component of sustainable productive agriculture. Knowledge of the effects of residue management e.g., residues left on the surface or mixed into the soil is essential when assessing effects of tillage practices resulting in different degrees of residue-soil contact (Yadvinder-Singh).

Many farmers consider no-tillage as the new norm for crop production in Western Cape (Botha, P). Understanding the effects of tillage and rotation on plant available nutrients is critical to develop nutrient management strategies to optimize yield while maintaining cropping system sustainability (Houx, M).

2. Material and methods

2.1. Experimental layout and treatment

The experiment was designed as a randomised complete block with a split-plot arrangement and four replicates. The crops annually planted are: wheat (*Triticum aestivum*), canola (*Brassica napus*), lupines (*Dolichos* spp.) and medics-clover mix (*Medicago* spp.).

The following four crop sequences were included in the research:

1. continuous wheat (WWWW),
2. medic-clover/wheat/medic-clover/wheat (McWMcW),
3. wheat/medic-clover/wheat/medic-clover (WMcWMc) and
4. lupine/wheat/canola/wheat (LWCW)

All crop phases of the rotation were present every year. All straw, chaff and stubble remained on the soil surface and no grazing was allowed on all tillage treatments. Each main plot was subdivided into four sub-plots allocated to four tillage treatments, namely:

1. zero-till(ZT) – soil left undisturbed and planted with a star-wheel planter, that places seed with minimal soil disturbance,

2. no-till (NT) – soil left undisturbed until planting and then planted with a tined planter that results in a maximum soil disturbance of 20% to a depth of 100 mm to 150 mm in the planting row,

3. minimum till (MT)– soil scarified March/April to depth of ± 100-150 mm in late March/early April and then planted with an Ausplow no-till planter, and

4. conventional tillage (CT)– soil scarified late March/early April to a depth of ± 100 - 150 mm late March/early April, then ploughed to a depth of ± 200 mm before planting with an Ausplow no-till planter.

The degree of soil disturbance increases from zero tillage to conventional tillage.

2.2. Site and soils

The study was done on a long-term crop rotation and tillage trial initiated 2007. It is located approximately 80 km north of Cape Town (33˚16'34" S, 18˚45'51" E; altitiude191 m). The soils are mainly derived from Malmesbury and Bokkeveld shales. These soils (Entisols and Alfisols) are hard and shallow (250-300 mm) in the dry state. The clay content of the upper 0 – 300 mm was between 10-15% and classified as a sandy loam soil with a gravel and stone content of 45% in the A horizon.
Langgewens has a typical semi-arid Mediterranean climate with a mean rainfall varies from 250 mm to 600 mm per annum of which about 80% falling during the winter between April and September. Summer months are warm and dry, while the winter is cool and wet.

2.3. Soil samples

Soil samples were taken with a 40 mm diameter steel cylinder. Soil samples were collected in 0-5, 5-10, 10-15, 15-20 and 20-30 cm depth increments. Samples were taken in all four crop rotations and tillage treatments. Ten subsamples randomly selected per plot were bulked to give a composite sample for each depth segment in each plot. The composite soil samples were air-dried and passed through a 2 mm sieve prior to chemical analysis. The following methods were used for analysis: organic C (Walkley-Black method), pH (1:2.5 soil to water suspension), exchangeable C, Mg, K, P and N (1 mole dm^{-3} NH_4OAc at pH 7), extractable Cu, Fe, Mn and Zn (DTPA method) and B (hot water method).

2.4. Statistical analysis

The data were subjected to analysis of variance (ANOVA) using General Linear Models Procedure (PROC GLM) of SAS software (Version 9.2: SAS Institute Inc., Cary). The Shapiro-Wilk test on the standardized residuals from the model verified normality after outliers were removed (Shapiro, S). Fisher's least significant difference was calculated at the 5% level to compare treatment means (Ott, R). A probability level of 5% was considered significant for all significance tests.

3. Results and discussion

CA results in vertical stratification of plant nutrients in the soil profile. Phosphorus (P), calcium (Ca), magnesium (Mg), zinc (Zn) and lime have a limited mobility in soil. Potassium is intermediate between nitrogen (N) and Phosphorus (P) in regard to mobility in soils (Foth, H). In the graphs, the small letter indicates significant differences among soil depths among the treatments ($p < 0.05$). Means followed by at least one common letter are not significantly different.

The results of the study revealed that after 12 years of CA substantial changes occurred in the vertical distribution in the long-term trials under different tillage and rotation treatments. The amount of extractable Ca, Mg, P, K and C are all higher in the surface 5 cm of the soil under ZT and NT. The available nutrient levels in the deeper soil layers remained adequate for crop growth. In Fig. 1 the 0-5 cm and 5-10 cm layers in ZT, NT and MT are significantly higher than the deeper layers. In CT the Ca is more evenly distributed in the 0-30 cm layer due to mixing of soil during conventional tillage. Hussain, I found that exchangeable Ca was significantly (P=0.05) greater with NT in the 0-5 cm layer compared to conventional tillage, this is contributed to the lack of tillage and concentration of crop residues at the soil surface.

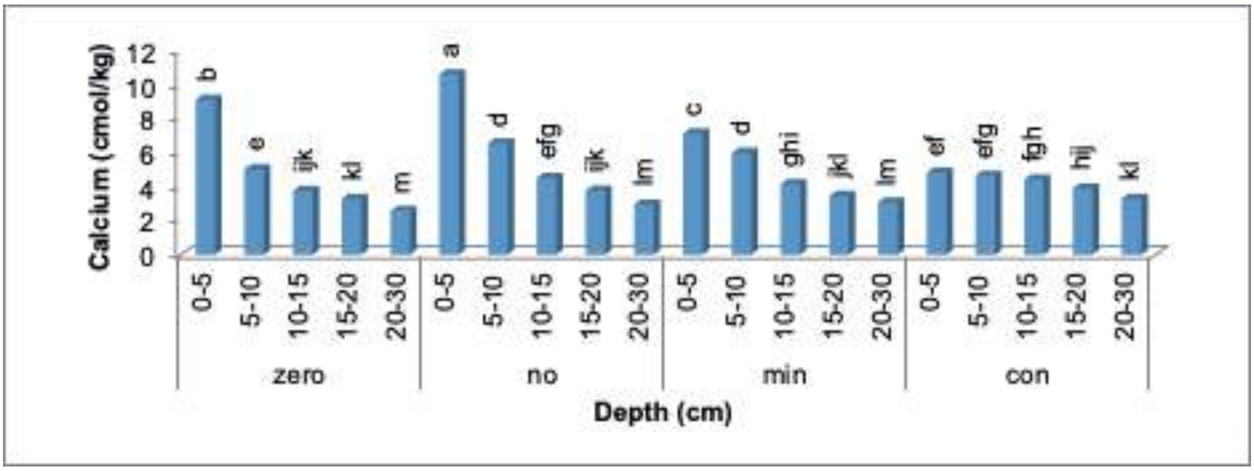

Fig. 1 Distribution of calcium under different tillage practices and depth

Hiel, M observed a clear stratification of the C, P and K between the different soil depth (0-10, 10-20 and 20-30 cm depths) in the reduced tillage treatment. In Fig 2 the 0-5 cm layer of ZT and NT is significantly higher than the other depths and tillage treatments. The P levels under CT is more evenly distributed. The accumulation of P near the surface of CA suggests that present soil testing methods for determining P fertiliser requirements my not be adequate for Conservation Agriculture systems for the soils of the Western Cape.

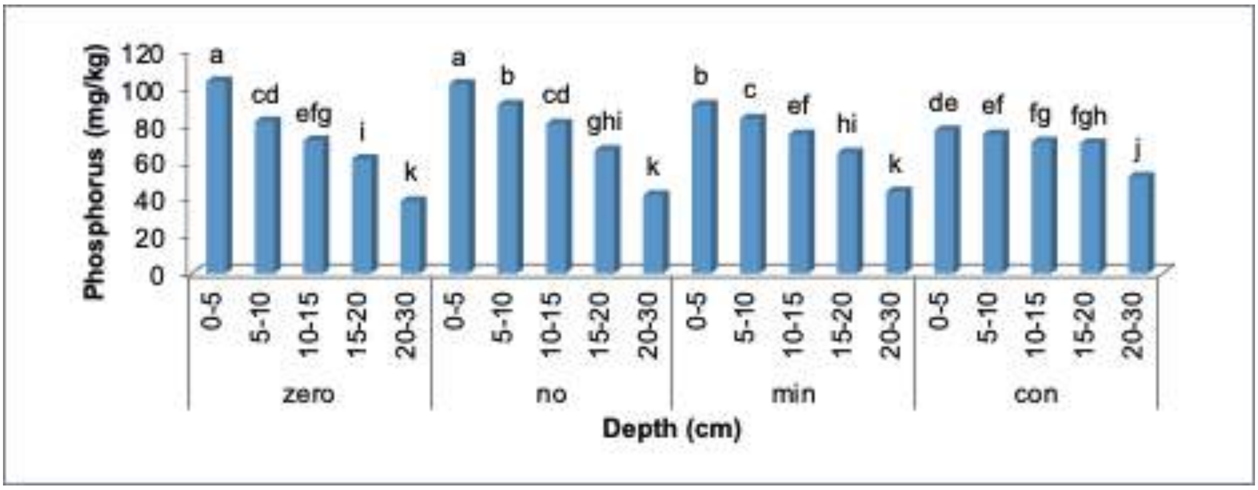

Fig. 2 Phosphorus at different tillage treatments per depth

The K levels in Fig 3 of the 0-5 cm depth of all the treatments are significantly higher than the other depths. The K in the soil decreased sharply with depth in all the treatments.

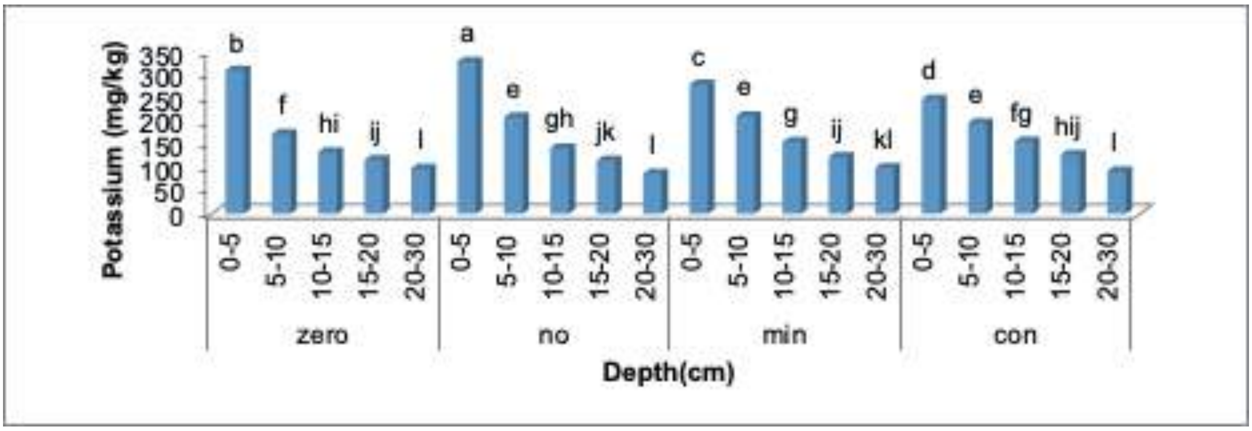

Fig 3 The distribution of soil Potassium for the different tillage treatments and depth.

The C levels in Fig 4 in the 0-5 cm layer of ZT is significantly higher than all the other treatments. The soil C levels under CT is more evenly distributed. The more soil disturbance that took place the lower the C levels was in the 0-15 cm layer. Soil organic matter is naturally very low in South Africa. It is estimated that 60% of the soils contain less than 0.5% SOM (Du Preez, C). Changes in organic matter content are probably the most important long-term effect of Conservation Agriculture and an important indicator of soil quality. Hernanz, J found that the interaction of tillage by soil depth on SOC revealed that CT was the system with the most uniform distribution of SOC within the soil profile. In the ZT system, the SOC significantly decreased with soil depth. Distribution of SOC under MT was intermediately stratified between CT and ZT.

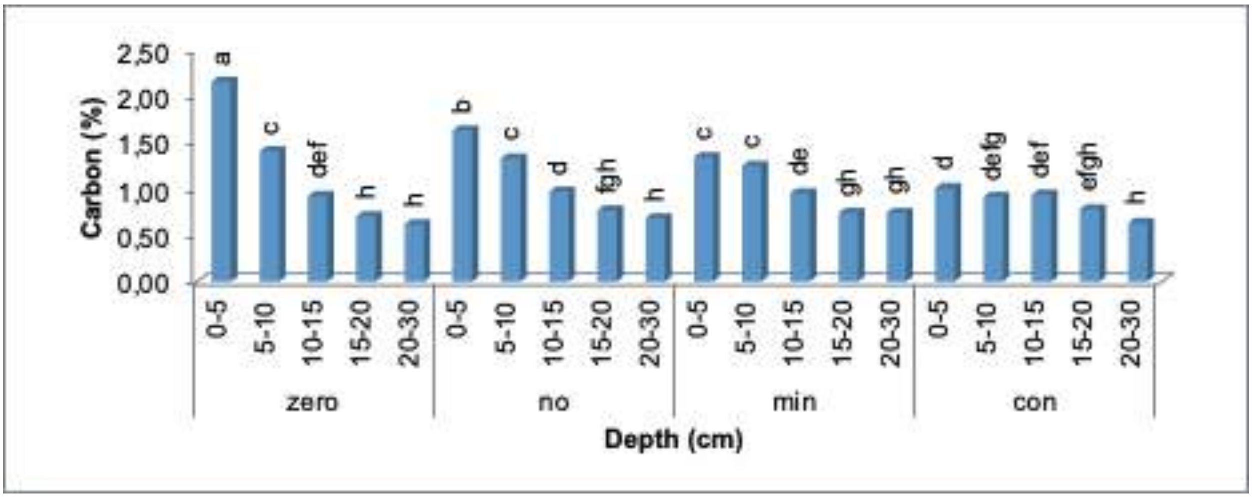

Fig 4 Carbon distribution for different tillage treatments and depth

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Remote sensing of winter wheat growth under conventional and no-tillage cultivation

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A pilot field was established in order to compare winter wheat performance under the following treatments: 1) Conventional cultivation (CO) including ploughing, seedbed preparation and sowing at a normal date, 2) No-tillage, (NT2) with direct drilling at the same date as 1, 3) No-tillage (NT1) with direct drilling three weeks earlier. The opportunity of early sowing is an important asset for no-tillage and the purpose of the present study was to showcase this benefit.

During the growing period, time-series of two vegetation indices (VIs), the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) were calculated from Sentinel-2 images. At the same time, Leaf area Index (LAI) was measured seasonally at certain points. The final yield was recorded with a combine harvester provided with a yield monitor.

The two VIs revealed different growth patterns for the three treatments. Until the end of February, the late sown CO and NT2 followed a similar, delayed pattern with low NDVI and EVI. The similar pattern evince that the absence of soil tillage doesn't actually affect the initial growth of the crop. On the other hand, the opportunity for earlier sowing with direct drilling on NT1 proved to be rather advantageous for seedling early emergence and performance. Indeed, the earlier crop emergence led to higher values of the two VIs until the beginning of March. These higher VIs were associated with a higher LAI as depicted from the corresponding regression analysis (R^2=0.88 and R^2=0.67 for NDVI and EVI respectively).

After March however, NT1 showed a delay and CO outperformed both NT1 and NT2. The weather data revealed a shortcoming of rainfall from 5/2 to 10/3 coincided with the critical stage of stem elongation on NT1.Therefore, growth was suppressed. Contrariwise, the two later sown methods (NT2 and CO) pulled through this adverse period because the plants were still at the less sensitive, tillering stage.

The superiority of CO lasted until the beginning of grain filling, at the end of April. After that period, it was the turn of NT2 to excel. The VIs showed that the crop remained green while the plants on the other two treatments were maturing. The yield data reveal that this was a decisive period. It is the stage where assimilates from photosynthesis are translocated from the leaves and the stem to the grain. And apparently, it was favored by no-tillage. Compared with CO, grain yield on NT2 was 1.7 times higher (1.91t/ha and 3.23t/ha respectively). The NT1 also outweighed CO with a mean yield of 2.63t/ha, which though was lower from NT2.

Remote sensing proved a valuable tool both for phenological monitoring between treatments, but also for determining critical stress periods during growth. Such data in conjunction with weather information are particularly essential and could be used in decision making systems under the framework of precision agriculture, to enhance yield quantity and quality when sustainable systems are adopted and the ordinary cultivation practices have to be adapted accordingly (i.e., earlier sowing, modification of irrigation and/or nitrogen application).

Keywords: *no-tillage; remote sensing;NDVI; winter wheat*

Abstract

A pilot field was established in order to compare winter wheat performance under the following methods: 1) Ploughing based conventional tillage (CT) and sowing at a normal date, 2) No-tillage, (NT2) and sowing with a no-till drill at the same date as 1, 3) No-tillage (NT1) and sowing with a no-till drill three weeks earlier. The ability for early sowing is considered one of the benefits of Conservation Agriculture and the purpose of the present study was to showcase this benefit.

During the growing period, time-series of two vegetation indices (VIs), the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) was obtained from Sentinel-2. At the same time, Leaf area Index (LAI) was measured at certain time-points. Final yield was monitored with a combine harvester provided with a yield monitor.

The two VIs revealed different growth patterns for the three treatments. Until end of February, the later sown CT and NT2 showed a similar delayed pattern, with low NDVI and EVI, evincing that the absence of soil tillage didn't affect the initial growth of winter wheat. On the other hand, the opportunity for earlier sowing with direct drilling on NT1 proved to be advantageous for seedling early emergence and performance. Indeed, the earlier crop emergence led to higher values of the two VIs until the beginning of March. These higher VIs were associated with a higher LAI as depicted from the corresponding regression analysis (R^2=0.95 and R^2=0.86 for NDVI and EVI respectively).

After March however, NT1 showed a delay and CT outperformed both NT1 and NT2. The weather data revealed a shortcoming of rainfall from 5/2 to 10/3 coincided with the critical stage of stem elongation on NT1.Therefore, growth was suppressed. Contrariwise, the two later sown methods (NT2 and CT) evaded this adverse period because the plants were still at the less sensitive, tillering stage.

