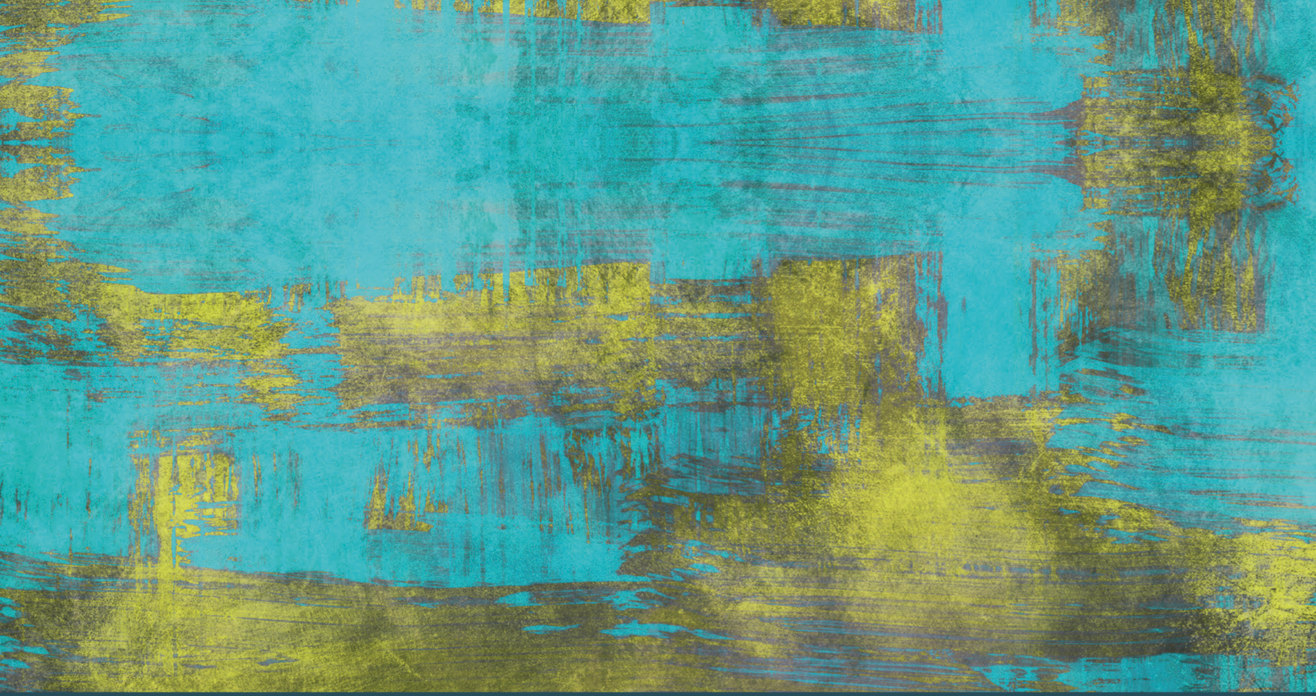

Earthscan Food and Agriculture

CONSERVATION AGRICULTURE IN INDIA

A PARADIGM SHIFT FOR SUSTAINABLE PRODUCTION

Edited by
A.R. Sharma

ROUTLEDGE

Conservation Agriculture in India

This book examines the current situation, levels of adoption, management practices, and the future outlook of conservation agriculture in India, and also in other tropical and subtropical regions of the world.

While conservation agriculture is proposed as an important means to combat climate change, improve crop productivity and food affordability, and to protect the environment, the adoption of conservation agriculture in India, and south-east Asia more broadly, has been slow. This volume reflects on the current status of conservation agriculture in India, asking why adoption has been slow and putting forward strategies to improve its uptake. The chapters cover the various aspects of crop management such as soil, water, nutrients, weeds, crop residues, machinery, and energy, in a range of environments, including irrigated and rainfed regions. The impact of climate change and the economic considerations behind the adoption of conservation agriculture are also discussed. The volume concludes by discussing the future outlook for conservation agriculture in India, in particular drawing out parallels with other tropical and subtropical regions of the world.

This book will be of great interest to students and scholars of conservation agriculture, sustainable agriculture, crop and soil management, and environmental and natural resource management.

A.R. Sharma is Director of Research at Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, India. Previously, he served as Director, ICAR–Directorate of Weed Research, Jabalpur (2012–2017); and Professor and Head at the Division of Agronomy, ICAR–Indian Agricultural Research Institute, Pusa, New Delhi (2009–2012). He possesses an unparalleled record of academic achievements throughout, and has made outstanding contributions in the field of natural resource management over the last 35 years of his professional career including nutrient and weed management, and conservation agriculture.

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Foreword I

The Green Revolution during the 1960s led to increased productivity and the elimination of acute foodgrain shortages in India. These technologies primarily involved growing of high-yielding dwarf varieties of rice and wheat, increased use of chemical fertilizers and other agrochemicals, and the expansion of irrigation facilities. This was also accompanied by the other so-called modern methods of cultivation, which included maximum tilling of land, virtually clean cultivation with complete removal of crop residues and in-field burning of biomass, fixed crop rotations mostly involving cereals, and the elimination of fertility-restoring pulses and oilseed crops in the highly productive north-western plain zone of the country.

Over the last 4–5 decades (since circa 1970), India has achieved not only self-sufficiency in foodgrain production but also the capability to export food commodities. This is cited as one of the greatest accomplishments of Indian agriculture in the post-independence era. However, the transformation from 'traditional animal-based subsistence farming' to 'intensive chemical- and tractor-based modern agriculture' has led to a multiplicity of issues associated with the sustainability of these production practices. The adoption of these technologies has led to declining factor productivity, degrading soil health, surface and groundwater eutrophication, air pollution, increasing cost of production, and lower profitability. Furthermore, soils are becoming impoverished due to the unbalanced use of fertilizers, and the discontinuation of traditional practices like mulching, intercropping, and inclusion of legumes in cropping systems. Consequently, the use of organic manures, compost, and green manure crops has also decreased considerably for various reasons. Similarly, water resources are under great stress due to their indiscriminate exploitation and also being polluted due to anthropogenic perturbations. Burning of fossil fuels and crop residues, and puddling for rice cultivation lead to the emission of greenhouse gases (GHGs), which are responsible for climate change and global warming. There is also a growing realization that productivity levels are stagnating, and the incomes of farmers are reducing due to the rising costs of the inputs and farm operations. Modern cultivation practices are not sustainable, and there is a need for a paradigm shift from the business as usual of crop production on arable lands.

Conservation agriculture (CA) is a new paradigm in resource management for alleviating the problems associated with the so-called modern cultivation practices. The three principles of CA are: (i) conversion to no-till or minimal mechanical soil disturbance, (ii) maintenance of permanent biomass mulch cover on the soil surface, and (iii) diversification of crop species and the use of cover crops and forages in the rotation cycle. These principles are universally applicable to all agricultural landscapes and land uses with locally fine-tuned and adapted practices. CA also requires suitable modifications in the use of supplemental irrigation, fertilizers, and weed and pest management practices as well as farm machinery compared with those for conventional tillage. It is a holistic approach to improving productivity and soil health.

Two major innovations in the latter half of the 20th century have led to a change in our thinking on crop production. These are the availability of: (i) new farm machinery, and (ii) effective herbicides, which suggest that ploughing of fields is no longer required for sowing, fertilizer placement, and weeding. A new generation of farm machinery can place the seed and fertilizer at an appropriate depth in the desired amounts. Furthermore, these machines can work in standing as well as slashed crop residues; thus, providing a very effective mulch cover for moisture and nutrient conservation, soil temperature moderation, and weed control. In addition to the availability of new herbicides, biotic systems of weed control (with mulching and cover cropping) have also necessitated a change in our thinking about weed management. Furthermore, other triggering factors for a shift towards CA are changing climate, increasingly scarce labour availability, degrading soil health, declining factor productivity, rising costs, and ever-decreasing farm incomes. Thus, CA systems help in overcoming the problems being experienced by ploughed systems.

CA-based technologies have been developed, and the benefits in terms of enhanced productivity, profitability, soil health, and climate resilience have been documented in most parts of the country. However, these technologies have been adopted on a limited scale due to the apparent apprehensions, lack of will, and some operational constraints. There exists an immense scope for bringing barren and fallow areas under profitable cropping systems with the adoption of CA-based technologies. Such a transformational change will require a coordinated effort involving multi-stakeholders to enhance farmers' awareness and demonstrate the effectiveness of these technologies on a large scale. Furthermore, necessary back-up in the form of suitable farm machinery (on a rental basis) is required to facilitate the adoption of these technologies.