The superiority of CT lasted until the beginning of grain filling, at the end of April. After that period, it was the turn of NT2 to excel. The VIs have shown that the crop remained green while the plants on the other two treatments were maturing. The yield data imply that this was a decisive period. It is the stage where assimilates from photosynthesis are translocated from the leaves and the stem to the grain. And apparently, it was favored by no-tillage. Compared with CT, grain yield on NT2 was 1.7 times higher (1.61t/ha and 2.73t/ha respectively). The NT1 also outweighed CT with a mean yield of 2.22t/ha, which though was lower from NT2.

Remote sensing proved a valuable tool both for phenological monitoring between treatments, but also for determining critical stress periods during growth. Such data in conjunction with weather information are particularly essential and could be used in decision making systems under the framework of precision agriculture, to enhance yield quantity and quality when sustainable systems are adopted and the ordinary cultivation practices have to be adapted accordingly (i.e., earlier sowing, modification of irrigation and/or nitrogen application).

1. Introduction

Remote sensing has been proved a valueable management tool in agriculture (Thieme et al., 2020) rye, and wheat help to improve soil structure by increasing porosity, aggregate stability, and organic matter, while reducing the loss of agricultural nutrients and sediments into waterways. The environmental performance of cover crops is affected by choice of species, planting date, planting method, nutrient inputs, temperature, and precipitation. The Maryland Department of Agriculture (MDA. Hyperspectral data from new generation satellites, such as Sentinel-2 are expected to provide significant improvements in retrieving quantitive information on several crop biophysical parameters. The involvement of such data in crop performance monitoring will facilitate not only management interventions but also yield prediction.

the present study we aimed at exploring the potential of satellite data in depicting winter wheat phenological stages and performance under different tillage treatments. We evaluated the information derived by remote sensed data through their correlation with ground-measured leaf area index (LAI) and final yield of the various treatments.

2. Materials and methods

2.1 Study site and experimental design

The study was conducted in the Thessaly Plain, central Greece, near Larissa (39°34'52.13"N, 22°35'46.22"E) during November 2018-June 2019. The experimental field of 6.7 ha was divided into three parts, in which the following treatments were performed:

1. Ploughing based conventional tillage (CT) and sowing on December 6, 2018
2. No-tillage (NT1) and sowing three weeks earlier, on November 16, 2018.

3. No-tillage, (NT2) and sowing at the same date as CT.

The CT treatment was ploughed and prepared with a tine cultivator, prior to sowing. The no-till drill (Kuhn SDliner 3000) was used for both no-tillage treatments, where residues of the previous cultivation, namely cotton, were present. Seeds of the winter wheat cultivar “Svevo” were sown at 230 kg/ha.

2.2. Satellite data and vegetation indices

During the growing period, time-series of two vegetation indices (VIs), the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) was obtained from Sentinel-2. Spectral data in red and near-infra red are used in VIs calculation, according to the following equations:

$$NDVI = \frac{R842 - R665}{R842 + R665} \qquad EVI = 2.5\,\frac{R842 - R665}{R842 + (6*R665) - (7.5*R490) + 1}$$

2.3. Leaf area index and yield measurements

Leaf area Index (LAI) was measured at certain time-points with the ACCUPAR LP-80 PAR/LAI Ceptometer (Decagon Devices Inc.). Final yield was monitored with a combine harvester provided with a yield monitor (John Deere S660i). The yield data are provided by John Deere as production map with spatial analysis of 1.5x1 m.

3. Results and Discussion

The time series of VIs during the experimental period are presented in Fig 1.

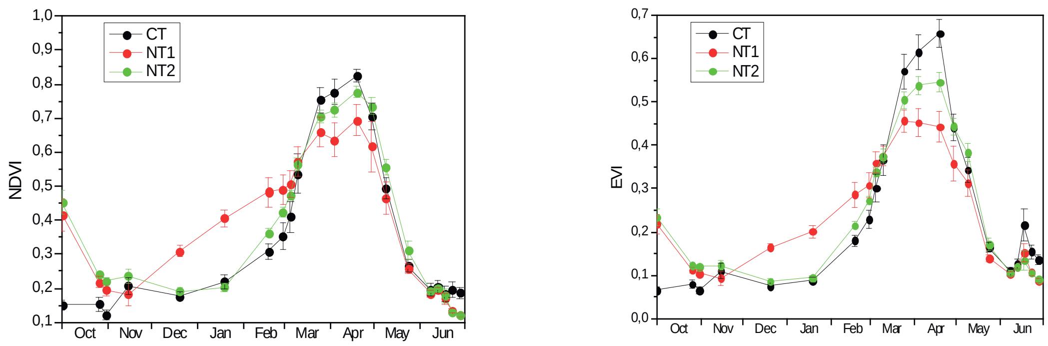

Fig 1: Time series of (a) NDVI and (b) EVI derived from Sentinel-2 data for the three treatments during the experimental period.

The two VIs revealed different growth patterns for the three treatments. Until the end of February, the later sown CT and NT2 showed a similar delayed pattern, with low NDVI and EVI, evincing that the absence of soil tillage didn’t affect the initial growth of winter wheat. On the other hand, the opportunity for earlier sowing with direct drilling on NT1 proved to be advantageous for seedling early emergence and performance. Indeed, the earlier crop emergence led to higher values of the two VIs until the beginning of March. After March however, NT1 showed a delay and CT outperformed both NT1 and NT2. The weather data revealed a shortcoming of rainfall from 5/2 to 10/3 which coincided with the critical stage of stem elongation on NT1. Therefore, growth was suppressed. On the contrary, the two later sown treatments (NT2 and CT) evaded this adverse period because plants were still at the less sensitive, tillering stage. The superiority of CT lasted until the beginning of grain filling, at the end of April. After that period, it was the turn of NT2 to excel. The VIs have shown that the crop remained green while the plants of the other two treatments were maturing. Thus, remotely-sensed data were found to successfully monitor wheat phenology, which is in accordance with recent research on phenological stages prediction by satellite VIs (Mercier et al., 2020).

The depiction of LAI seasonal fluctuation presented in Fig 2 confirms that NT2 remained green in the early May measurements. Overall, LAI and both VIs were found to correlate well after February, as is obvious from the corresponding regression analysis (R^2=0.95 and R^2=0.86 for NDVI and EVI respectively, Fig 3). Since LAI is an important indicator of biomass and percent vegetative ground cover, its retrieval though satellite-derived data might be a useful tool for crop monitoring at high spatial and temporal scale (Verrelst et al., 2015)as well as planned imaging spectrometers, will unleash an unprecedented data stream. The processing requirements for such large data streams involve processing techniques enabling the spatio-temporally explicit quantification of vegetation properties. Typically retrieval must be accurate, robust and fast. Hence, there is a strict requirement to identify next-generation bio-geophysical variable retrieval algorithms which can be molded into an operational processing chain. This paper offers a review of state-of-the-art retrieval methods for quantitative terrestrial bio-geophysical variable extraction using optical remote sensing imagery. We can categorize these methods into (1.

VIs, LAI, and yield data collectively imply that early May was a decisive period for wheat productivity. It is the stage where assimilates from photosynthesis are translocated from the leaves and the stem to the grain. And apparently, it was favored by no-tillage. Compared with CT, grain yield on NT2 was 1.7 times higher (1.61t/ha and 2.73t/ha respectively). The NT1 also outweighed CT with a mean yield of 2.22t/ha, which though was lower from NT.

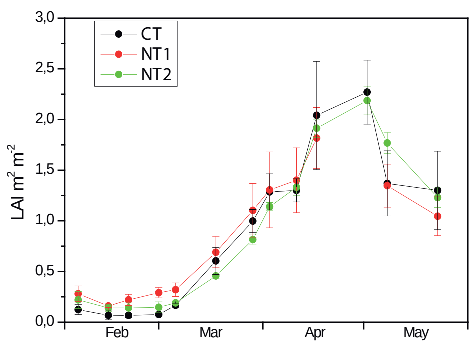

Fig 2: The seasonal fluctuation of LAI during the experimental period.

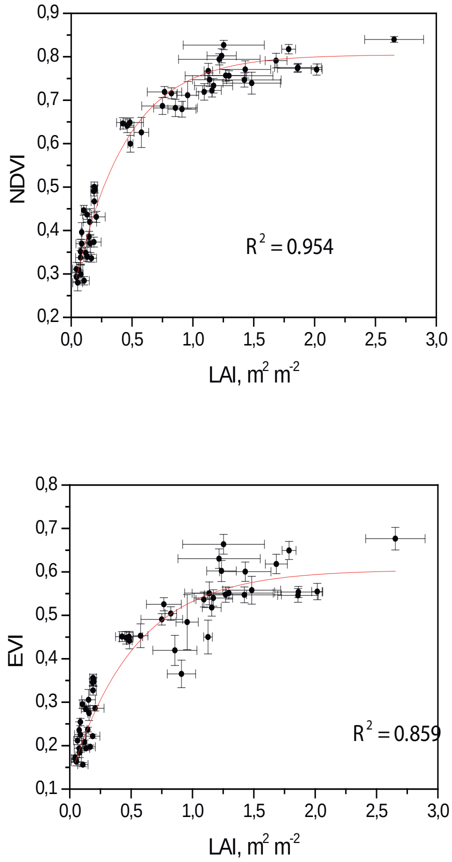

Fig 3: Regression analysis between (a) NDVI and (b) EVI with LAI, all treatments incorporated.

4. Conclusions

No-tillage treatments resulted in higher wheat yields compared to conventional tillage treatment. Early planting of winter wheat may be a profitable option, though late planting (NT2) showed the best performance in terms productivity. VIS depicted well the phenological stages of the crop and indicated critical points during plant development that may account for shifts in plant performance.

Remote sensing proved a valuable tool for phenological monitoring between treatments, but also for determining critical stress periods during growth. Such data in conjunction with weather information are particularly essential and could be used in decision making systems under the framework of precision agriculture, to enhance yield quantity and quality when sustainable systems are adopted and the ordinary cultivation practices have to be adapted accordingly (i.e., earlier sowing, modification of irrigation and/or nitrogen application).

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The adoption of automatic navigation technology for row-followed no-till seeding in China

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Automatic navigation technology (ANT), a promising technique for promoting smart agriculture because of its high precision and efficiency, was applied at no-till seeder in China to avoid the standing stubble and root system of the crop in the underground during row-followed no-till seeding. Relevant studies have revealed that ANT was effective in escalating quality and efficiency of row-followed no-till seeding, especially for wheat no-till seeding in North China Plain where annual maize-wheat rotation.

According to the principle of navigation, there were mainly three automatic navigation technologies applied at row-followed no-till seeding: touch type ANT, machine vision type ANT and Global Navigation Satellite System (GNSS) type ANT. For touch type ANT, a detection device designed according to crop cultivation characteristics is the key component of the system. The detection device mounted on the front of the tractor can generate a path signal while row-followed no-till seeding. Then, the control center processes and decides the steering command, and controls the actuator to avoid the stubble. The maximum error of touch type ANT was less than 6 cm when the tractor forward speed was no more than 1m/s. However, the touch type ANT could not be extended because the error path signal will be generated when there's inconsistent plant spacing or plant absence. For machine vision type ANT, the stubble row images can be collected by the industrial camera during row-followed no-till seeding. After that, the relative spatial information between the stubble row and the no-till seeder can be calculated through image processing algorithms. Afterwards, the control center activates the actuator to avoid the stubble. The seeder forward speed was not more than 1.2m/s to avoid the standing stubble and root system of maize. Nevertheless, robust and effective algorithms for stubble row recognition need to be explored due to the little color difference between stubble row, residues in rows and naked land surface. In recent years, GNSS type ANT was proposed to apply at row-followed no-till seeding because of its high precision. Unlike Touch type ANT and machine vision type, ANT of GNSS type captures absolute location information of stubble. Therefore, the electronic map of the stubble spatial location information needs to be obtained in advance. According to the electronic map of the stubble spatial location information and GNSS, the control center can guide the actuator to avoid the stubble. However, the electronic map of the stubble spatial location information is difficult to obtain because GNSS ANT is not fully applied at agricultural production in China.

In short, ANT can be employed to improve the level of automation, informatization and smart in row-followed no-till seeding, hence achieving variable operations, ultimately leveraging quality and efficiency of Conservation Agriculture (CA) operation.

Keywords: *no-till, automatic navigation, technology, stubble, row-followed, China*

Abstract

Automatic navigation technology (ANT), a promising technique for promoting smart agriculture because of its high precision and efficiency, was applied at no-till seeder in China to avoid the standing stubble and root system of the crop in the underground during row-followed no-till seeding. Relevant studies have revealed that ANT was effective in escalating quality and efficiency of row-followed no-till seeding, especially for wheat no-till seeding in North China Plain where annual maize-wheat rotation.

According to the principle of navigation, there were mainly three automatic navigation technologies applied at row-followed no-till seeding: touch type ANT, machine vision type ANT and Global Navigation Satellite System (GNSS) type ANT. For touch type ANT, a detection device designed according to crop cultivation characteristics is the key component of the system. The detection device mounted on the front of the tractor can generate a path signal while row-followed no-till seeding. Then, the control center processes and decides the steering command, and controls the actuator to avoid the stubble. The maximum error of touch type ANT was less than 6 cm when the tractor forward speed was no more than 1m/s. However, the touch type ANT could not be extended because the error path signal will be generated when there's inconsistent plant spacing or plant absence. For machine vision type ANT, the stubble row images can be collected by the industrial camera during row-followed no-till seeding. After that, the relative spatial information between the stubble row and the no-till seeder can be calculated through image processing algorithms. Afterwards, the control center activates the actuator to avoid the stubble. The seeder forward speed was not more than 1.2m/s to avoid the standing stubble and root system of maize. Nevertheless, robust and effective algorithms for stubble row recognition need to be explored due to the little color difference between stubble row, residues in rows and naked land surface. In recent years, GNSS type ANT was proposed to apply at row-followed no-till seeding because of its high precision. Unlike Touch type ANT and machine vision type, ANT of GNSS type captures absolute location information of stubble. Therefore, the electronic map of the stubble spatial location information needs to be obtained in advance. According to the electronic map of the stubble spatial location information and GNSS, the control center can guide the actuator to avoid the stubble. However, the electronic map of the stubble spatial location information is difficult to obtain because GNSS ANT is not fully applied at agricultural production in China.
In short, ANT can be employed to improve the level of automation, informatization and smart in row-followed no-till seeding, hence achieving variable operations, ultimately leveraging quality and efficiency of Conservation Agriculture (CA) operation.

1. Introduction

Conservation Agriculture (CA), which can decline soil erosion and increase yields, has formed a series of mature technologies and equipment in China after years of study and development (Kassam A et al., 2018). It is well known that CA has the standing stubble and root system of the crop in the underground during row-followed no-till seeding, which results in the blocking issue of machine and high labor intensity (He et al., 2018). To avoid these problems, the approach that integrating agricultural machinery with measurement and control, navigation and other technologies to realize the automation, intelligence and precision of CA production was proposed (Zhao., 2019; Zhang et al., 2020; Liu et al., 2020).

In the past decades, numerous smart technologies have applied at CA. The objective of this paper is to review the application progress of Automatic Navigation Technology (ANT) applied at row-followed no-till seeding in China, especially for wheat row-followed no-till seeding in north China plain where summer maize and winter wheat are cultivated in sequence.

2. Principle of ant applied at row-followed no-till seeding

Generally, in north China plain where annual maize-wheat rotation, wheat seed spacing, maize standing stubble row spacing, and maize root system radial radius are 20 cm, 60 cm, 3~5 cm, respectively (Li., 2004). In addition, the maize stubble will be uprooted when the furrow opener is within 5 cm of the maize root system radius, which indicates that the lateral deviation of the no-till seeder in row-followed operation is only ±5 cm (Li., 2006). If the deviation exceeding ±5 cm, the furrow opener is easy to meet with maize stubble, which will cause blockage or shutdown of no-till seeder, and seriously negative effect on seeding (Wei et al., 2005). To sum up, although it is difficult to achieve the required accuracy only by manual operation, but ANT could be a promising technology to solve the problems. The principle of ANT applied at row-followed no-till seeding is shown in figure 1, the no-till seeder guided by ANT can avoid the maize stubble row and seed wheat between two maize stubble rows. Consequently, this way can improve the precision and efficiency of row-followed no-till seeding.

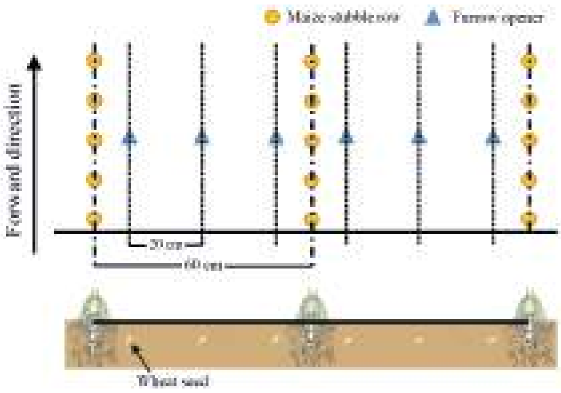

Fig. 1. Principle of ANT applied at row-followed no-till seeding

3. Ant applied at row-followed no-till seeding

According to the principle of navigation, ANT includes mechanical touch navigation, machine vision navigation, GNSS navigation, laser navigation, compass navigation, etc (He et al., 2018). Currently, the ANT applied at row-followed no-till seeding mainly includes touch type ANT, machine vision type ANT and GNSS type ANT. The following sections presented the research status of row-followed no-till seeding based on three types ANT.

3.1. Touch type ANT

The basis of touch type ANT is the detection device of stubble row (Fig. 2), which is designed according to crop cultivation characteristics. The detection device generates path signal and transfers to control center when the seeder is in operation. Then control center calculates steering signal and controls the actuator to complete operation of stubble avoidance (Fig. 3). The actual wheel angle was fed back to the control center to form a closed-loop control. The Vehicle monitoring PC is monitoring the module which adjusts navigation real-time parameters and responds to the failure of machine in unexpected risky situations (Hu. 2015).

Fig. 2. Detection device

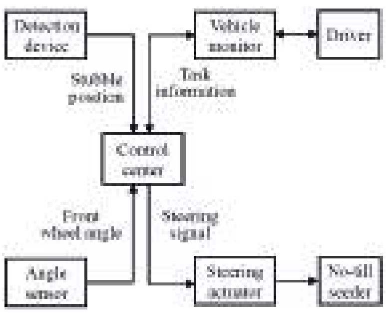

Fig. 3. Principle of row-followed no-till seeding based on touch type ANT

The row-followed no-till seeding based on touch type ANT was developed a decade ago in China. Wei et al. (2005) proposed an automatic guidance system based on electro-mechanical servo following stubble. It was proved that the maximum offset was 6cm when tractor speed was less than 1m/s. He et al. (2007) presented an automatic guidance system based on touch type and compass type navigation. The test results showed that the maximum offset was 3cm when tractor speed was less than 1m/s.

However, the premise of row-followed no-till seeding based on touch type ANT is detection device contacting with stubble. Hence, it is easy to lead to miss detection signal when the standing stubble is lost or uneven maize grows unevenly. Therefore, the technology which can obtain accurate target location information in real time without contacting target is still necessary to study and develop to solve problem mentioned above.

3.2. Machine vision type ANT

The machine vision type ANT is a non-contact technology to acquire the relative location information between the seeder and the stubble row (Guan et al., 2020). During no-till seeding operation, visual sensor is directly mounted on the no-till seeder to collect images of stubble row and sends to control center. Then, control center calculates the offset signal according to seeder speed and guides offset actuator movement to realize row-followed seeding without contacting maize stubble (Fig. 4).

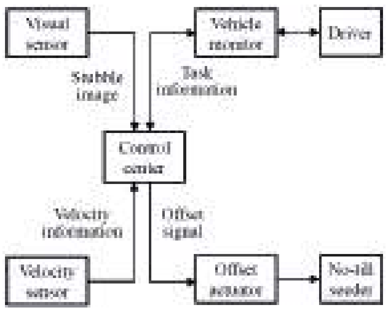

Fig. 4. Principle of row-followed no-till seeding based on machine vision ANT

At present, the research on machine vision navigation around the world mainly focuses on automatic weeding, automatic spraying, etc. In addition, researchers in China also have applied machine vision type ANT at row-followed no-till seeding and carried out related research. Chen et al. (2008) presented a navigation line detection algorithm based on the passing a known point Hough transform for the maize stubble row without stubble residues coverage between rows. The tests showed that the processing time of a 640×480 pixels image was less than 0.1s. But further research and improvement are undergoing for the maize stubble row cover with stubble residues coverage. Based on the detection of maize stubble row, Li et al. (2009) designed a no-till seeding navigation control system to perform row-followed no-till seeding operation. The actual deflection range of the control system was –10.8°~+10.7°, maximum error angle of tracked signal was 1.5°. Chen et al. (2018) proposed a method to detect maize stubble row with maize residues covering between rows and designed a row-followed control system to realize stubble avoidance and furrow opening operation. The field experiment revealed that the furrow openers could effectively avoid the maize stubble when the seeder speed was less than 1.2 m/s.

At current stage, in addition to the effects of natural illumination, weather, etc., there are many factors that affect the detection accuracy of the maize stubble row, such as naked land surface, maize residues between rows, which has little color difference with maize stubble row. Simultaneously, complex and changeable field operating environment also affect the robustness and precision of control system. Therefore, it is necessary to study detection algorithms of maize stubble row and row-followed control system with high robustness, real-time performance and high accuracy.

3.3. GNSS type ANT

The GNSS type ANT is not a non-contact technology either, but it obtains the absolute position information of the machine (Liu et al., 2018). The control center compares the current position information received from GNSS sensor with the previously specified navigation path information and generates steering signal. After receiving the steering signal, steering actuator moves to achieve stubble avoidance and row-followed no-till seeding (Fig. 5).

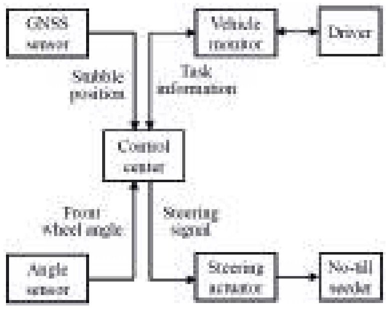

Fig. 5. Principle of row-followed no-till seeding based on GNS type ANT

Nowadays, research on GNSS type ANT in China mainly concentrated in path planning, navigation control, etc. In addition, GNSS ANT is not fully applied at agricultural production in China. To be specific, GNSS

ANT is separately applied in tillage, seeding, field management and harvesting in agricultural mechanization production. Moreover, due to the seeding precision and growth environment, the maize stubble row is not a straight line. Consequently, row-followed seeding operation needs real-time path planning according to the electronic map containing maize stubble position information. To sum up, the key to the realization of row-followed no-till seeding based on GNSS type ANT is the advance acquisition of electronic map containing stubble absolute position information.

3.4. Contrast and summary of three types ANT

Table 1 shows the performance comparison of three types ANT applied at row-followed no-till seeding (He et al., 2018; Wang et al., 2020; Zhang et al., 2017).
Table 1. Performance comparison of three types ANT applied at row-followed no-till seeding

ANT type	Advantages	Disadvantages
Touch type	Simple mechanism. Low cost. Easy installation.	Labile detection signal because of contact measurement. Low precision.
Machine vision type	High cost. Real-time path planning due to relative measurement. High precision.	Easily affected by illumination and environment. High computer configuration due to Time-consuming image processing algorithm
GNSS type	High cost. High precision. Increasing agricultural production applications year by year.	Signal is susceptible to weather and building shielding. Non-real-time path planning due to absolute position

4. Prospect

Automation, intelligence and precision is the future development direction of CA. ANT is a key technology in smart agriculture technologies, which has been gradually applied at CA over the past years in China. However, actual field operating environment is complex, since it could have natural illumination, uneven crop growth and other obstacles potentially affecting application of ANT in row-followed no-till seeding. Therefore, accuracy, robustness and efficiency of ANT applied at row-followed no-till seeding is still necessary to study and develop to solve problems mentioned above.

Based on analyzing the present research situation, it is suggested that the future research can be considered from three aspects: (1) Optimizing conventional algorithms and exploring new algorithms for stubble detection. (2) Further improving ANT control system to achieve great performance in complex farmland environment; (3) Developing a real-time and rapid acquisition technology for electronic map containing stubble absolute position information.

5. Conclusions

On the foundation of summarizing the principle of ANT applied at row-followed no-till seeding, the adoption of ANT for row-followed no-till seeding in China was introduced in detail in this paper. Then this paper has prospected the future development directions of ANT in row-followed no-till seeding. This paper intended to provide a reference for the development of ANT for CA.

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Smallholder agroecology training – the low-hanging fruit of Conservation Agriculture

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The world's lowest hanging fruit for a global shift to Conservation Agriculture is in the opportunity for smallholder farmers to adopt regenerative agroecology practices. Our global food system is responsible for about half of greenhouse gas emissions but small farms in economically disadvantaged countries also hold the greatest promise to stop global warming.

A shift to regenerative agroecology could be the cornerstone for stabilizing the climate and feeding the world. The '4 per 1000' (4p1000) initiative [Soussana et al. 2019] launched by France during the UNFCCC COP21 in 2015 aims at capturing CO2 from the atmosphere through changes to agricultural and forestry practices at a rate that would increase the carbon content of soils by 0.4% per year [Rumpel et al. 2018]. If global soil carbon content increases at this rate in the top 30–40 cm, the annual increase in atmospheric CO2 would be stopped [Dignac et al. 2017]. At the same time, it will increase soil fertility, improve public health, secure food sovereignty, reduce global strife, and protect water sources.

Seventy percent of the world's food is produced by 500 million smallholder farmers [HLPE 2013] who are ready to embrace agroecology as the most beneficial form of Conservation Agriculture. Those who get adequate technical assistance demonstrate how it improves biodiversity, water resources, climate stability, diet, health and income for the long-term.

An agroecology extension program such as the one operated by Sustainable harvest International would cost $250 billion per year for four years before farmers would become self-sufficient. This is a fraction of the $600 billion provide in agricultural subsidies ever year [Mamun et al 2019] And, this shift in funding will get us more and better food, as well as our best chance at regenerating a healthy planet. Tragically, half of the world's hungriest people are themselves smallholder farmers, who only need access to a farmer-centric, multi-year training program to grow plenty of good food for themselves and others with techniques that improve the health of the planet too. For most of these smallholders, the shift to regenerative agroecology comes with little to lose and much gain.

Keywords: *smallholders, extension, training, regenerative, agroecology*

Abstract

The world's lowest hanging fruit for a global shift to Conservation Agriculture is in the opportunity for smallholder farmers to adopt regenerative agroecology practices. Our global food system is responsible for about half of greenhouse gas emissions but small farms in economically disadvantaged countries also hold the greatest promise to stop global warming.

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1. The nexus of poverty, hunger + climate change

Most of the world's 500 million smallholder farmers suffer from poverty and malnutrition having never been offered adequate training in alternatives to farming practices such as short rotation slash-and-burn or chemical intensive farming that degrade the land and soil, decrease biodiversity, contribute significantly to climate change and degrade the land's long-term ability to grow crops. Hunger has been on the rise again since 2015, with the majority of the 821 million hungry, including 49.5 million children suffering from acute malnutrition, living in rural areas [FAO, 2019]. This is partially caused by and a consequence of roughly 33% of the world's soils being degraded, which has led to large losses of soil organic carbon [FAO, 2017]. Soils from various global agroecosystems such as croplands and grazing lands have lost 25–75% of their original soil organic carbon. Deforestation for farmland accounts for 17% of total greenhouse gas emissions [Allen], while the Haber-Bosch process of fabricating nitrogen-based fertilizers accounts for another 7.2% [Meinhausen et. al. 2009].

2. An agroecology extension success story

Over 24 years working with smallholder farmers in Belize, Honduras, Nicaragua and Panama, SHI has: provided direct technical assistance to over 3,000 families (15,000 people), catalyzed the regeneration of over 26,000 acres of previously degraded land and planted over 4 million trees. Of our 3,000 graduated families, 91% continue using the agroecology practices they learned while sharing the knowledge with others. Communities where SHI has established relationships remained largely unscathed by impacts of the pandemic and hurricanes of 2020. Some participant farmers noted their reforested lands prevented erosion and landslides. Others noted their ability to "stay home and stay safe" as they had food from their own harvests. None fell back into poverty. SHI graduates become more than just farmers. With increased self-confidence, many participate intake jobs with community organizations, or become community leaders, or become SHI Field Trainers. Some have spoken at national conferences about their work, something unimaginable before working with SHI.
Each family that chooses to participate in the program receives frequent, technical assistance from their field trainer. Visits and trainings are tailored to each participant's goals, preferences, and abilities with new skills and knowledge building upon each other and that of the program participants. Our current five-phase program supports one field trainer visiting each of approximately 30 farms every week or two for four years and also leading occasional workshops for groups of farmers in participating communities.

At a current cost of $1,000 per farm per year and anticipated future cost of $500 per farm per year with the addition of farmer mentors to complement the technical assistance provided by the professional extensionists, families see an average 23% increase in farm income in addition to cost savings from growing more of their own food and making their own inputs, while also enjoying a better quality of life working for themselves with their families rather than on exploitive and dangerous commercial farms. The shift to regenerative agroecology practices also allows each farm to drawdown / sequester 16 tons of CO^2 per farm per year for multiple decades by regenerating 8 acres of land including the planting of 1,000 trees and increase of soil organic carbon.

3. The potential of agroecology extension

The 2015 Status of the World's Soil Resources report highlights that past losses of soil organic carbon provide an opportunity since the recoverable carbon reserve capacity of the world's agricultural and degraded soils is estimated to be between 21 to 51 billion tons of carbon. The trees being planted in agroforestry systems add another carbon sink to agroecology-based farms. "The global tree restoration potential" report shows that the restoration of forested land at a global scale could increase the world's forested area by 25%, capturing 200 billion tons of atmospheric carbon at maturity. [Science, 2019] Tom Crowther, a researcher at ETH Zürich, and senior author of the report says that while it doesn't alter the vital importance of protecting existing forests and phasing out fossil fuels while new forests mature, "If we act now, this could cut carbon dioxide in the atmosphere by up to 25 percent, to levels last seen almost a century ago." [National Geographic, 2019]

Agriculture extension programs, historically focused on use of destructive agrochemicals to grow a small number of commodity crops, could have much greater impact with our extension model. For instance, Mexico's national extension service had 25,000 employees before it disbanded. As of 2010, this service was provided by 8,000 private contractors. [Qamar, M., 2013] On average, a receptive country such as this could reach several of their targets for the SDGs by supporting just 2,000 extensionists using an agroecology extension model such as the one developed by Sustainable Harvest International (SHI) over the past 24 years. With farmer mentors supplementing the work of the professional extensionists SHI anticipates each extensionist can impact 100 farms per three-year cycle. Thus 2,000 extensionists would allow 200,000 farms to shift to regenerative agroecology every four years or 400,000 over two four-year cycles. Three countries doing this for two four-year cycles would reach 1.2 million farms that support 6 million people.

Large scale farms are and must be part of this movement to regenerative agroecology practices, but it's going to take a lot more incentive for those that have millions of dollars invested in the old way of doing things to switch to this ecologically based approach. The low-hanging fruit of climate stabilization is helping smallholder farmers in the Global South who have so little to lose and so much to gain by making this transition. All over the world smallholder farmers are embracing this opportunity when given the chance.

If the world's 500 million smallholder farms shift to regenerative agroecology practices, they'll draw down six billion tons of carbon from the atmosphere into the soil every year, which is equivalent to closing every coal-fired plant on earth. [Toensmeir, 2016] Three billion acres of biodiversity-rich habitat will be created on their farms too [GRAIN]. That's thirty times bigger than all the national parks in the United States combined. [NPS 2020] As an added bonus, these farmers will also provide more nutrient-dense, poison-free food for all of us. The world's 500 million small-scale farmers are ready to do their part, but they can only do so with adequate technical assistance to get started.

The cost to deliver agroecology extension programs such as SHI's would be approximately $60 billion per year for 12 years, or 10% of the $600 billion per year that governments of the world currently provide in subsidies to industrial agriculture, GMOs, globalized exports and factory farms [RI], all of which are collectively responsible for about half of the world's greenhouse gas emissions. Redirecting this current government spending away from degenerative farming to regenerative agroecology training could cover the costs of providing technical assistance for those 500 million farms thus ending hunger and poverty for 2.5 billion people while also mitigating climate change and restoring degraded lands.

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Application of soil suppression technique in no-tillage sowing in China

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No-tillage sowing is a conservation tillage technique which can effectively save production cost and increase harvest benefit, its soil covering and suppression are of great significance in no-tillage sowing. The application of mulching and suppression techniques in the tillage process directly affects the germination and growth of seeds. In the seeding operation, the seeds are first opened into the ditch through the seed guide pipe, then the seeds are covered under the action of the soil covering device, and then the soil is compacted by the suppression wheel to maintain a certain soil compactness. The Turns the soil process had a certain effect on the sowing depth and distribution uniformity of seeds falling into the seed ditch, while suppression affected the emergence of seeds by controlling the soil compactness. In addition, in terms of the current soil covering technology, the common passive recovery of Turns the soil has a certain degree of uneven return soil. In terms of suppression technology, there is a lack of active suppression according to the real-time operation requirements combining soil moisture and agronomic requirements. In the future research direction, based on electronic control technology and hydraulic transmission technology is the main research direction to solve the above mentioned soil covering and suppression initiative.

Keywords: *No-till sowing, Turns the soil, The return soil is not uniform, Active suppression, Soil compactness*

1. Introduction

No-tillage seeding is an important part of conservation tillage technology. The quality of no-tillage seeding operation is closely related to production cost, work efficiency and crop yield. As an important part of the sowing operation, the soil covering operation realizes the uniform distribution and coverage of seeds, while the suppression operation achieves the required soil compactness according to different agronomic requirements to create conditions for the germination and growth of seeds. As a key component of soil, the overlay suppression device has a direct effect on the consistency of sowing depth and emergence rate of seeds. In the actual field sowing, the soil thickness is not uniform, which affects the consistency of sowing depth. The suppression intensity is too low, the soil compactness is not enough to play the role of entropy raising; Excessive repression, The soil tends to harden and thus affect the emergence rate. Therefore, the research of active soil covering suppression under the requirements of agronomy provides a theoretical basis for the design and transformation of the key parts of soil of the subsequent seeding machine. And then realize the sowing operation quality improvement and increase the purpose of income.

2. Effects of no-tillage sowing on soil physical and chemical properties

As the foundation of crop growth, good physical and chemical properties of soil are particularly important. The purpose of no-tillage sowing is to create a good soil environment and achieve a high yield and harvest of food. In recent years, with the development of green agriculture adapted to ecological environment, conservation tillage mode has been paid more and more attention. Under conservation tillage mode, no-tillage sowing has a positive effect on soil physical and chemical properties, including soil water storage capacity, soil temperature and soil respiration, etc.

2.1. Influence on the ability of water storage and moisture conservation

In conservation tillage mode, no tillage sowing operations retain stubble mulch, by effectively shading the surface with field stubble, reducing soil evaporation, Retain soil moisture. At the same time, the soil erosion can be prevented by the stacking structure of the surface stubble under the rainfall condition. Based on the soil water use efficiency experiment of dryland wheat-bean rotation cropland in Dingxi area, the results showed that conservation tillage could significantly increase the soil water storage in 0-200cm soil layer compared with conventional tillage, At the same time, according to the effects of different mulching treatments on water consumption characteristics of summer maize and soil water and heat environment changes, the results showed that complete mulching with straw reduced crop water consumption by 27.6% and increased crop yield by 21.22%,In the field experiments of three tillage methods of no-tillage, subsoiling and plowing under different tillage modes on wheat fields in the Weibei dry tableland, the results showed that no-tillage and subsoiling had better effects than plowing, and the effect of no-tillage was the best(Guo Qingyi et al.,2005;Wang et al.,2007;Mao Hongling et al.,2010).In summary, it can be seen that no-tillage sowing can effectively improve soil water storage and soil moisture retention ability, and the key equipment of soil in the process of no-tillage sowing has a direct impact on soil water storage and soil moisture retention ability.