CA is a challenging and exciting subject for researchers, requiring a multidisciplinary approach to address all the related issues in a comprehensive manner. Resource management scientists should take the lead to finetune CA for the site-specific conditions and perfect the technologies in their respective domains. Focus must be on reducing the cost of production while enhancing productivity, and improving soil quality and soil health. CA-based on-farm research should be an integral part of on-station research, without which research findings cannot be transformed into technologies. CA has been adopted globally on about 200 M ha, including in North and South America, Australia, etc., and this transformation must also happen in India.

India has made commendable progress in developing CA-based technologies in different eco-regions. This book is an up-to-date synthesis of the available information on the potential and challenges of adopting CA in India. I am pleased that Dr. A.R. Sharma has taken this initiative to collate, organize, and present the available information, which is of interest to academicians, scientists, policy makers, research administrators, and field functionaries for enriching their knowledge on CA-based technologies. I commend the hard work and commitment of Dr. Sharma for preparing the book. It is indeed an important milestone in promoting the adoption of CA in India, South Asia, and elsewhere with similar biophysical and social environments.

Rattan Lal
(Rattan Lal)
(World Food Laureate 2020)
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Foreword II

The invention of the plough for soil inversion and growing crops during the mid-19th century was one of the major milestones in the history of agriculture. For centuries, conventional agricultural systems have been characterized by intensive tillage and soil inversion operations, clean cultivation, extensive use of irrigation water, and chemical fertilisers. These have no doubt brought yield revolutions, but at the cost of over-exploitation of our natural resources. In South Asia, the adoption of intensive tillage practices since the Green Revolution in the mid-1960s has led to a factor productivity decline, deterioration in soil health, depletion of groundwater, increase in the cost of production, lower profitability, and environmental degradation. Therefore, it has been argued that the system of crop production should be suitably modified in accordance with the changing environment and deteriorating natural resources.

Also, the Sustainable Development Goals (SDGs) demand an emphasis on regenerative, climate-smart, and profitable farm innovations. Over recent years, attention has been given to conservation agriculture (CA) as a strategy towards 'sustainable intensification' and regenerative agriculture (RA), especially for smallholder farming in South Asia. Accordingly, CA has emerged as an alternative to inefficient tillage-based agriculture. CA is actually an ecosystem approach towards RA, mainly based on three interlinked principles: (i) no-till or minimum mechanical soil disturbance, (ii) permanent maintenance of soil mulch (crop biomass and cover crops), and (iii) diversification of the cropping system (economically, environmentally, and socially adapted rotations, including legumes and cover crops).

Conservation agriculture has been adopted so far on about 200 M ha in countries such as the United States, Canada, Brazil, Argentina, and Australia. In contrast, the uptake of CA has rather remained slow in Asian and African countries. In India, efforts to promote CA started in the mid-1990s, primarily in the rice–wheat cropping system in the north-western plains. The area of zero-till wheat reached about 3 M ha in the early part of the 21st century. In recent times, issues related to crop residue burning have assumed serious concern. In this context, the recycling of crop residues under the CA system is a rather practical, economically viable, and environmentally sound option to deal with the problem. It will help in managing crop residues in combine-harvested fields by avoiding their burning, reducing the cost of cultivation by eliminating elaborate tillage operations, and improving soil health due to residue recycling. Science-based evidence has demonstrated that the adoption of CA-based sustainable intensification has merits beyond resource conservation for minimizing climatic risks and in reducing environmental footprints due to reduced GHG emissions and sequestering C in the soil.

Conservation agriculture is a knowledge-intensive concept, which requires specialized expertise and location-specific adaptation. Despite its proven benefits, adoption of the CA system requires a paradigm shift from commodity- and technology-centric conventional agriculture to system-based management using portfolio approaches. The CA technologies are essentially herbicide-driven, machine-driven, and knowledge-driven. It, therefore, requires good expertise and resources for adoption on a large scale. For wider adoption, there is a need to change the mindset of policy makers, researchers, and farmers. Tremendous efforts will be needed to persuade farmers to adopt CA, especially in dryland areas. In addition to new science, knowledge, and capacity, the accelerated adoption of CA would need urgent policy changes, especially to incentivize farmers for the ecosystem services by adopting CA on their farms, thus helping the nation in carbon sequestration. We must aim to cover at least 20 M ha under CA in India by 2030.