2.2. Soil temperature

The normal emergence and growth of seeds in no-tillage sowing is closely related to the soil temperature, and the appropriate soil temperature can better improve the crop yield and quality. In conservation tillage mode, straw mulch can effectively form a temperature control protective layer, which can effectively reduce the diffusion of soil temperature to the atmosphere, When the external temperature is too low, straw mulching can effectively inhibit the diffusion of ground temperature and heat, and realize temperature control and maintain soil respiration activity; When the external temperature is too high, the stralk-covered surface actively absorbs heat from the outside and stores it in the straw layer, which effectively inhibits the rapid rise of surface temperature and reduces the soil water storage capacity(Shen Yuhu et al.,1998;Li Hongxiaet al.,2020).Therefore, soil temperature not only affects the hydrothermal properties of soil, but also reflects the environmental conditions of the near surface atmosphere of soil.

2.3. Soil respiration

Soil respiration is an important part of the carbon cycle in the ecological environment, The process is mainly a CO2 release cycle, It mainly includes decomposition of soil organic matter, respiration of microorganisms and respiration of plant roots(Nannipieri P, Ascher J, Ceccherini M T, et al.,2017).The main factors affecting soil respiration are soil moisture content, the number and activity of microorganisms, soil temperature and enzyme activity(Beringer J,et al.,2013).Crop root respiration is the main influencing factor of soil respiration, and its respiration rate is closely related to soil temperature. Through the no-tillage sowing operation under the straw returning mode of conservation tillage, Straw mulching has a thermal insulation effect on the surface of the soil, effectively maintaining the enzyme reaction of the soil and accelerating the soil respiration rate. The increasing soil respiration rate promotes root respiration and the decomposition of organic matter such as straw, thus realizing a virtuous cycle of soil environment.

3. Earth-covering suppression device

3.1. Research status of soil covering device at home and abroad

The main function of the soil covering device is to press the soil opened by the ditch opener into the seed ditch, and to achieve the purpose of uniform soil thickness and uniform soil amount. The main role of seeding and soil covering seed germination to create a good physical and chemical environment.

The soil covering device mainly has three structural forms: double disc soil covering device, plowshare soil covering device and eight-character shaped plate soil covering device (Guo H.,2019). In addition to three common types of soil covering devices, scholars and experts have carried out a series of in-depth studies on different soil covering requirements. In order to obtain the optimal structural parameters, make the most ideal soil covering effect and minimize the impact on seed displacement during soil covering operation, the uniform design method was used to carry out the soil covering test for the double-layer disc type soil coverer(Liu Xuanwei, et al.,2016).In the intercropping mode, according to the requirements of soil covering during sowing in the hilly area of southwest China, the parameter optimization test of the chain-ring type soil covering device was carried out, and the optimal structural parameters were obtained, and the qualified rate of soil covering reached 98.07%(GouWen, et al.,2011).Through the analysis of the research status of the soil covering device, the domestic scholars' research on the soil covering device mainly realizes the expansion of the soil covering function and the optimization of the soil covering effect under different operation conditions through the design of the structure parameters. At present, there is a lack of restraining the seeds falling into the seed bed and bringing back the soil to achieve uniform soil covering, so as to improve the quality and efficiency of soil covering operation.

3.2. Research status of suppression device at home and abroad

The suppression device is mainly used for a series of compaction operations, such as crushing the soil block, compressing the ploughing layer and leveling the land after sowing. Its main role is to improve soil compactness, increase the water storage capacity of the seedling belt soil and also play the role of soil moisture conservation.

China has a large span of arable land, and different regions of arable land in the temperature environment, soil conditions and tillage patterns are not the same, at the same time, there are differences in crop planting. Therefore, the suppression method should be adapted to local conditions and the purpose should be suitable for the agronomic requirements of crop sowing. In order to realize the regulation of sowing depth through suppression, a sowing depth regulation system based on Flex sensor was designed. The system monitored the ground pressure of sowing unit through Flex sensor, and adjusted the ground pressure mechanism by establishing a regulation model based on Mamdani fuzzy algorithm, which effectively improved the performance of sowing depth operation(Zhou Shuhui, et al.,2020).In order to realize the real-time control of sowing depth and down pressure in the process of precision sowing, a monitoring and evaluation system for sowing depth and down pressure of multi-row seeder was designed. The system CAN achieve better control effect of sowing depth and down pressure (Pan Haoran, et al.,2021). The development technology of foreign seeder is earlier than that in China. The development and use of foreign seeder have achieved wide width and high speed operation, and the overall structure has tended to be stable. Kverneland developed an Angle adjustable suppression device. Before seeding, manually adjust the position of the axle of the suppression wheel relative to the disc knife ditching device, so that it can achieve better suppression performance. Case IH has designed an adjustable suppression device with profilation capability that can change the position of the suppression wheel relative to the rack depending on the planting depth requirements. The pressing wheel adopts the external convex rubber pressing wheel, which can make the soil and the seed contact closely. The suppression device is applied to suction type 2000 series seeder.

4. Research direction of active overlay suppression device

4.1. Main research contents

In recent years, with the progress of science and technology and the continuous attention in the field of agriculture, machines and tools with different functions in no-tillage sowing mechanization have sprung up like bamboo shoots after a spring rain, which not only improves the work efficiency but also reduces the production cost. On the basis of summarizing and analyzing previous studies, through electronic control and hydraulic transmission and other technologies to realize the active suppression function of soil covering, the purpose of the soil covering in the process of soil covering uniform, consistent thickness and in line with the requirements of planting agronomic suppression intensity and other requirements.

The main research content of this paper is to design an active trench overlaying mechanism and active suppression technology based on the defects of the above existing technologies. Through the action of the planting ditch overlaying device and the return soil and limit deep wheel, the soil can actively fall back and fill the soil during the sowing operation, so as to ensure the thickness of the overlaying and improve the uniformity of the overlaying. Through the research progress of suppression technology at home and abroad and the classification of suppression devices, an active suppression mechanism and control system is designed to realize real-time profiling control and adjust effective pressure suppression. Make the soil reach the suitable soil compactness required by the crop.

4.2. Working principle of active overlay suppression device

Before field operation, adjust the position of the return wheel with limited depth according to the agronomic requirements of sowing depth. When the seeder is working in the field, the active ditching and overlaying mechanism moves forward with the unit. The stubble cutting wheel at the front of the mechanism cuts off the stalks and crop stubble, and moves the stalks to both sides through the paddle wheel, so as to provide a relatively bare sowing belt without straw cover for the subsequent furrowing and soil covering operation. When working, the shovel tip of the furrowing and overlaying device in the active furrowing and overlaying device will scoop up the soil and transport it backwards along with the advance of the unit. The seed falls into the seed ditch along the seed guide pipe. The soil is then transferred back through the arc plate and slowly spread over the seed bed as the machine progresses, The limited depth returning wheel plays the role of returning soil to the seed belt after covering soil, thus completing the operation process of ditching, sowing and covering soil.

When the active suppression system works, set target pressure at cab terminal in advance (The actual measured soil compactness required for planting crops is converted to the suppressing pressure), and send the set value to the controller of the active suppression device through the nRF24L01 wireless transmission module. The active suppression device controller controls the hydraulic directional solenoid valve, which adjusts the suppressing pressure of the suppression wheel by adjusting the action of the hydraulic cylinder. Where a pressure sensor mounted on the suppression wheel sends a signal to the active suppression controller, The active suppression controller sends the measured value to the cab terminal through the nRF24L01 wireless transmission module. The cab terminal controller compares the measured value with the set value, calculates the difference between the measured value and the set value, calculates the new control value based on the controller, and sends it to the controller of the active suppression device as a signal, so as to realize the real-time regulation of pressure suppression.

5. Conclusion

In this paper, the effects of no-tillage sowing on soil physical and chemical properties under conservation tillage mode were analyzed. Existing studies have shown that the effects of no-tillage and sowing operations have a direct impact on soil water storage and moisture retention capacity, soil temperature and soil respiration. As an important part of no-tillage sowing operation, a new technology based on electric control technology and hydraulic transmission is proposed as the main research direction to solve the above mentioned initiative of soil covering and suppression.

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The development and extension of subsoiling technology in China

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Subsoiling is a typical mechanized tillage method used in conservation fields in China. Due to long-term conventional tillage, soil bulk density and hardness are increased while soil porosity is decreased, which is unfavorable to crop growth. Current studies in China show that subsoiling can break the compacted soil hardpans, increase aeration and permeability of the soil, and improve physical and chemical properties of the soil. Because of these obtained effects, this technology makes the root elongation into deeper soil, benefits to the absorption and utilization of water and nutrients by crop roots, and then increases the crop yields.

The subsoiling technology started to be studied in 1960s in China. In recent years, more and more attention has been paying to the research and development of subsoiling shanks and subsoiling machines. According to the specific soil condition and farming system in different regions of China, several subsoiling technology and supporting machines have been developed, such as interval subsoiling, omni-directional subsoiling, layered subsoiling and vibrating subsoiling. Since the State Council decided to subsidize the subsoiling in 2009, this technology has been rapidly adopted in suitable provinces in China. Within four years after the implementation of subsoiling subsidy, the national subsoiling area increased significantly. In 2012, the national subsoiling area was 10.5 M ha, which was 1.83 M ha more than that in 2008. In 2016, the Ministry of Agriculture and Rural Affairs issued the *National agricultural machinery subsoiling and land preparation operation implementation plan(2016-2020)*, which points out that during the 13th five-year plan period, the nationwide annual operation area of subsoiling and land preparation via agricultural machinery exceeds 10 M ha. And in 2020, the national suitable cultivated land will be able to be subsoiled once, and then enter the positive cycle of suitable periodic subsoiling. According to *The maximum subsidy amount of national general agricultural machinery central financial funds (2018-2020)* formed by the Ministry of Agriculture and Rural Affairs, the maximum subsidy for purchasing subsoiler was 4900 RMB. In 2018, the national subsoiling area was 10.6 M ha, which was 1.93 M ha more than that in 2008. The national policy and financial support, locally applicable scientific research, better extension and training for farmers, and international cooperation and communication will further accelerate the extension and adopation of subsoiling technology in China.

Keywords: *subsoiling;technology; machine; development; extension; experiences;measures*

1. Introduction

Subsoiling is a typical mechanized tillage method used in conservation fields in China. Due to long-term conventional tillage, soil bulk density and hardness are increased while soil porosity is decreased, which is unfavorable to crop growth. Current studies in China show that subsoiling can break the compacted soil hardpans, increase aeration and permeability of the soil, and improve physical and chemical properties of the soil (Wang, S.B), without disrupting the original soil structure (He, J). Because of these obtained effects, this technology makes the root elongation into deeper soil, benefits to the absorption and utilization of water and nutrients by crop roots, and then increases the crop yields (Feng, X.M; Zhang, R.F). In recent years, more and more attention has been paying to the development and extension of the subsoiling technology. In this paper, the national policy and financial support for the promotion and application of the subsoiling technology was summarized, the changes of the subsoiling area and the possessing capacity of subsoilers in China in recent years was generalized, the different types of subsoilers researched and applied in China was introduced, and the measures for further development and extension of subsoiling technology in China were proposed.

2. National policy and financial support

Since the State Council decided to subsidize the subsoiling in 2009, the subsoiling technology has been rapidly adopted in suitable provinces in China. Within four years after the implementation of subsoiling subsidy, the national subsoiling area increased significantly. In 2012, the national subsoiling area was 10.5 M ha, which was 1.83 M ha more than that in 2008. In the meanwhile, the Ministry of Agriculture issued the *National agricultural machinery subsoiling and land preparation operation implementation plan (2011-2015)* in 2011. This plan encourages nationwide to develop high-powered tractors and supporting subsoiling machines. In addition, the pilot programs to subsidize agricultural mechanized operation of subsoiling and land preparation should be conducted actively. And suitable operation modes of subsoiling and technical routes need exploring and concluding. By the end of the 12th Five-Year Plan period in China, the possessing capacity of large tractors, whose power was above 80 hp, and subsoiling machines respectively was 750 thousands and 236 thousands, which was 414 thousands and 95 thousands more than at the end of the 11th Five-Year Plan period, respectively. Over these five years, the total area of agricultural mechanized operation of subsoiling and land preparation was 5.67 M ha. The cultivated land in the suitable areas of northern China had almost all been subsoiled. And seven suitable areas for subsoilimg and their respective operation modes had been formed. Monitoring data of some provinces showed that the subsoiled lands, whose subsoiling depth reaching 30 cm, could store about 400 mm^3 more water per hectare than those unsubsoiled lands. And then the average moisture content increased by about 7% during the summer drought. Besides, the drought-tolerance time of crops was extended by about 10 days. And thus, the average yield of wheat, corn and other crops increased by about 10%. However, due to the relatively high cost of agricultural mechanized operation of subsoiling and land preparation, farmers in some areas are reluctant to adopt this technology. In addition, the possessing capacity of tractors with great power and subsoiling machines in some areas is insufficient, which is difficult to meet the operation requirements. These factors limit the rapid promotion and adaptation of the mechanized subsoiling technology.

In order to further accelerate the extension and application of mechanized subsoiling technology in suitable areas of China, the Ministry of Agriculture and Rural Affairs issued the *National agricultural machinery subsoiling and land preparation operation implementation plan (2016-2020)* in 2016, which points out that during the 13th Five-Year Plan period, the nationwide annual operation area of subsoiling and land preparation via agricultural machinery exceeds 10 M ha. And in 2020, the national suitable cultivated land will be able to be subsoiled once, and then enter the positive cycle of suitable periodic subsoiling. According to *The maximum subsidy amount of national general agricultural machinery central financial funds (2018-2020)* formed by the Ministry of Agriculture and Rural Affairs, there are subsidies for purchasing vibrating and non-vibrating subsoiling machines. The minimum subsidy for purchasing subsoiler was 1400 RMB, which is applicable when purchasing non-vibrating subsoilers with three or less shanks. Meanwhile, the maximum subsidy for purchasing subsoiler was 4900 RMB, which is applicable when purchasing vibrating subsoilers with six or more shanks. In addition, China has issued other relevant documents and policies to promote the development and adaptation of subsoiling technology. In 2018, the national subsoiling area was 10.6 M ha, which was 1.93 M ha more than that in 2008. The national policy and financial support is a significant action for the development and extension of subsoiling technology.

3. Classification of subsoiling machines

The subsoiling technology started to be studied in 1960s in China. In recent years, more and more attention has been paying to the research and development of subsoiling shanks and subsoiling machines. According to the operation function, subsoiling machines can be divided into two types. The one is machines, which are capable of subsoiling only, and another one is machines, which are able to complete several operation processes at one time, including stubble breaking, rotary tillage, subsoiling, fertilization, sowing, covering soil and other operations. In addition, the machines, which only have subsoiling function, are further divided into vibrating subsoilers and non-vibrating subsoilers. And the latter mainly includes chisel subsoilers and omni-directional subsoilers. Different types of subsoiling machines can be selected according to the specific soil condition and farming system in different regions of China.

3.1. Chisel subsoiler

Under the traction of the tractor during the subsoiling operation, the soil is loosened and broken by the chisel subsoiler, of which the main operation principle is that the soil is squeezed and lifted at the shovel tip as well as is cut at the shovel handle. The subsoiling depth of the chisel subsoiler ranges between 30cm and 50cm, and the shank space sizes from 40cm to 80cm (Jing, M). The common type of the chisel subsoiler mainly includes ordinary type (Fig.1) and winged type (Fig.2). The ordinary-type chisel-subsoiler is suitable for interval subsoiling, its loosening coefficient is only 0.2~0.3(Zhou, G.X.). Due to the shovel tip and shovel handle generate strong extrusion on both sides of the soil in the deeper soil layer, the soil compaction increases, which is unfavorable to loosening soil. Besides, there is a vertical gap in the soil layer caused by the shovel handle after subsoiling, which leads to moisture evaporation. This is especially not conducive to the preservation of soil moisture in arid areas (Zhu, R.X.). The winged type chisel-subsoiler is formed through adding winged shovels on both sides of the shank of the ordinary-type chisel-subsoiler.

Fig. 1. Hedongxiongfeng 1S-250A subsoiler.

Fig. 2 Haofeng 1S-250 subsoiler

3.2. Omni-directional subsoiler

Omni-directional subsoiler mainly includes two types, subsoiler with V-shaped shank and subsoiler with side bended shank. V-shaped shank is the critical component of the subsoiler, which is composed of a bottom knife and two symmetrical side knives (Fig.3). After the subsoiling operation, the soil was cut into strips with trapezoidal sections. The subsoiler with side bended shank is a combination of the omni-directional subsoiler and chisel subsoiler, of which the principle of breaking soil is similar to the subsoiler with V-shaped shank (Fig.4). Its key component, L-shaped side bended shovel handle, is divided into a vertical part and an inclined part, and the shovel tip is installed at the lower end of the inclined part.

Fig. 3. Chunxiang 1SQ-340 subsoiler.

Fig. 3. Oron Shandong 1SQZ-520 subsoiler.

3.3. Vibrating subsoiler

Traction resistance can be effectively reduced by using the vibrating subsoiler to complete operation. Exciting source is the key to make the shank vibrating during subsoiling. Under the influence of external factors such as excitation source and soil, the shank is subjected to positive and negative forces repeatedly in the process of operation, and thus reducing resistance. According to whether the excitation source requires power drive or not, the vibration mode can be divided into two types, forced vibration (Fig.5) and self-excited vibration (Fig.6). The power output of tractor is the excitation source of forced vibration subsoiler. Its principle is that the output shaft of the tractor transits the power to the vibration mechanism of the subsoiler. And then the vibration mechanism turns the rotation into the vibration with fixed frequency and amplitude of the shank. Meanwhile, the soil is carried to vibrate by the shank, and after periodic vibration, it is broken (Shahgoli, G.). The exciting source of the self-excited subsoiling mainly comes from the change of soil resistance, which caused by the uneven soil surface, non-uniform mechanical properties of soil in different ranges and unequal straw amounts, etc (Qiu, L.C.). The elastic elements of the excitation source are mainly springs and hydraulic components.

Fig. 5 Yunnong ZS-180 forced vibration subsoiler.

Fig. 6 1SZ-190 self-excited vibration subsoiler.

3.4. Subsoiling and land preparation combined machine

The subsoiling and land preparation combined machine is capable of loosening the soil at the middle or deeper layer while breaking soil and making it flat at the surface, which is commonly a combination of subsoiling shanks, rotary roller or disc harrows, etc. There are three common types of the subsoiling and land preparation combined machine, including subsoiling and rotary tillage combined machine (Fig.7), subsoiling, rotary tillage and bad forming combined machine (Fig.8), subsoiling and harrowing combined machine (Fig.9). The main working parts of the subsoiling and rotary tillage combined machine include vibrating or non-vibrating subsoiling shanks, rotary roller composition and compression parts. And the structure characteristics of it is that the subsoiling shanks are installed on the frame in front of the rotary roller, and the carriage used to make the soil surface flat or compressing roller is arranged behind the rotary roller. Rotation speed of rotary roller is generally 200~400r/min. The subsoiling, rotary tillage and bad forming combined machine is obtained by adding the rotary tillage and bad forming combined machine to the subsoiler, which reduces the tillage time of the soil. The subsoiling shanks are installed in front or behind the rotary roller, and the single shank is in front of the midline of two adjacent ridging ploughshares. The subsoiling shanks of the subsoiling and harrowing combined machine is at the front of the machine, and are combined with the disc harrows. The disk gang commonly has double row and adopt offset installation.

Fig. 7 1SZL-210A subsoiling and rotary tillage combined machine.

Fig. 8. Shuangya 1Gkn 200SL-300SL subsoiling, rotary tillage and bad forming combined machine.

Fig. 9 1DSL-3600 subsoiling and harrowing combined machine.

4. Conclusion

The development and extension of subsoiling technology in Chine has improved the efficiency and quality of agricultural production, and increased the economic benefits of farmers. More importantly, it has promoted the sustainable development of agriculture. Some measures, such as the national policy and financial support, locally applicable scientific research, better extension and training for farmers, and international cooperation and communication, will further accelerate the extension and adopation of subsoiling technology in China.

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Effect of cover crops on modern agricultural production of cherry trees in Chile

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The use of plant covers has a positive impact on soil management, since they allow to increase the content of organic matter and nutrients, product of the degradation of above-ground and underground biomass. Vegetable covers can also improve the porosity and structure of the soil, because some of the species used, can provide a deep decompression of the soil (Chen and Well, 2010). They also increase moisture retention and biological activity, as well as reduce water runoff and prevent erosion (Frye and Blevins, 1989). In recent years, other benefits associated with plant covers have also been discovered, such as weed control, due to the competitive effect of plant cover on weeds, which it exerts through shading and competition for water and nutrients (Ovalle et al., 2007) Another important effect of the use of plant covers is on pest control, since its implementation favors the development and action of natural enemies, which increases their abundance and effectiveness in reducing pests (Ripa and Larral, 2008).

A research project is being developed in Chile jointly by Syngenta and Pontificia Universidad Católica de Chile. It aims to determine protocols for addressing the challenge of making modern agricultural production more sustainable by finding means to improve the condition of biodiversity in agro-environments. This project has been entitled LivinGro™, which aims to create scientific data from field trials that demonstrate that the use of products, together with ecological compensatory measures can sustainably improve biodiversity and soil health in agricultural landscapes. Specifically, this study monitors the effects of the use of plant covers on soil parameters (physical, nutritional), soil microbiota, diseases, insects (beneficial and pests) and the possible impact on the quality and quantity of fruit produced.

Keywords: *Sustainable cherries, biodiversity, sustainability, regenerative agriculture, soil health*

Abstract

The use of plant covers has a positive impact on soil management, since they allow to increase the content of organic matter and nutrients, product of the degradation of above-ground and underground biomass. Vegetable covers can also improve the porosity and structure of the soil, because some of the species used, can provide a deep decompression of the soil (Chen and Well, 2010). They also increase moisture retention and biological activity, as well as reduce water runoff and prevent erosion (Frye and Blevins, 1989). In recent years, other benefits associated with plant covers have also been discovered, such as weed control, due to the competitive effect of plant cover on weeds, which it exerts through shading and competition for water and nutrients (Ovalle et al., 2007) Another important effect of the use of plant covers is on pest control, since its implementation favors the development and action of natural enemies, which increases their abundance and effectiveness in reducing pests (Ripa and Larral, 2008).

A research project is being developed in Chile jointly by Syngenta and Pontificia Universidad Católica de Chile. It aims to determine protocols for addressing the challenge of making modern agricultural production more sustainable by finding means to improve the condition of biodiversity in agro-environments. This project has been entitled LivinGro™, which aims to create scientific data from field trials that demonstrate that the use of products, together with ecological compensatory measures can sustainably improve biodiversity and soil health in agricultural landscapes. Specifically, this study monitors the effects of the use of plant covers on soil parameters (physical, nutritional), soil microbiota, diseases, insects (beneficial and pests) and the possible impact on the quality and quantity of fruit produced.

Three experimental units established were established during June 2020 in commercial cherry fruit orchards in the Libertador Bernardo O'Higgins region. Orchards were located at San Francisco de Mostazal (33° 97,109´ S; 70° 72,826´ W), Las Cabras (34° 28,457 ´ S; 71° 31,511´ W) and Chimbarongo (34° 69,616´ S; 70° 91,408´ W). They were evaluated during the first season out of at least three seasons (2020, 2021 and 2022) to determine the effect of covers crops on the nutritional characteristics of the soil, its microbiota, insects, pests and diseases and the possible impact on the quality and quantity of fruit in each orchard (Figure 1).

Figure 1. View of cherry orchards sown with cover crops in June 2020 were soil, its microbiota, insects, pest and diseases and fruit were evaluated.

Cover crops

To evaluate the effect of cover crops establishment, random photographic records were made, every 30 days, in areas with and without cover crops. A 25x25 cm quadrant was used, and all vegetation was collected and taken to San Joaquín campus at Pontificia Universidad Católica de Chile, where each species present and their respective total biomasses were identified. The data indicate that covers did not achieve all the expected presence, being displaced by weeds present in the fields. Of the sown species, *Lolium* sp. stands out, which was present in the fields with greater frequency, followed by *Medicago polymorpha* L. and *Raphanus sativus* L.. Because of this, coverages will be re-sown in patches during the fall, to ensure and generate the desired cover crop density.

Soil

Regarding soil and plant nutrition, periodic samplings were carried out to determine the effects of the treatments of each plant cover on the initial fertility, organic matter, pH, electrical conductivity (EC) and basal respiration of the soils from each orchard field. Physical characteristics (undisturbed samples) such as porosity, texture, apparent density, and distribution of aggregates were also analyzed. The samplings were carried out from the month of September in the between row and the over row in a distance gradient from the established vegetation covers. Furthermore, the main species and relative abundance in the eukaryotic and prokaryotic rhizosphere were determined by means of metagenomics.

Insects

The arthropod monitoring was carried out with the different methodologies (visual monitoring, sweeping net, Malaise traps and soil traps). It seeks to demonstrate the effect on both abundance and diversity of species, and its spread into the orchards. Pests have been rare, without clear trends in relation to the cover and the different distances from it. The diversity and abundance of species collected by sweeping net did not show clear patterns, probably due to the low density of cover plants during this first year and the presence of weeds in the orchards. Malaise traps captured numerous specimens belonging, amongst others, to Diptera and Hymenoptera. Their identification at the lowest level possible is in progress. The capture of pitfall traps was dominated by Collembola (springtails) in the springer, and then by Arachnida (spiders) and Coleoptera (beetles). The underground traps (20-40 cm depth) captured springtails, followed by Chilopods (centipedes).

Plant diseases

Disease monitoring was carried out to study the presence, type and percentage of infection that could be affecting cherry plants, both at the wood and leaf level. These monitoring were carried out in the field periodically from sprouting to postharvest and focused on the main diseases that may affect each orchard, being the case of monitoring cherry trees focused on *Botrytis cinerea*, *Alternaria* sp. and *Pseudomona syringae* pv. *syringae*. Although the oldest orchards were already affected by certain wood diseases, these have no increase or greater relationship with the establishment of cover plants.

Fruits

Regarding the fruit analysis, at harvestings fruits were counted to estimate yield, fruit weight, size, color and estimated volume were recorded. Firmness, soluble solids, pH and acidity values were recorded in the laboratory. At the same time, samples were also stored in cold chambers, to detect the development of diseases 30 days after harvest. This report presents the results of the fruit measurements made in the harvests of the three cherry orchards, which will serve as baseline values at the beginning of the project.

This first experimental season is currently ending and preliminary results allow us to make initial conclusions. It seems important to ensure cover plants domination over weeds present in the fields, allowing to truly contrast sown areas with bare soil (untreated control) used yet in many fields in Chile. Soil results indicate a high variability between different fields selected and it will allow us to obtain a baseline for monitoring trough out years. That variability corresponds to nutrition management made within fields (such as fertilization or amendments), and not to cover plants presence. In both, disease and insect sampling, neither shows clear trends regarding the effect of installation of cover plants. It seems of great importance to align experimental protocols with field practices and also to contrast them with environmental conditions. Finally, fruit analyses do not show positive or negative effect of cover plants, which is encouraging to continue monitoring for the following seasons.

Fig. 2 Field data collected in three cherry orchards in Chile.

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Exploring approaches to strategic and effective communication for profitable and sustainable farming with Conservation Agriculture

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Conservation Agriculture (CA) provides many answers to the world's food production and environment issues. While its uptake in the Americas and Australia has been remarkable, in Africa, Asia and Europe uptake needs to be accelerated through greater policy and institutional support. The question is how? CA stresses the importance of system thinking but why should this philosophy stop at the farm gate? The paper's authors are communications experts working in the international and rural development sectors and they suggest that a systems approach must be central to communication about CA. They argue that a simultaneous, three-layered approach focusing on the farmer and aimed at the grassroots, at the institutional level and also at the level of policy and governance can cut through at all levels, to reveal how CA represents a food system to which all global stakeholders can subscribe for a sustainable future.

Both policymakers at the top and farmers at the bottom of the decision-making hierarchy depend upon institutions for knowledge, advice and support. Knowledge needs to flow both ways and institutions are at the intersection of that information traffic. But how is that information conveyed and manufactured? Farmers are willing to risk change when they can analyse and assess what is involved. But who do they believe most when it comes to their livelihoods? Policy makers have the power to effect change and provide a safety net for managing the bottom-of-the-pyramid risk-taking, but how do they make informed decisions if they can't hear the very practitioners for and about whom they are making crucial decisions? And how can they become convinced that CA represents a means of addressing the broader, pressing issues which they and society must face.

Institutions, where improved systems are theorised and farmer experiences categorised, have a crucial role to play in convincing the grassroots *and* policymakers that CA works in everyone's best interests. Peer-to-peer messaging tools overcome a credibility barrier when it comes to communicating with farmers. That evidence of impact is also key to underpinning institutional and governmental decision-making.

A systems-based communication strategy requires innovative communication approaches and, crucially, durational commitment and vision: what needs to be conveyed, how will it be conveyed, to whom and to what end? As any Theory of Change chart will demonstrate, impact takes time. Documenting to demonstrate that impact also takes time. As much as any field development project needs to be planned, any communications project also needs to be planned. The authors advocate an integrated, long-duration and evidence-based approach to documentation.
There is a wealth of supporting empirical evidence that such approaches work. Examples drawn from the authors' own experience with other innovatory agricultural systems is called upon to show through a poster illustration that 'stories from the field' do provide talking points at conferences, they have an impact in the media and crucially also have the ability to influence policy advisers and change makers.

Keywords: *Conservation Agriculture, Development, Communication, ComDev*

Abstract

Conservation Agriculture (CA) provides many answers to the world's food production and environment issues. While its uptake in the Americas and Australia has been remarkable, in Africa, Asia and Europe uptake needs to be accelerated through greater policy and institutional support. Drawing from their experiences as communicators working in the international and rural development sectors, the authors argue for a simultaneous, three-layered, horizontal and vertical communication approach, combining the farmer at grassroots, the development professional at an institutional level and the policymaker in government. CA stresses the importance of system thinking but why should this philosophy stop at the farm gate? Knowledge needs to flow, and institutions are at the intersection of that information traffic. Both policymakers at the top and farmers at the bottom of the decision-making hierarchy depend upon institutions for knowledge, advice and support. Institutions, where improved systems are theorised and farmer experiences categorised, have a crucial role to play in convincing the grassroots and policymakers that CA works in everyone's best interests. The question is how should information be manufactured and conveyed? Farmers are willing to risk change when they can analyse risk and assess what is involved. But who do they believe most when it comes to their livelihoods? Policymakers have the power to effect change and provide a safety net for managing the bottom-of-the-pyramid risk-taking – but how do they make informed decisions if they can't hear the very practitioners for and about whom they are making crucial decisions? And how can they become convinced that CA represents a means of addressing the broader, pressing issues which they and society in general must face? The long-term sustainability and environmental benefits of CA extend beyond the farmer's scope of immediate concerns and belong in the flow of institutional knowledge that is aimed upwards: CA represents advantages to the farmer that policy must take into account, but it promises much more - to the nation, to the planet and to the future. This must also be an important part of a strategic and effective communication plan.

The opportunity

Conservation Agriculture (CA) represents the solution to many global challenges at a time when the world is looking to and for sustainable food systems that can take us into the future. And yet despite declared desires, at every level of society, to address those challenges, uptake of CA is still surprisingly slow, particularly in Africa, Asia and Europe. One of the reasons for this is that CA has not been effectively communicated to the right people. We suggest that the CA community has an opportunity to conceive a systems-wide communication strategy that can help address this key issue and explain to farmers, institutions and policymakers what CA is, and why it should be supported. Rather than a laying down of guidelines, the development of a communication strategy should be viewed as an opportunity to provide a framework for action. The participants - and particularly the farmers themselves – ought to contribute to and be as responsible for its realization as anyone. Particularly at the institutional level, the communication of CA demands significant creative engagement in order to convince policymakers and, by extension, members of the general public, of the profound value of this remarkable system that, at this stage in the planet's climate change crisis, should feature prominently in high-level plans to rethink food systems.

Communication about development and advocacy for change have become increasingly complex. However, the words of Erskine Childers written in 1968 are as applicable now as they were when Development Communication was in its infancy:

> *If you want development to be rooted in the human beings who have to become the agent of it as well as the beneficiaries, who will alone decide on the kind of development they can sustain after the foreign aid has gone away, then you have got to communicate with them, you have got to enable them to communicate with each other and back to the planners in the capital city. You have got to communicate the techniques that they need in order that they will decide on their own development. If you do not do that, you will continue to have weak or failing development programs. It's as simple as that. (Colle, R. D., 2008, pp. 101-2)*

The CA community can and should be more strategic about communication in order to promote uptake. The right kind of messages need to be delivered to the intended audience in a correct way. If it is to be effective, like the practice of CA itself, communication about it must be understood to be experimental and adaptive. Childers stressed the systemic nature of a successful communication strategy, arguing that in one country it might be important to focus attention on a cadre of civil servants in a government department, whereas in another place, efforts might focus on a folktale traditionally told by a travelling midwife (Colle, R.D., 2008, p.106). In each instance, communication strategy has to adapt to local conditions. Nevertheless, there are some rules by which to advance. In all instances, communication must be tailored to a particular audience. As communication is so adaptive, this paper cannot possibly supply a complete vision of the landscape, however it can provide an outline of the terrain while making a case for communication to be placed at the centre of CA practice.

Communication as framework for action

As noted in a recent PhD thesis about ICT use and CA in Kenya, while numerous studies have investigated communication practices related to agriculture knowledge-sharing systems, research about CA communication practices is still relatively limited (Achora, J.C., 2019). There is currently little research aimed at identifying pathways to impact regarding CA and improving uptake through communications. However, one rare study about how farmers received messages about CA in a Malawian Agriculture Development Program from 2013, aimed to provide recommendations and guidelines for the development of a communication strategy for a sector wide approach (Ndilowe, U.M., 2013). In his conclusion, the researcher argued that literacy was a significant factor as 50% of the farmers in his sample were unable to read the print material distributed and perhaps most significantly, he found that the most preferred form of communication for farmers was face-to-face dialogue with extension workers, from which finding he concluded that the training of extension workers in improved communication ought to become a priority (Ndilowe, U.M., 2013 p.98). Research from other agricultural systems show that farmers will adopt changes that show a reduction in seed usage, improved yields, higher incomes, better living conditions and improved soil. However, farmers invariably want some sort of proof that making a change will work for them, before jeopardising their livelihoods. While agricultural extension workers with high communication skills are essential for a communication strategy, another fact known the world over is that farmers learn from other farmers. Farmer testimony and demonstrations of impact are highly persuasive and should be used to encourage take-up and to reinforce messaging. Therefore, a first step in terms of strategic communication could include the recording of a range of CA success stories and engaging farmers with a concerted campaign of peer-to-peer communication. The immediacy of FAO's Farmer Field School (FFS) methodology would also be highly effective in practically demonstrating CA principles, combined with village meetings and field day visits to other sites. Print communication through the use of leaflets and messages via electronic media, especially rural radio should be developed. Other potential forms of electronic communication include television reports and training videos made accessible by social and other media.

Horizontal & vertical communication

Peer-to-peer messaging tools overcome a credibility barrier when it comes to communicating with farmers. That evidence of impact is also key to underpinning institutional and governmental decision-making on whether to support an approach which bureaucrats may find challenging due to CA's unconventional and occasionally counterintuitive nature. As has been noted, over the three decades that CA has been practiced globally, 'the adoption and spread of CA requires a change in commitment and behaviour of all stake-holders' (Kassam et al., p.1, 2014). CA calls for a transformation in mindset, not only for the farmers who are being asked to learn new practices and experiment, but also for policymakers who have grown accustomed to the modern approaches of agriculture based on tillage and purchased inputs, and for whom the sometimes counterintuitive and unfamiliar practices of CA can prove to be challenging. Enabling farmers 'to communicate with each other and back to the planners in the capital city' becomes all the more important in the case of CA, as farmer experience has greatly helped to shape thinking on the subject, as has been noted by numerous scholars: 'In general, scientific research on CA lags behind farmers' own discoveries' (Friedrich & Kassam, 2009; Milder et al., 2011; FAO, 2011).