A great deal of research has been carried out on CA across diverse cropping systems, soils, and ecological conditions in India. In most of these studies, CA has had either the same or higher crop yields, besides other direct and indirect benefits. However, there has not been a comprehensive synthesis on the work done on CA so far. I am pleased to note that Dr. A.R. Sharma has taken this initiative to compile the available information on CA for the benefit of researchers, extension agents, policy planners, and other stakeholders. I am sure this book will prove to be highly useful in appreciating the expected benefits and promote faster adoption of CA in India. Dr Sharma deserves full appreciation for the timely bringing out of this useful publication.

(R.S. Paroda)
(Padma Bhushan Awardee)
Founder Chairman, TAAS
Former Director General, ICAR and
Secretary, DARE, Government of India

Preface

Conservation agriculture is the fastest adopted technology globally, covering >200 M ha and showing a double-digit annual growth (>10%) over the last two decades. Currently, it occupies around 15% of the global cropped area, mainly in the countries of South America (>65% coverage), North America (>30%), and Australia and New Zealand (50%). Adoption in other parts of the globe, including Russia, Asia, Africa, and Europe, remains low (<5%) but it has been picking up in recent times. It is envisaged to cover 50% of the global cropped area under conservation agriculture by 2050.

In India, the Green Revolution during the mid-1960s resulted in a tremendous increase in foodgrain production, leading to food sufficiency over the next two decades by the mid-1980s. However, the productivity levels stagnated thereafter, and also there were emerging concerns about resource degradation due to excessive exploitation of natural resources in the highly productive zones of the country. Indiscriminate use of chemical fertilizers and other agro-chemicals, excessive exploitation of ground and surface water for flood irrigation, energy for intensive tillage operations, crop residue burning, and decreased use of organics are also responsible for deteriorating soil health. Furthermore, climate change has emerged as a major challenge, having adverse effects on agricultural productivity in conventional farming systems.

Research on conservation agriculture in India has been on-going since the mid-1990s, and picked up from the mid-2000s as seen from the number of research articles published in leading Indian journals and elsewhere. Most research on conservation agriculture in different regions of the country on crops like wheat, rice, maize, soybean, and other crops has shown that in >80% of cases, the yields are either greater than or equal to those with a conventional agriculture system but with less use of inputs, thus resulting in increased profitability and beneficial effects on soil health. However, the adoption levels on farmers' fields are low, except in some localized regions of north-western and central India for wheat cultivation, coastal areas of Andhra Pradesh for maize and sorghum cultivation, the north-eastern hill region for mustard cultivation, and the Konkan region of Maharashtra for rice and other crops. This is mostly due to a lack of awareness and expertise, farm machinery, incentives, and policy support.

This book is the first up-to-date compilation on the available information on various aspects of conservation agriculture in the Indian context. It presents the practical experiences of research workers associated with this subject for more than two decades. It covers the global scenario and status of conservation agriculture in India; management options; soil health and GHG emissions; economics, adoption and future of conservation agriculture in India, in four different sections and 17 chapters. In addition, internationally renowned scientists, Prof. Rattan Lal, World Food Laureate (2020) and Dr. R.S. Paroda, Padma Bhushan Awardee (2012) have forwarded their inputs for promotion of conservation agriculture in India.

I have acquired adequate knowledge and experience since the late 1990s on conservation agriculture based on my researches in the hilly regions of the western Himalayas, alluvial soils of the Indo-Gangetic plains, vertisols of central India, and now in the impoverished soils of Bundelkhand region. I am thankful to my mentors, Dr. J.S. Samra, Dr. C.L. Acharya, Dr. H.S. Gupta, Dr. Raj Gupta, and Dr. R.S. Paroda; my colleagues, Dr. U.K. Behera, Dr. T.K. Das, and Dr. M.L. Jat, and a large number of post-graduate students who guided and assisted me in my endeavours on this subject.

It is hoped that this book will provide insights and encouragement to my fellow agronomists and other resource management scientists to become not only preachers but practitioners of conservation agriculture to achieve the target of covering 20 M ha in the country by 2030. It will be immensely useful to post-graduate students, teachers and researchers, policy makers, extension personnel, and other stakeholders to enrich their knowledge and further refine this technology in their respective domains.