This raises questions related to two fundamental forms of information-sharing: vertical communication, the hierarchical, top-down messaging through a chain of command; and lateral communication between and among peers at every hierarchical level. The difficulties in adopting a viable development communication policy which has to be simultaneously analysed horizontally and vertically was acknowledged over four decades ago by early theorists of Development Communication (Habermann, P. and De Fontgalland, G., 1978). It is crucially important to understand the different types of communication used in each level and between the levels which often accentuates the difference between knowledge as information and the more dialogic 'know-how'. At each horizontal level there are specific modes of exchange among its members. At the grassroots, knowledge is often better described as 'know-how' which is harder to summarise and often contains content better suited to demonstration and dialogue as opposed to 'information' that is written down. This know-how will involve often location-specific factors – or factors that involve other specificities – that are unique to farmers or to certain farmers and that do not factor into policy-level decision-making. Farmers themselves respond to *what* information needs exchanging as well as *how* it is exchanged. So, farmers and agriculture extension workers use a language and set of communication tools highly suited to them. However, this form of horizontal communication might be inappropriate and difficult to follow for those at the institutional or governance levels and therefore communication material intended for exchange needs to be considered and then adjusted accordingly. Similarly, the scientific and technical language typically found at the institutional level might be inappropriate for use at the grassroots or at the governance level and therefore this needs to be adapted for the intended audience. At the institutional level communication material is also often produced for a more general audience which requires very careful crafting. Thus, knowing the audience and speaking the same language, whether that means communicating in vernacular or dialect, or by conveying *relevant* information in the simplest manner by using familiar expressions, words or images which carry the same meaning as more scientific or technological expressions should be a major consideration at all levels.

CA communication and sustainability

Also, a systems-based communication strategy requires innovative communication approaches and, crucially, durational commitment and vision: what needs to be conveyed, how will it be conveyed, to whom and to what end? As any Theory of Change chart will demonstrate, impact takes time. Documenting to demonstrate that impact also takes time. As much as any field development project needs to be planned, any communications project aimed at showing impact also needs to be planned. An integrated, long-duration and evidence-based approach to documentation would be most effective. Communication activities need to be embedded as one of the core components of research projects for continuous audience engagement and interest throughout the life of the project. Not only should circumstances prior to intervention be recorded, to provide a baseline for comparison with later developments, but evidence of impact, or its absence, should also be captured after the project has ended in order to establish whether sustainability was made possible. If not, this might help to identify the reasons for that outcome. These findings are highly relevant to all stakeholders. However, this approach rarely occurs due to the nature of project finance: when projects finish the funding for communication, coverage is no longer available and project sites are rarely revisited. A serious CA communication strategy with sustainable uptake as its goal should factor in such an approach.

Observations drawn from authors' experiences[1]

- The acceptance of a project and its scalability depend on how findings or lessons are presented to key stakeholders.
- Synthesize project findings into user friendly forms so that they are widely read or watched with keen interest by the various stakeholders.
- User-friendly evidence summaries are important for policymakers to encapsulate what an initiative or form of research is about.

1 Since beginning their collaboration with N.T. Uphoff and Cornell's SRI-Rice in 2012 the authors have developed communication materials promoting agricultural systems in rural settings in Burundi, Rwanda, Madagascar, Sierra Leone, Laos, Cambodia, Thailand, Vietnam, Nepal and India. See www.floodedcellar.com

- Video serves as an excellent vehicle to convey the key messages of a project. Stakeholders can hear farmers' voices as they tell their own stories. Its immediacy allows policymakers and members of the general public to see where and how farmers live and what agricultural systems they practice. Farmers themselves recognise the farming practices they see in video.

- The audio-visual representation of project impact can help organisations to make a case for scaling up their work. Video can serve as an 'ice-breaker' at meetings, seminars, workshops and conferences, whether at a side-panel or in a plenary hall.

- New developments in internet and social media provide still further opportunities for the ways in which key messages can be delivered.

Conclusion

Today, 'visibility' matters, and development agencies now publicise their mission in much the same way as corporations market their brands. Participants at the institutional level are well aware that the media consumer is a key stakeholder. Development agencies are dependent upon the support of taxpayers while non-profits and private enterprises work hard to protect their image. Now, modern digital communication tools have greatly enhanced the capacity for lobbying and 'people power' is being institutionalised through the support of citizen journalists. As new and various players compete within development, this means that it has become necessary to engage audiences in innovative ways. Communication professionals frequently frame project experience by telling personal stories of individuals so that farmers' voices can now be heard on a global stage. This remarkably powerful form of storytelling is highly suited to CA experience because it is a system that has relied upon innovation and experimentation at the farmer level for its remarkable successes.

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Effect of Conservation Agriculture and precision water management on wheat productivity and irrigation water use under rice-wheat cropping systems in the Indo- Gangetic Plains of India

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In the present scenario the biggest challenge is to produce more food for the continually increasing world population with in the limited land and water resources. Serious water deficits, diminishing profitability and deteriorating natural resources are some of the major threats to the agricultural sustainability in many regions of South Asia. Food security and water sustainability may be achieved by bringing improvement in the crop water productivity and the amount produced per unit of water consumed. The increase in the crop water productivity may be achieved by pursuing alternative agronomics approaches, which are more friendly and efficient in utilizing natural resources. Therefore, a research trial on Conservation Agriculture (CA) and precision water management (PWM) was conducted in 2018-19 at Karnal, India to evaluate the effect on crop productivity and irrigation in rice-wheat (RW) systems of Indo-Gangetic Plains (IGP). Eight scenarios were compared varied in the tillage, crop establishment, residue and irrigation management *i.e.,* {First four scenarios irrigated with flood irrigation method;Sc1-Conventional tillage (CT) without residue, Sc2-CT with residue, Sc3- Zero tillage (ZT) without residue, Sc4-ZT with residue}, and {last four scenarios irrigated with sub-surface drip irrigation method; Sc5-ZT without residue, Sc6- ZT with residue, Sc7-ZT inclusion legume without residue and Sc8- ZT inclusion legume with residue}. Results revealed that CA-flood irrigation (S3, Sc4) and CA-PWM system (Sc5, Sc6, Sc7 and Sc8) recorded about 3-5% and 12-15% higher wheat yield, respectively compared to Sc1. Similar, CA-PWM saved 30-40% irrigation water compared to Sc1. Rice yield was not different under different scenarios in the first year (kharif 2019) but almost half irrigation water saved under CA-PWM system. Therefore, results of our study on best agronomic practices including CA and precision water management (subsurface drip irrigation) systems for RW rotation would be of huge interest to farmers, for addressing the existing and future challenges in the RW system.

Keywords: *Sub-surface drip, crop residue, crop yield and zero tillage*

Abstract

In the present scenario the biggest challenge is to produce more food for the continually increasing world population with in the limited land and water resources. Serious water deficits, diminishing profitability and deteriorating natural resources are some of the major threats to the agricultural sustainability in many regions of South Asia. Food security and water sustainability may be achieved by bringing improvement in the crop water productivity and the amount produced per unit of water consumed. The increase in the crop water productivity may be achieved by pursuing alternative agronomics approaches, which are more friendly and efficient in utilizing natural resources. Therefore, a research trial on Conservation Agriculture (CA) and precision water management (PWM) was conducted in 2018-19 at Karnal, India to evaluate the effect on crop productivity and irrigation in rice-wheat (RW) systems of Indo-Gangetic Plains (IGP). Eight scenarios were compared varied in the tillage, crop establishment, residue and irrigarion management *i.e.,* {First four scenarios irrigated with flood irrigation method;Sc1-Conventional tillage (CT) without residue, Sc2-CT with residue, Sc3- Zero tillage (ZT) without residue, Sc4-ZT with residue}, and {last four scenarios irrigated with sub-surface drip irrigation method; Sc5-ZT without residue, Sc6- ZT with residue, Sc7-ZT inclusion legume without residue and Sc8- ZT inclusion legume with residue}. Results revealed that CA-flood irrigation (S3, Sc4) and CA-PWM system (Sc5, Sc6, Sc7 and Sc8) recorded about 3-5% and 12-15% higher wheat yield, respectively compared to Sc1. Similar, CA-PWM saved 30-40% irrigation water compared to Sc1. Therefore, results of our study on best agronomic practices including CA and precision water management (subsurface drip irrigation) systems for RW rotation would be of huge interest to farmers, for addressing the existing and future challenges in the RW system.

1. Introduction

Since the early 1970s (Green Revolution era), there has been a steady decline in groundwater table in most of the RW domain area of North-West (NW) India which has now accelerated rapidly in central Punjab and parts of Haryana in India. In NW India, conventional cultivation practices in RW system consumes huge quantities of water and energy, is labour-intensive, and can deteriorate soil health (Kakraliya et al., 2018, Jat et al., 2020). Furthermore, crop residue burning also wastes a precious resource and farmers are forced to apply one more irrigation (10 Lakh liters/ha) to fields to compensate the soil moisture lost during the burning. Conventional cultivation practices (flood irrigation) of rice-wheat (RW) consumes 2,000-2,500 mm of irrigation water for crop production (Jat et al., 2019). If sustainable measures are not taken soon to ensure sustainable use of groundwater, the IGP of NW India may soon experience decline in crop productivity and farm profitability, and shortages of potable water leading to extensive socio-economic stresses. The adoption of surface drip irrigation has always remained cumbersome process of anchoring laterals at the beginning and removing after every crop due to field operations. To eliminate this hurdle and looking to the constraints of water shortages in future, it is imperative that we focus on developing alternative and remunerative approaches for increasing water productivity in the '*Green Corridors*' of NW India. Therefore, site-specific water management (SSWM) based RZI/ SDI was evaluated first time in the country under cereal (rice/maize based) systems approach for irrigation water saving, higher water use efficiency and water productivity.

2. Methodology

The experiment was laid out in the completely randomized block design with three replications. The base soil samples were taken for site characterization before laser levelling and after that the SSDI system was layed out as per the treatment protocols. Eight scenarios were compared varied in the tillage, crop establishment, residue and irrigarion management *i.e.,* {First four scenarios irrigated with flood irrigation method;Sc1-Conventional tillage (CT) without residue, Sc2-CT with residue, Sc3- Zero tillage (ZT) without residue, Sc4-ZT with residue}, and {last four scenarios irrigated with sub-surface drip irrigation method; Sc5-ZT without residue, Sc6- ZT with residue, Sc7-ZT inclusion legume without residue and Sc8- ZT inclusion legume with residue}.The soil of the experiment was sodic in nature with a pH (1:2, soil:water) of >8.5 at 0-15 cm soil depth.

Fig. 1 Wheat crop under CA and precision water management practices

3. Results

In the present scenario the biggest challenge is to produce more food for the continually increasing world population with in the limited land and water resources. Serious water deficits, diminishing profitability and deteriorating natural resources are some of the major threats to the agricultural sustainability in many regions of South Asia. Food security and water sustainability may be achieved by bringing improvement in the crop water productivity and the amount produced per unit of water consumed. The increase in the crop water productivity may be achieved by pursuing alternative agronomics approaches, which are more friendly and efficient in utilizing natural resources. Therefore, a research trial on Conservation Agriculture (CA) and precision water management (PWM) was conducted in 2018-19 at Karnal, India to evaluate the effect on crop productivity and irrigation in rice-wheat (RW) systems of Indo-Gangetic Plains (IGP). Results revealed that CA-flood irrigation (S3, Sc4) and CA-PWM system (Sc5, Sc6, Sc7 and Sc8) recorded about 3-5% and 12-15% higher wheat yield, respectively compared to Sc1 (Fig. 2a). Higher grain yield in PWM scenarios were due to favourable conditions provided for water and N supply under drip irrigation cum fertigation (Sidhu et al., 2019 and Jat et al., 2019). Sub-surface drip irrigation provides water and nutrients directly to the root zone that leads to efficient water use, prevents weed emergence, reduces labor cost, and allows direct seeding with no-tillage practices (Kakraliya et al., 2018). Similar, CA-PWM saved 30-40% irrigation water compared to Sc1 (Fig. 2b). Therefore, results of our study on best agronomic practices including CA and precision water management (subsurface drip irrigation) systems for RW rotation would be of huge interest to farmers, for addressing the existing and future challenges in the RW system.

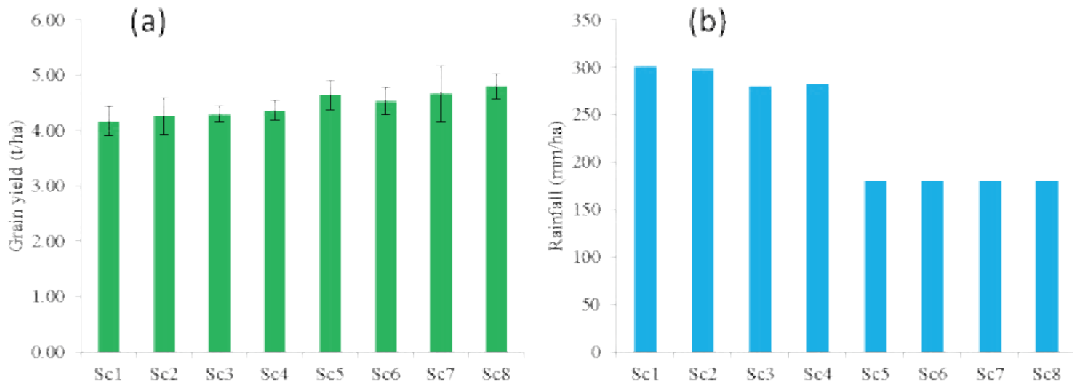

Fig. 2. Wheat grain yield and irrigation water under different scenarios

4. Conclusion

The subsurface drip irrigation combined with Conservation Agriculture (CA) approaches like zero till, retaining residues on soil surface and dry seeding requires ~40% less irrigation water than flood irrigation for wheat with the same or higher amount of yields, and would still be cost-effective for farmers.

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Modeling and verification of corn straw based on no-tillage cutting process in Conservation Agriculture

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Corn straw as an important agricultural resource plays an important role in Conservation Agriculture. However, the existing corn straw model cannot reflect the stress and strain of each part of the straw corn during the shearing process and cannot be used for the numerical simulations and structure optimization of no-tillage stubble cutting device.

A Discrete Element Model of corn straw was established by Hertz-Mindlin with Bonding model in discrete element software EDEM. The normal stiffness per unit area, shear stiffness coefficient per unit area, critical normal stress, critical shear stress and bonded disk radius were demarcated by the mechanical test of straw rind and inner pith. The straw rind model was transversal isotropic and formed by two kinds of 264 longitudinal fibres bonded along elliptical coordinates, each fibre was bonded by 222 particles with a radius of 0.225 mm along a straight line. The calibrated longitudinal bonding parameters between the rind particles were 2.86×10^{10} N/m^3, 1.11×10^{10} N/m^3, 1.42×10^8 N/m^2, 1.2×10^7 N/m^2 and 0.6 mm; The calibrated transverse bonding parameters were 8.84×10^9 N/m^3, 1.23×10^9 N/m^3, 2.00×10^6 N/m^2, 1.54×10^6 N/m^2 and 0.6 mm. The inner pith model was isotropic and made up of 1090 particles of the same type at equal intervals, and the radius of particle was 1.05mm. The calibrated bonding parameters between the inner pith particles were 4.15×10^8 N/m^3, 5.00×10^6 N/m^3, 1.32×10^6 N/m^2, 4.42×10^6N/m^2 and 1.2 mm. The verifying tests revealed that the shear force trend of the straw model in the simulation test was consistent with that in the physical test, and the maximum shear force deviation remains within 10%, the deformation and damage of the straw mechanical model in the shearing process were identical. The results demonstrated that the discrete element model can be used to simulate compared of shearing force and shearing process of the stubble cutting device, which was of great significance to the study of the interaction mechanism of the stubble cutting device with straw and the structure optimization of the stubble cutting device.

Keywords: *corn straw; straw shear; transversal isotropy; discrete element method; model*

1. Introduction

Straw mulching as a component of conservation tillage has an important role in reducing wind and water erosion, increasing soil moisture, improving soil structure and increasing crop yield (Li, R.). The performance of stubble cutting devices becomes the key factor that affects the anti-blocking performance and operating performance of the no-tillage machine because of the corn straw is difficult to cut off (He, J.). Therefore, the establishment of straw model suitable for the numerical simulation of stubble cutting device is of great significance for the optimization and improvement of stubble cutting devices and the research on the anti-blocking performance of no-tillage working machine.

The present research mainly aimed at the straw crushing, harvesting, compression and other aspects to establish the isotropic discrete element model, has not establish the transverse isotropic mechanical model suitable for numerical simulation of shearing process. Based on the study of mechanical and physical properties of corn straw, this article uses the Hertz-Mindlin with Bonding Model in the discrete element software EDEM to establish a mechanical model of transversely isotropic oval corn straw, the contact and bond parameters of straw were calibrated by mechanical test. Finally, the shear force and deformation of corn straw in physics were used to verify the validity of the straw model, so as to provide theoretical support for the optimization and improvement of the stubble device and the no-tillage equipment anti-blocking performance research.

2. Materials and methods

2.1. The Corn straw discrete element model

The bonding model in the discrete element software EDEM was selected as the contact model between the particles of the corn stalk model. In the bonding model, two adjacent particles within the contact radius were bonded in parallel, and the bonds between the particles could withstand forces and moments. By adjusting the inter-particle bonding parameters and contact parameters could adjust the critical stress and deformation and simulated the stress and deformation of the straw rind and inner pith during the shearing process.

Due to the differences in the physical and mechanical properties and the differences in load and destruction form of the straw rind and inner pith during the shearing process of the cutter, chose to establish discrete element model and perform parameter calibration according to the stress and deformation of the straw rind and inner pith. The discrete element model of corn straw was shown in Fig.1, Among them, the straw rind was formed by two kinds of 264 longitudinal fibers bonded along elliptical coordinates, and each fiber was bonded by 222 particles with a radius of 0.225 mm along a straight line, a total of 58608 particles. The inner pith was made up of 1090 particles of the same type at equal intervals, and the radius of particle was 1.05mm. The dimensions of the long and short axis of the discrete element model for straw were 23 and 18 mm respectively, and the length was 100 mm.

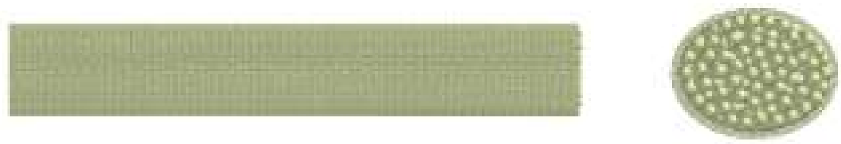
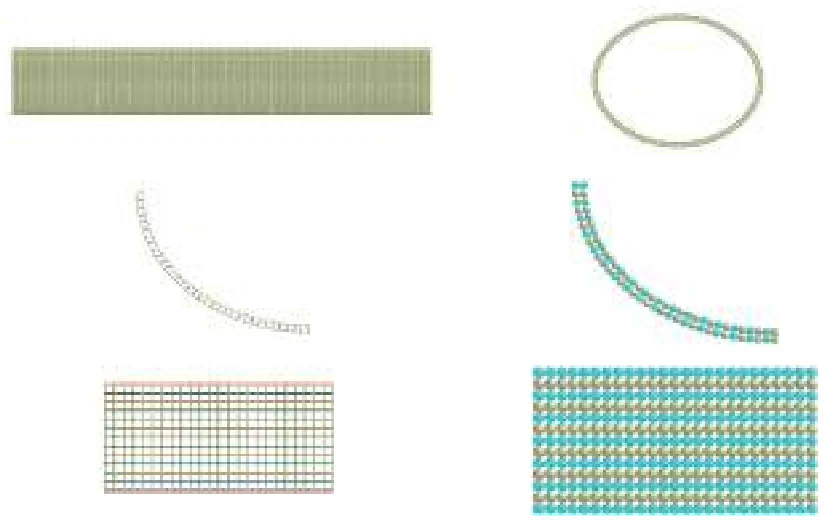


Fig.1 Discrete element model of corn straw

2.2. Construction of straw rind model

The straw rind includeed epidermis and tube bundle tissue mainly. The epidermis was composed of tough and smooth cells, the tube bundle tissue composed of 2-4 layers of fibroblasts and catheter arranged along the rind longitudinally. The corn straw was hypothesized as a model of transverse isotropy formed by multi-layer of longitudinal cellulose bonded to each other (Murphy J.D; McCarthy K.). According to the arrangement direction and connection mode of cellulose, the discrete element model of cellulose was established.

The discrete element model of rind was shown in Fig.2. In order to accelerate the simulation speed, two layers of particles with a radius of 0.225 mm were used to establish the rind model. Different colors in the picture represented different types of particles, the two particles were alternately arranged to isolate the same kind of particles. The red and blue in the figure was the bond between the same kind of particles, and the green were the bonds between different kinds of particles. In the simulation, the stress of bonds between the same kinds of particles were used to simulate the internal stress of rind fiber, the force of the bonds between different kinds of particles simulates the force between rind fiber.



Particle bonds **Particle configuration**

Fig. 2 Discrete element model of straw rind

Straw rind was mainly subjected to tensile and shear loads during the cutting process of the stubble cutting device. Therefore, in the rind parameter calibration test, the transverse and longitudinal direction of tensile and shear tests of the rind were used to calibrate the bonding parameters of the rind particles.

2.3. Construction of straw inner pith model

The straw inner pith was loose and porous, the elasticity was large, which played an important role in the stability of the straw. Based on the structure of the inner pith and the stress characteristics of the shearing process, a discrete element model of the corn stalk inner pith was established as shown in Fig.3. The model was composed of 3264 particles with a radius of 1.05mm, and the porosity of the discrete element model was 40%. The cross section of the model was elliptical, the dimensions of the long axis and short axis were 21.2, 16.2mm, and the total length was 100mm.

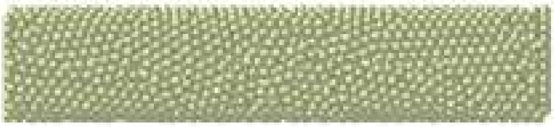
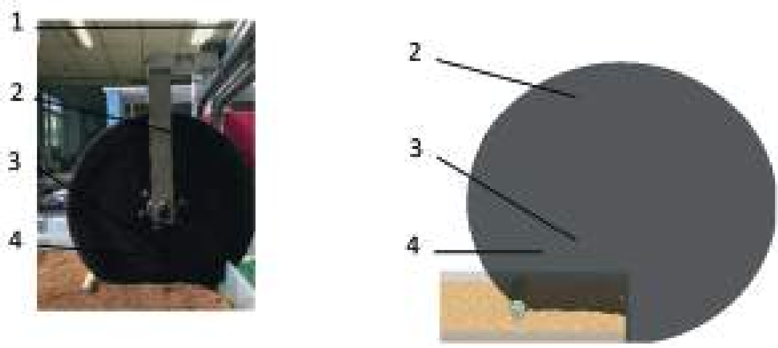


Fig. 3 Discrete element model of straw inner pith

2.4. Verification test of straw model



Physical test **Simulated test**

1. Pressure sensor; **2.** Stubble cutting disk; **3.** Corn straw; **4.** soil box

Fig.4 Shear force verification test of straw model

In the verification test, used the shear force measuring device to get the vertical force acting on the disk during the shearing progress and compared it with the force of the straw acted on the disc model in the simulation test. In physical test, the disc shearing force test device was shown in Fig.4, and corn straw were horizontally placed on soil box with width of 400 mm, length of 600 mm, height of 120 mm for shearing. In order to facilitate the shearing force measurement and reduce the impact of the frame vibration on the sensor, one end of the pressure sensor was fixed to the frame, and the other end was fixed to the disk holder. The change of the voltage signal output from the pressure sensor was used to determine the real-time acting force of the disk on the vertical direction. In the simulation test, the disk model with the same size as that in the physics test was established in the 3D software and imported into simulation test. The Hertz-Mindlin(no slip) model was selected as the contact model of soil.

At the same time, the high speed camera was used to record the shear deformation process of corn straw on No 45 steel plate The shooting direction of the high-speed camera was parallel to the side of the disk, 40° to the plane of the conveyor belt, and the Shutter speeds was 1/1000 second. During the test the soil compaction was 650kPa; the diameter of the disk was 460mm; the thickness was 4mm and the advance speed of the conveyor belt was 3km/h.

2.5. Model shear force

The shear force-displacement curve of the stubble cutting disk in the physical test and simulation test was shown in figure.5. The variation trend of straw shear force in physical and simulation test was the same. The rind of straw simulation model was first bent under the action of the cutter, and the inner pith was compressed, the model was cut off when the maximum shear stress of straw was reached. The average maximum shear force of the straw in the physical test was 486N, the maximum shear force of the straw model in the simulation test is 453N, the maximum shear force deviation of the straw model was 6.8%. The average compression force of the straw in the physical test was 170N, and in the simulation test was 210N, the deviation of the compressive force of the straw model was 19.0%. The shear work of straw in physical test was 13974J, and in the simulation test was 13666J, the deviation of the shear work of the straw model was 2.2%. The discrete element model of corn straw after straw calibration could be used to simulate the stress process of straw cutting device.

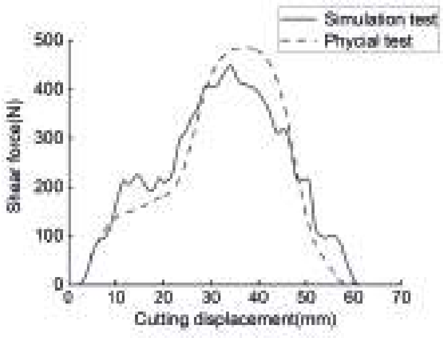
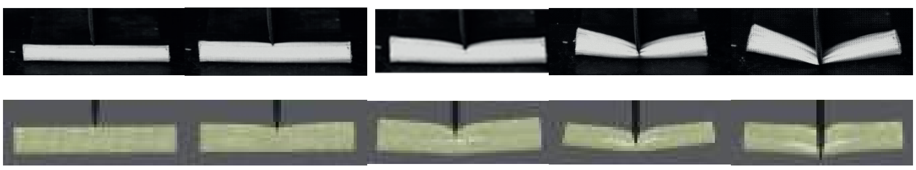


Fig. 5 Comparison of force on stubble disk

2.6. Model deformation

The comparison of the deformation of the corn straw under the action of the stubble cutting disk in the physical and the simulation test was shown in Fig.6. When the displacement was S0, the stubble disk was contact with the corn straw. As the stubble disk going forward, the inner stalk of the corn stalk was compressed firstly, When the stress between the rind fibers reaches the transverse critical tensile strength, longitudinal cracks appear in the skin. With the further advancement of the disk, the number and length of longitudinal cracks generated by the cutting position increased. When the straw reached the critical stress of tensile or shear, the straw was cut off by the stubble cutting disk. In the physical test, the cutter displacement during the elastic deformation stage of the straw was 9.2mm, which was 11.6mm in the simulation test. When the straw reached the maximum shear force the cutter displacement was 36.5mm, which was 33.9mm in the simulation test. When the straw was completely cut-off in the physical test, the displacement of the straw was 58.3mm, which was 60.7mm in the simulation test. In the simulation and physical tests, the deformation and destruction of the rind and inner pith of the straw were similar. The discrete element model of the straw could simulate the deformation of the straw during the cutting process of the stubble cutting device.



S_0 **S_0+15mm** **S_0+30mm** **S_0+45mm** **S_0+60mm**

Fig. 6 Comparison of corn straw deformation

3. Conclusion

A transverse-isotropic model of corn straw was development using the Hertz-Mindlin with Bonding mode of EDEM, the model was able to simulate the cutting progress of no-tillage stubble cutting device. The normal stiffness per unit area, shear stiffness per unit area, critical normal stress, critical shear stress and bonded disk radius were demarcated by the mechanical test of straw rind and inner pith. The straw rind model were transversal isotropic, and the calibrated longitudinal bonding parameters were 2.86×10^{10}N/m^3, 1.11×10^{10}N/m^3, 1.42×10^8N/m^2, 1.2×10^7N/m^2, 0.6mm; The transverse bonding parameters were 8.84×10^9N/m^3, 1.23×10^9N/m^3, 2.00×10^6N/m^2, 1.54×10^6N/m^2, 0.6mm. The inner pith model was isotropic, and the calibrated bonding parameters were 4.15×10^8N/m^3, 5.00×10^6N/m^3, 1.32×10^6N/m^2, 4.42×10^6N/m^2, 1.2mm. The verification test results showed that and the shear work of cutting device deviation was 2.2%, when the straw reached the maximum shear force the deviation of cutter displacement in physical and simulation test was 2.6mm and the maximum shear force deviation was 6.8%. The deformation and damage of the straw mechanical model in the shearing process were identical, which was of great significance to the study of the interaction mechanism of the stubble cutting device and the design and optimization of the stubble cutting device. The modeling and calibration methods of corn straw, provided a method for modeling transversely isotropic materials from structural analysis, parameter measurement to numerical simulation.

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Effects of Soil bioactivation and fertilizer on common bean grain yield in Brazil

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The technology use of soil and plant bioactivation has been proposed for increasing soil microbiota, promote better nutrient equilibrium and enhance general soil attributes (biological, physical and chemical), as well achieving higher crop yield due to further optimization in the use of soil nutrients, especially phosphorus. The objective of the study was to determine the common bean performance, grain yield and yield components of common bean as affected by bioactivation and different dosis of inorganic phosphorus. The experiments were conducted in field conditions irrigated in two growing seasons. The experimental design was a randomized block design in a factorial 4 x 2. The treatments consisted of four levels of phosphorus in the soil (0, 40, 80 and 120 kg ha^{-1} of P_2O_5) in the presence and absence of bioactivation (penergetic) applying. Phosphorus applying allowed significant increases in grain yield and yield components of common bean in the two growing season. The bioactivator applying independent of the phosphorus use attained higher bean grain yield than the treatments without applying in the two growing season. In 2013, the bioactivator applying allowed the highest grain yield (5,313 t ha^{-1}) at a lower phosphorus than in the absence of the bioactivator (3903 kg ha^{-1}) at the highest dose of P (120 kg P_2O_5 ha^{-1}). The results showed that cultivate in a good P status in the soil, with an adequate soil management including the bioactivation it´s possible to enhance soil attributes, optimize the use of phosphorus, increasing bean grain yield, decreasing production costs and enhance the net income in a sustainable way towards sustainability.

Keywords: *nutrient uptake efficiency, better soil attributes by soil and plant bioactivation, phosphorus use efficiency, Phaseolus vulgaris reduction production costs*

The technology use of soil and plant bioactivation has been proposed for increasing soil microbiota, promote better nutrient equilibrium and enhance general soil attributes (biological, physical and chemical), as well achieving higher crop yield due to further optimization in the use of soil nutrients, especially phosphorus. The objective of the study was to determine the common bean performance, grain yield and yield components of common bean as affected by bioactivation and different dosis of inorganic phosphorus. The experiments were carried out in field conditions irrigated in two growing seasons. The experimental design was a randomized block design in a factorial 4 x 2. The treatments consisted of four levels of phosphorus in the soil (0, 40, 80 and 120 kg ha^{-1} of P_2O_5) in the presence and absence of bioactivation (penergetic) applying. Phosphorus applying allowed significant increases in grain yield and yield components of common bean in the two-growing season. The bioactivator applying independent of the phosphorus use attained higher bean grain yield than the treatments without applying in the two-growing season. In 2013, the bioactivator applying allowed the highest grain yield (5,313 t ha^{-1}) at a lower phosphorus than in the absence of the bioactivator (3903 kg ha^{-1}) at the highest dose of P (120 kg P_2O_5 ha^{-1}). The results showed that cultivate in a good P status in the soil, with an adequate soil management including the bioactivation it´s possible to enhance soil attributes, optimize the use of phosphorus, increasing bean grain yield, decreasing production costs and enhance the net income in a sustainable way towards sustainability.

Introduction

Common bean crop represents strong economic relevance for Brazil, normally produced in three seasons called water, drought and winter season, comprising different environmental conditions, according to the season, soil, water regime, cultivars and level technological used. The winter season is characterized by the use of sprinkler irrigation, high technological level applied and also higher speed technologies adopted by bean producers. Among the other factors that can contribute to enhance grain crop yield, an adequate and balanced supply of nutrients can provide a positive impact on grain yield. In this sense, the phosphorus (P), an essential element in the metabolism of plants contributes significantly to increase root development, in addition favoring higher number of pods, mass of grains which can lead to increment grain productivity (Zucarelli et al., 2010). Phosphorus is one of the nutrients that most limits bean production, especially in low fertility soils such as those in the Cerrado/Savannah area (Fageria & Baligar, 2008). This is due to the high rate of P clay-adsorption in tropical soils, provoked mainly by Fe and Al precipitation, reaction with hydrated oxides of the same metals and reactions with silicate clays, due to which the amount absorbed by crop varies from 5% to 25% of the total applied (Malavolta, 1980). In order to increase the availability of nutrients in the soil, the most technologically advanced producers have used Penergetic technology, which consists of the application of Penergetic products “K” and “P”, which according to the manufacturer come from bentonite clay submitted to the application of electric fields magnetic (Brito et al., 2012). Also, according to the manufacturer, these products are used as a soil bioactivator (Penergetic “K”, applied to the soil) that increases and balances activities microbiological in the soil and as a plant bioactivator that provides more energy to the photosynthetic process and facilitates the plant + beneficial microorganism interaction (PENERGETIC, 2013). Even though the use of the product in Brazilian agriculture is quite recent, there are promising results of its use in wheat (Kadziuliene et al., 2005; Pekarskas, 2012a), cucumber and tomato (Jankauskiene & Surviliene, 2009), common bean (Brito et al, 2012), potatoes (Jakiene et al., 2008) and barley (Pekarskas, 2012b) and others. Thus, it was assumed that the application of Penergetic K and P will provide better use of soil phosphorus and higher bean grain yield with the application of lower doses of the chemical nutrient (P). The objective of the work was to evaluate the effects of phosphate fertilizer and Penergetic K (soil), Penergetic P (leaf) bioactivators, on common bean grain yield as well the production components.

1. Material and methods

The experiment was carried out in different locations at Fazenda Guaribas, in the municipality of Unaí, Minas Gerais State, Brazil in the years 2012 and 2013. The soils were classified as Latossolo Vermelho-Amarelo (2012) (Red-Yellow Latosol) and Latossolo Vermelho (2013) (Red Latosol), dystrophic with frank- clayey. Before the installation of the experiments, soil samples were collected and chemical and physical analyzes were performed, according to the recommendations of Claessen (1997) (Table 1).

The region's climate was classified as Aw, tropical savannah, mesothermal, according to the Koppen classification. The region's historical average from 1983-2013 is 32, 8.3, 4.3 and 12.6 mm precipitated in the months of May, June, July and August, respectively and average temperatures of 21.8, 20.6, 20.8 and 22.6 ° C in the same months, respectively. The experiment was installed in a no-till area after soybean cultivation. The application was with a bar sprayer with a spray volume of 200 L ha^{-1}. The sowing of common bean, cultivar Pérola, which is the most planted in Brazil, was carried out on 05/15/2012 and 05/19/2013, with the emergency occurring 5 and 6 days after sowing for the 2012 and 2013 harvests, respectively. The spacing between the rows was 0.50 m and the sowing density was 8 seeds per linear meter. After sowing, 65 kg ha^{-1} of K_2O (KCl) and 90 kg ha^{-1} of N (Urea) were applied (without incorporation). Cultural treatments were carried out according to the needs of the culture, using the recommended products (Vieira et al., 2006). In the two agricultural years, the sprinkler irrigation system was used by central pivot. In water management, three crop coefficients (Kc) were used, distributed over four periods between emergence and harvest. For the vegetative phase, the value of 0.4 was used; for the reproductive phase there were two values of Kc, the initial of 0.7 and the end of 1.0 and for the maturation phase these values were inverted, that is, the initial of 1.0 and the end of 0.7.Thus, the control of irrigation considering the depth of exploration of the root system of 0.2 m, started with the available water capacity at its maximum, successively subtracting the value of the crop evapotranspiration until the total water reach a minimum limit of 40% of CAD (Silveira & Stone, 2003). The crop cycle was 102 and 107 days for the years 2012 and 2013, respectively. As supplementary information, the agronomic efficiency of P applying, in which the productivity of a given treatment was subtracted from the productivity of the control treatment (without P) and dividing the result by the amount of P applied. The data were submitted to analysis of variance and when the F test was significant, the Tukey test was performed ($p < 0.05$). For quantitative data (phosphorus doses), regression analysis was performed.

Table 1. Chemical attributes of the areas where the experiments were conducted. Unaí, MG, Years 2012 and 2013.