Jhansi, India (A.R. Sharma)
Editor

Acronyms and Abbreviations

ACRP	Agricultural Crop Residue Burning
AESR	Agroecological sub-region
AICRPDA	All India Coordinated Research Project on Dryland Agriculture
AMF	Arbuscular Mycorrhizal Fungi
APA	Alkaline phosphatase activity
AQI	Air Quality Index
ASS	Automatic Survey System
ATARI	Agricultural Technology Application Research Institute
AWRC	Available Water Retention Capacity
BBF	Broad-bed furrow
BD	Bulk density
BISA	Borlaug Institute for South Asia
BMP	Best management practice
BP	By-product
CA	Conservation agriculture
CAAAP	Conservation Agriculture Alliance for Asia and Pacific
CAAQMS	Continuous Ambient Air Quality Monitoring Station
CEC	Cation Exchange Capacity
CHC	Custom Hiring Centre
CIMMYT	International Centre for Maize and Wheat Improvement
CPE	Cumulative Pan Evaporation
CR	Crop Residues
CREAMS	Consortium for Research on Agroecosystem Monitoring and Modelling from Space
CRI	Crown root initiation
CRM	Crop residue management
CRP-CA	Consortium Research Platform on Conservation Agriculture
CSISA	Cereal Systems Initiative for South Asia
CT	Conventional tillage
CV	Coefficient of variation
CW	Cotton-wheat
DACFW	Department of Agriculture, Cooperation and Farmers' Welfare
DAP	Diammonium phosphate

DARE	Department of Agricultural Research and Education
DEW	Differential Earth Work
DHA	Dehydrogenase Activity
DI	Deficit irrigation
DLI	Differential Levelling Index
DLUC	Differential Land Uniformity Coefficient
DSH	Dry sub-humid
DSR	Direct-seeded rice
DSS	Decision support system
DT	Deep tillage
DTPA	Diethylene triamine penta acetic acid
ECAF	European Conservation Agriculture Federation
ET	Evapotranspiration
EUE	Energy-use efficiency
FAO	Food and Agriculture Organization
FB	Flat-bed
FDA	Fluorescein diacetate
FFP	Farmer fertilizer practice
FI	Flood irrigation
FIRB	Furrow-irrigated raised-bed
FLD	Frontline demonstrations
FP	Farmers' practice
FPO	Farmer producer organization
FYM	Farmyard manure
GDD	Growing degree days
GHG	Greenhouse gas
GNP	Gross national product
GoGHG	Global greenhouse gases
GR	Gross returns
GS	Green Seeker
GWP	Global warming potential
HS	Happy seeder
HST	Happy seeder Technology
HTC	Herbicide-tolerant crop
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
ICT	Information Communication and Technology
IDM	Integrated disease management
IEC	Information Education and Communication
IFPRI	International Food Policy Research Institute
IGP	Indo-Gangetic plains
IISS	Indian Institute of Soil Science
INM	Integrated nutrient management
INR	Indian National Rupee
IPCC	Inter-Governmental Panel on Climate Change

IPM	Integrated pest management
IPNI	International Plant Nutrition Institute
IR	Infiltration rate
IRRI	International Rice Research Institute
ISAAA	International Service for the Acquisition of Agri-Biotech Applications
IW	Irrigation water
IWM	Integrated weed management
IWUE	Irrigation water-use efficiency
KAP	Knowledge attitude and practice
KVK	Krishi Vigyan Kendra
LCC	Leaf Colour chart
LED	Light-emitting diode
LFOM	Light fraction organic matter
LLL	Laser land levelling
LLWR	Least limiting water range
M ha	Million hectares
M t	Million tonnes
MB	Mouldboard
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
MCM	Million cubic meter
MDS	Minimum data set
MEA	Millennium Ecosystem Assessment
MER	Machinery energy ratio
MI	Mechanization index
MIT	Mineralization-immobilization turnover
MNRE	Ministry of New and Renewable Energy
MODIS	Moderate resolution imaging spectroradiometry
MOOC	Massive Open Online Course
MSH	Moist sub-humid
MSM	Manual survey method
MT	Minimum tillage
MW	Maize–wheat
MWD	Mean weight diameter
NAAS	National Academy of Agricultural Sciences
NARES	National Agricultural Research and Education System
NARP	National Agricultural Research Project
NASA	National Aeronautical Space Agency
NCT	National Capital Region
NDVI	Normalized difference vegetative index
NE	Nutrient expert
NRS	Nitrogen-rich strip
NT	No tillage
NUE	Nutrient-use efficiency

NW	North-western
OM	Organic matter
OPT	Optimum application rate
PAU	Punjab Agricultural University
PAWC	Plant-available soil water capacity
PB	Permanent bed
PBB	Permanent broad-bed
PM	Particulate matter
PMN	Potentially mineralizable nitrogen
PNB	Permanent narrow-bed
POM	Particulate organic matter
PPCB	Punjab Pollution Control Board
PRB	Permanent raised-bed
PTR	Puddle transplanted rice
RDF	Recommended dose of fertilizer
RDN	Recommended dose of nitrogen
RI	Response index
RM	Rice–maize
RS	Relay seeding/Remote sensing
RT	Reduced tillage
RWCS	Rice–wheat cropping system
RWS	Rice–wheat system
SDD	Stress degree days
SDI	Surface drip irrigation
SFD	Seed-cum-fertilizer drill
SHG	Self-help group
SMB	Soil microbial biomass
SMP	Soil matric potential
SMS	Straw management system
SOC	Soil organic carbon
SOM	Soil organic matter
SPAD	Soil plant analysis development
SPR	Soil penetration resistance
SQI	Soil quality index
SR	State recommendation/Strip rotor
SSDI	Sub-surface drip irrigation
SSNM	Site-specific nutrient management
SYI	Sustainability yield index
TBO	Tree bearing oilseed
TDR	Time domain reflectometry
THS	Turbo happy seeder
TOC	Total organic carbon
TP	Total product
TSN	Total soil nitrogen
WCCA	World Congress on Conservation Agriculture

WHO	World Health Organization
WP	Water productivity
WRG	Water Resources Group
WSA	Water-stable aggregate
WUE	Water-use efficiency
ZT	Zero tillage
ZTDD	Zero tillage double disc
ZTT	Zero tillage inclined T-type

Part I

Conservation Agriculture

Global Scenario and Status in India

1 Conservation Agriculture for Sustainable Intensification

Global Options and Opportunities

Amir Kassam, Y.S. Saharawat, and I.P. Abrol

Introduction

The term sustainable intensification has become popular in recent years. While its definition can vary, it can be considered in both a narrower and a broader sense as a process to optimize production system performance on farms and watersheds as well as at the sector level within the local and national economy so that it is optimal institutionally for society and the environment along the value chains serviced by the public, private, and civil sectors. The narrower ecological definition at the production level applies to the process of optimizing production systems performance. This involves maximizing yields (total output) and factor productivity (efficiency) of the whole production system in space and time with minimum negative consequences on the environment while maximizing system resilience to biotic and abiotic stresses and shocks, and building and sustaining ecosystem resources and functions and the flow of ecosystem societal services (Kassam 2013). This combines increasing biological outputs, productivity (efficiency), resilience, and ecosystem or environmental services through integrated production systems and landscape management in rainfed and irrigated conditions. Protection and management of all the ecosystem functions and services on agricultural and natural landscapes are considered.

In the broader context, the sustainable intensification definition applies at the sector level across value chains for society and the environment and would also encompass the existence of effective demand for biological products by consumers and industry, input and output supply chains for production inputs and biological outputs, as well as the existence of supporting social and economic organizations for social equity, employment, livelihoods, economic growth, and the environment. This implies improving the capacities of people and informal and formal institutions to deliver and utilize affordable inputs efficiently, distribute and utilize biological outputs efficiently so as to avoid excessive wastage, and harness ecosystem services at all landscape levels that benefit producers and consumers alike. This further implies the existence of a supportive knowledge and innovation system, and above all, of enabling policies for public, private, and civil sector engagement to sustain and keep improving the whole food and agriculture system for farmers, society, and the planet.

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Whichever way sustainable intensification is defined, it is necessary to achieve desired yields of crops and livestock in ways that do not harm the natural resource base and the environment, and even improve them in terms of quality and functions. One of the common reasons promoted to justify the need for sustainable production intensification is to meet the increasing demand for food and raw materials for industry due to increases in population, income, and urbanization. The other reason is based on the fact that the land resource and environmental degradation caused by conventional tillage-based agricultural production systems, as well as by traditional grazing systems, has become unacceptable worldwide, including to producers themselves, to society in general, to governments, and to the development community globally.