				2012				
	pH	O.M.[1]	Ca	Mg	Al	H+Al	V	
m(cm)	(water)	g dm^{-3}	--------------------mmol$_c$ dm^{-3}---------------					
---------		------%------						
0-20	5,8	4,1	3,2	1,1	0,1	5,1	48	
2								
K	P	B	Cu	Iron	Mn	Zn	clay	Silt
sand mg dm^{-3}	mg dm^{-3}	------------------------mg dm^{-3}-------------------					------------g	
kg^{-1}----------								
187	16,7	1	1,8	19,6	17	10,2	510	
	310	180						
				2013				
	pH	M.O.	Ca	Mg	Al	H+Al	V	
m(cm)	(water)	g dm^{-3}	-----------------mmol$_c$ dm^{-3}---------------					
------	--------%-----							
0-20	6,6	4,4	4,0	1,6	0,0	4,0		
	77,7	0						
K	P	B	Cu	Iron	Mn	Zn	clay	Silt
sand								
mg dm^{-3}	mg dm^{-3}	------------------------mg dm^{-3}--------------------					----------g kg^{-}	
^{1}------------								
203	16,8	1,2	0,4	10,5	27,3	4,6	493	
	328	179						

Extractor: P-Mehlich; B- Hot water; Cu/Fe/Mn/Zn – DTPA. V- bases saturation; m - % of Al saturation

[1]O.M. – soil organic matter.

2. Results and discussion

Data analysis revealed that in the 2012 agricultural crop, bean plants produced fewer pods m^{-2} and a mass of 100 grains, resulting in less grain yield compared to the 2013 harvest (Table 2). Since the experiment was conducted in different areas, the higher grain yield obtained in the second harvest may be due to the better soil characteristics that occurred in the 2013 harvest compared to the 2012, such as pH (5.8 in 2012 and 6 , 6 in 2013), Al (0.1 in 2012 and 0 mmolc dm-3 in 2013), H + Al (5.1 in 2012 and 4.0 mmolc dm-3 in 2013), organic matter (4.1 in 2012 and 4.4 g dm-3 in 2013), Ca levels (3.2 in 2012 and 4.0 mmolc dm-3 in 2013), Mg (1.1 in 2012 and 1.6 mmolc dm-3 in 2013), K (187 in 2012 and 203 mg dm-3 in 2013), resulting in a higher base saturation value (48 in 2012 and 77.7% in 2013) (Table 1). According to Nascente et al. (2013) soil organic matter improves the physical and chemical characteristics of the soil, providing a better environment for crops development. Additionally, Fageria et al. (2011) reported that improving soil fertility contributes significantly to increasing crop productivity. In 2012 it was found that there was no significant effect of the number of pods m^{-2}, number of grains pod^{-1} and mass of 100 grains for the phosphorus doses factor, having an important effect on the variable of greatest grain crop yield (Table 2). Regarding the application of Penergetic, there was an effect on the mass of 100 grains and also on bean grain yield. The highest doses of phosphorus applied (80 and 120 kg ha^{-1}) did not provide positive increases in the grain yield of the crop. Thus, it appears that the supply of P in the furrow of sowing up to the dose of 40 kg ha^{-1} of P_2O_5 was sufficient to achieve productivity similar to highest doses of P. This result may have occurred due to the high levels of P in the soil (Table 1), being considered average, a common fact in areas under properly no-till system conducted. The undisturbed soil avoids the contact of the particles of phosphorus applied in the previous crops with the soil colloids, thus decreasing the potential P-adsorption process. In addition, the excessive amount of certain nutrients does not always promote a yield increase mainly due to nutrients disequilibrium (Malavolta, 1980), as already reported in the bean culture by Silva et al. (2012). Regarding the use of Penergetic in 2012, it was found that its application provided significant increases in the mass of 100 grains (from 24.6 to 26.1 g) and also in the bean grain yield (from 2815 to 3006 kg ha^{-1}) (Table 2). Brito et al. (2012) also found that the application of Penergetic provided significant increases in bean grain yield when compared to control treatment (without Penergetic). According to the authors, Penergetic technology provides better conditions for the plant development, more equilibrium in all soil attributes, and better absorption of nutrients such as phosphorus. In this sense, the results of the present study allow us to infer that the use of these products provided better conditions for the development and plant performance, resulting in greater bean grain yield.

It is worth mentioning that the agronomic efficiency of phosphorus application had higher values in 2013 (from 16.7 to 53.4 kg of grain per kg of P^{-1}) than in 2012 (from 2.9 to 7, 4 kg of grain per kg of P^{-1}) due to the difference in productivity between the years, which was 3006 kg ha^{-1} in 2012 and 4543 kg ha^{-1} in 2013, since the calculation of this efficiency is done by subtracting the grain yield of a given treatment by the grain yield of the control (without P) and dividing the result by the amount of P applied.

Corroborating this information, it appears that when the Penergetic was applied, the agronomic efficiency phosphorus application was much higher than the absence of product application, notably in 2013, with much greater efficiency at lower phosphorus doses.

It is necessary to develop other studies to confirm these hypotheses, since the producers are using these products and reporting positive increases in the crop grain yield and as observed in the present experiment. On the other hand, without the penergetic applying, the response to phosphorus in the soil was linear, with the maximum being 3903 kg ha^{-1} of grain yield. Based on the results it can be inferred that the application of Penergetic provided higher grain yield with less dose of phosphorus applied. This result may indicate that there was a greater availability of phosphorus for plants when Penergetic was applied, possibly from soil colloids and or organic part due to the greater microbial activity in the soil (PENERGETIC, 2013), as reported by Kadziuliene et al. (2005), Jakiene et al. (2008), Jankauskiene & Surviliene (2009), Brito et al. (2012) and Pekarskas (2012a).

Table 2. P values for the variables number of pods m^{-2} (POD), number of grains pod^{-1} (GRAIN), mass of 100 grains (MASS) and grain yield (YIELD) of common bean as a function of the agricultural harvest and the phosphate fertilization (P), applying of penergetic (PEN) and interactions. Unaí-MG, 2012 and 2013.

Factors	POD	GRAIN	MASS	YIELD
	number	number	grams	kg ha^{-1}
YEAR				
2012	256 b[1]	4,52 a	25,4 b	2911 b
2013	305 a	4,69 a	28,1 a	4061 a
Value of *p* (probability test F)				
Year	<0,001	0,1186	<0,001	<0,001
CV (%)	10,0	8,7	5,3	8,4
		Year 2012		
Phosphorus doses (P)				
0	250	4,71	24,3	2799
40	207	4,29	25,2	2889
80	253	4,73	26,0	3123
120	254	4,34	25,7	2831
Penergetic applying (Pen)				
WITHOUT	252 a	4,59 a	24,6 b	2815 b
WITH	260 a	4,45 a	26,1 a	3006 a
Value of *p* (probability test F)				
P	0,7117	0,5849	0,5547	<0,001
Penergetic (Pen)	0,2879	0,3587	<0,001	<0,001
P x Pen	<0,001	<0,001	0,8421	0,7002
CV (%)	7,0	10,4	4,8	4,5
		Year 2013		
Phosphorus dosis (P)				
0	246	4,71	26,9	3120
40	322	4,68	28,9	4368
80	318	4,73	28,0	4247
120	336	4,66	28,7	4510
Penergetic applying (Pen)				
WITHOUT	283 b	4,61 b	27,3 b	3579 b
WITH	328 a	4,76 a	28,9 a	4543 a
Value of *p* (probability test F)				
P	<0,001	0,4493	<0,001	<0,001
Penergetic (Pen)	<0,001	<0,001	<0,001	<0,001
P x Pen	0,1254	0,2591	0,2752	<0,001
CV (%)	12,2	5,0	3,9	12,0

[1]Same letter vertically does not differ from each other by the Tukey test for $p < 0.05$

Further research should be carried out to better clarify the effects of these products on the plant and soil that promoted this better development.

Conclusions

Phosphate fertilizer provided significant increases in grain yield and production components of common beans in the two years cropping.

The use of Penergetic regardless of the dose of phosphorus used provided higher grain yield than treatments without applying in the two years cropping.

In 2013, the application of Penergetic provided highest bean grain yield (5313 kg ha^{-1}) in a lower dose of phosphorus (82.2 kg of P_2O_5 ha^{-1}) than in the absence of bioactivator (3903 kg ha^{-1}) in the highest dose of phosphorus (120 kg of P_2O_5 ha^{-1}).

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The future of farming

Profitable and Sustainable Farming with Conservation Agriculture

8WCCA

8th World Congress on Conservation Agriculture

ANNEXES

8th World Congress on Conservation Agriculture

The future of farming
Profitable and Sustainable Farming with Conservation Agriculture

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Declaration & Action Plan

DECLARATION

The 8th World Congress on Conservation Agriculture (8WCCA) was held virtually on 21-23 June 2021 in Bern, Switzerland and attended by 783 participants from farmer associations, international organisations, scientific institutions, private sector, non-governmental and civil society organizations, from more than 108 countries, from the developed and developing world. The main objective of the 8WCCA was to celebrate the Conservation Agriculture Community's success as the driver of the biggest farming revolution to have occurred in our lifetimes, and to build on this and boost the quality and speed of this transformation globally towards sustainable agriculture in support of the Sustainable Development and the international climate goals.

Naturally grown soil is a limited, scarce, nonrenewable resource. It is the base for the production of healthy food and native wood, a buffer element for the global hydrological cycle, filter substrate for clean drinking water, global carbon store, habitat of a huge biodiversity and element of attractive landscapes. At the interface of atmosphere, hydrosphere and lithosphere, the soil fulfills indispensable ecological, economic and social functions. The future of the world's food security requires soils which are unpolluted, of stable structure and productive, in short – a sustainable soil use.

Conservation Agriculture (CA) and its many locally adapted variants offer the best means of using soils for productive farming while enhancing their ability to fulfil their vital societal and planetary functions.

Accumulated positive experiences and scientific knowledge about Conservation Agriculture (CA) are leading to its rapid adoption world-wide. Farmers now apply CA on over 200 million hectares (15% of the word's annual cropland area) in over 100 countries across a diverse range of agro-ecological zones and farm sizes, in all continents but particularly in Africa, Asia and Europe. It has enhanced farm production and reduced costs while conserving and enhancing the natural resources of land, water, biodiversity and climate.

In contrast, conventional tillage practices are not ecologically sustainable since they degrade land by destroying soil structure and biodiversity, reduce soil organic matter content, cause soil compaction, increase run-off and erosion and contaminate water bodies with pollutants and sediments, threatening land productivity, environment and human health. In addition, they produce unacceptable levels of greenhouse gas emissions, speeding up climate change. World-wide, they have accelerated degradation of many natural ecosystems, decreased biodiversity and increased risks of desertification.

CA avoids many of the negative consequences of conventional tillage agriculture by replicating natural processes through the continuous avoidance of soil tillage, permanent maintenance of a soil mulch cover through which diverse crops are directly seeded or planted and rainfall can enter the soil and be retained, cutting erosion. CA enhances the crop root environment (soil structure, carbon, nutrients and moisture) and cuts the build-up of pests and diseases.

In these ways, CA results in a productive agriculture for food security and improved rural livelihoods, especially women's welfare since they provide a high proportion of agricultural labour. Its many economic, social and environmental benefits justify a fundamental re-appraisal of common farming methods.

This Congress has confirmed that CA is here to stay. It has shown that the CA Community is in very good health, full of energy and new ideas. It has confirmed the validity of the Community's way of operating, with farmers in the driving seat, innovating, sharing experiences, spreading the word and creating demands for supportive services from the public and private sectors. All of us who have participated feel proud of our Community's achievements and are determined to do everything within our power - and working with others who share our determination - to contribute to the emergence of a truly sustainable future of farming world-wide. We are confident that the millions of CA farmers whom we have sought to represent here will echo our commitment.

We call upon politicians, international institutions, environmentalists, farmers, private industry and society as a whole, to recognise that the conservation of natural resources is the co-responsibility, past, present and future, of all sectors of society in the proportion that they consume products resulting from the utilization of these resources, noting the increasing interest in plant-based diets to improve human and planetary health. Further, it calls on society, through these stakeholders, to conceive and enact appropriate long-term strategies and to support, further develop and embrace the concepts of CA as a fundamental element in achieving agricultural-related Sustainable Development Goals including those with a social and economic perspective, and those of ensuring the continuity of the land's ongoing capacities to yield food, other agricultural products, water and environmental services in perpetuity. It follows that the environmental services provided by farmers who nurture soil health should be recognised and recompensed by society.

ACTION PLAN

The Congress participants declare their commitment to engage the CA Community in achieving the following goal and to taking the actions needed for this.

GOAL

Given the urgent need to accelerate the global move to sustainable food systems, and in particular to respond to the global challenge to mitigate the advancing climate change, the Congress agreed that the CA Community should aim at bringing at least 50% of the global cropland area or 700 million hectares under good quality CA systems by 2050.

These holistic CA systems would involve CA farmers in engaging progressively in the full array of sustainable approaches to farming, adapted to their ecological and social conditions so as to maximise the sustainability benefits of growing crops without tillage.

PRACTICAL ACTIONS

To achieve the goal, a massive boost should be injected into the momentum of the CA Community's activities with a concentration on the following six themes:

1. Catalysing the formation of additional farmer-run CA groups in countries and regions in which they do not yet exist and enabling all groups to accelerate CA adoption and enhancement, maintaining high quality standards.
2. Greatly speeding up the invention and mainstreaming of a growing array of truly sustainable CA-based technologies, including through engaging with other movements committed to sustainable farming.
3. Embedding the CA Community in the main global efforts to shift to sustainable food management and governance systems and replicating the arrangements at local levels.
4. Assuring that CA farmers are justly rewarded for their generation of public goods and environmental services.
5. Mobilizing recognition, institutional support and additional funding from governments and international development institutions to support good quality CA programme expansion.
6. Building global public awareness of the steps being taken by our CA Community to make food production and consumption sustainable.

In order to facilitate the implementation of above thematic activities, the Congress endorses the need to: (a) operate the Global CA-CoP as an independent non-profit mechanism, with ongoing hosting support of ECAF and FAO, with an advisory panel, and authorised to set up task forces and working groups to help implement the priority practical actions; (b) strengthen the CA-CoP Moderator capacity within the CA Community; and (c) create a CA Hall-of-Fame in time for the 9th Congress. It would also oversee and support future processes for convening CA World Congresses. The Global CA-CoP would require a permanent IT systems development and operating capacity, with sound financial management, programme monitoring and reporting capacities.

The Congress participants feel confident that much of the extended moderation function can continue to be provided by CA Community participants who are willing to provide their time, knowledge, expertise and energy on a voluntary basis.
This Congress has reinforced our conviction that it is entirely possible to meet the global goal of making our food systems sustainable in every sense of the word and that our Community has a vital role to play in this transformation. Our own experience shows that farming can quickly respond to new challenges when farmers see that these are in their own interests.

Our aim is to engage our whole Community as quickly as possible in creating and spreading optimal and profitable low-input, high-output CA-based farming systems that are dependent on biological forms of crop protection and plant nutrition management with maximum energy efficiency and minimal use of externally sourced inputs. This approach shows our commitment to making all we do together in future still better than what we do now.

We pledge to work at all levels with all who share this vision of farming for the future, seeking their guidance and sharing what we learn with them. And we will also partner with those who champion complementary changes in downstream elements of the food chain to eliminate food waste and to bring to healthy nutrition to all people..

Healthy soils are the very heart of healthy lives and a healthy planet!

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List of Actions

The Congress suggested the following specific list of action areas:

1. Farmer associations and networks should be encouraged and reinforced at national and international levels, as the most effective bottom-up means of disseminating and developing CA.

2. Benefits of CA such as increased land productivity, diversification prospects, climate change adaptability and mitigation and increased profits for smallholders and larger-scale farmers should be drawn to the attention of national and international communities as well as global benefits on land resources, health and environment.

3. Given that major information, experience, capacities and tools concerning CA are available in South and North America and Australia, and are quickly developing in Africa, Asia and Europe, international organizations should encourage south-south and south-north co-operation for CA development programmes to make greater use of the available knowledge and expertise.

4. The private and the public sectors as well as NGOs and civil society should actively collaborate in the development with farmers, of the technologies needed to achieve CA such as adapted and accessible information, practices, tools, seeds and safe use of chemicals when needed. Of particular importance in this context are technologies for a CA oriented sustainable agricultural mechanization including related agri-hire services and businesses with the potential of new jobs and increasing attractiveness of farming with specific focus on smallholder farmers particularly in Africa, Asia and Latin America.

5. Greater attention should be given to transform paddy rice systems into CA systems as well as to integrating legumes and cover crops, trees and shrubs, and perennial systems such as orchards and plantations, into CA systems.

6. Promote the adoption of CA as the most suitable way to restore degraded land and to stop future land degradation. Special attention should be given to promote the adoption of CA in areas with high degradation risks.

7. Increased support needs to be provided to strengthen CA Centres of Excellence worldwide as well as to the use of communication and information technology and digital tools to maximize the generation, sharing and application of CA knowledge and expertise.

8. The role of the public sector should be to promote CA as an institutional policy framework, with inter-agency working agreements to provide appropriate support from public sources for the adoption of CA:

   - to recognise the public benefits of CA – including fight against climate change, the conservation of natural resources (water, soil, biodiversity), the protection of the environment, the reduction of flooding and damage to civil infrastructure among others – which result from the farmers' private initiatives,
   - to recompense farmers for these societal services and help them to face the costs necessary to make the transition to CA, especially the purchase of machinery and implements conducive to the adoption of CA which farmers may not be able to initially afford,
   - to fund appropriate key research and advisory service with the public and private sectors, to support access to appropriate knowledge through the development of training and capacity building sessions for farmers, advisors, institutions, etc.,
   - to implement information campaigns, policies and activities to encourage CA and appropriate private investment into this area as well as to discourage inappropriate practices,
   - to provide appropriate infrastructures to facilitate the transport, processing, distribution and if necessary, the exportation of the surplus production,
   - to support adoption and continuity of CA systems managed at local levels through legislation, incentives and investment support.

   These measures should be linked with existing legislation and other appropriate instruments such as the UNFCCC, UNCCD, UNCBD and their programmes.

9. Contributions should be made to the work of international conventions (UNFCCC, UNCCD, UNCBD). Also, a special synergy with the IPCC and carbon-related initiatives should be examined so that carbon sequestration via CA systems could become a substantial incentive to make it happen.

10. The representatives of the various stakeholders attending the Congress should develop partnership and make commitments to design, plan and implement actions as well as monitoring procedures, in order to be able to present them along with some results during the 9WCCA in 2024.

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BOOK OF EXTENDED ABSTRACTS OF THE 8th WORLD CONGRESS ON CONSERVATION AGRICULTURE

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