Since the mid-1990s, much has been debated about the need for sustainable production intensification by the mainstream research and development community, and quite rightly so. Generally, at the ecological level, a sustainable production intensification approach would be adopted at the practical level by farmers only if it offers the following crop and land production performance: (i) maximum farm biological outputs with minimum inputs, i.e. maximum yields and total output with minimum costs, and therefore maximum profit; (ii) maximum efficiency of utilization of purchased inputs and natural resources, i.e. maximum individual factor productivities and maximum total productivity; (iii) maximum resilience to biotic and abiotic stresses, including those arising from climate change requiring climate change adaptability and mitigation; and (iv) best quality ecosystem services at all levels from production fields to landscapes and territorial, to sustain maximum output and productivity and meet societal and environmental needs. Additionally, a suitable sustainable production approach must also have the ability to help mitigate potential damage to agricultural land or restore any damage or loss that may occur in agro-ecological land potentials and in ecosystem services during production or rehabilitate agricultural land that has been abandoned due to degradation. Consequently, terms such as regenerative agriculture, climate-smart agriculture, or ecological agriculture have recently become fashionable in describing the kind of agriculture needed to achieve sustainable intensification.

Some 85% of our crop lands globally are under tillage systems (Kassam et al. 2021), and therefore unsustainable in every sense. These systems rely on regular tillage of different types for land preparation, seeding and crop establishment, and for weeding. In addition, farmers managing much of the tilled cropland, especially mechanized tillage farmers, also rely on the use of herbicides to control weeds, making tillage-based production systems unsustainable due to continuous soil degradation and erosion, inefficient use of all purchased inputs such as seeds, nutrients, pesticides, fuel, and labour. We need a production paradigm which not only enables farmers to build and manage production in systems that are sustainable over the longer term but that also is able to restore the total agronomically attainable agro-ecological land potentials (of annual and perennial crops including grasses, pastures, shrubs, trees, and livestock, and of ecosystem services) that have been lost, and at the same time is capable of self-recuperation to cope with normal wear and tear. Indeed, what we need now is a paradigm which has all the above key characteristics, upon which to build sustainable food and agriculture systems, and its principles can be put into practice gainfully by any serious land-based farmer, small or large, rich or poor, men or women, mechanized or not, and by any government and by any public, private, and civil sector institution which is willing to service and support the farmers and food and agriculture system (Kassam 2016a; Paroda 2016).

These characteristics thus allow the conservation or preservation of the natural resource base, as well as the restoration or rehabilitation of any lost agro-ecological functions and productivity potential due to land degradation and erosion, and lead to the enhancement of the ecological functions and productivity potential of the resource base and the environment. Thus, it can be argued that only when all these features are operating satisfactorily in a production system, does the system qualify to be labelled as being 'smart' or 'regenerative'.

These multiple outcomes from a production system, and the fact that they all can be harnessed simultaneously, imply that the terms agro-ecology, regenerative, sustainable, sustainable intensification, and smart or climate-smart agriculture can have real meanings and can be made to work at the practical level by farmers and supported by their service providers and supported by relevant institutions and policies.

The ability of agriculture to meet future demand placed upon it by society is generally analysed by mainstream scientists and policy analysts in terms of available resources and production inputs to supply the required level of agricultural products. Similarly, production systems are commonly assessed on the efficiency and effectiveness of different combinations of inputs, technologies, and/or practices to produce certain agricultural outputs. It is only relatively recently that analyses have begun to address externalities of production systems, such as environmental damage, the associated input factor inefficiencies, and poor resilience against major external biotic and abiotic challenges. However, relatively rarely do mainstream researchers question the actual agricultural paradigm (characterized here as conventional tillage-based agriculture) itself in terms of its continuing appropriateness for the sustainable development agenda and for the environmental challenges faced by agriculture around the world. Equally, the delivery of supportive, regulatory, provisioning, and cultural ecosystem services to society by conventional tillage agriculture has not been an area of serious mainstream research concern.

In general, mainstream approaches to agricultural assessments are simplistic and limited in scope. As a result, they are unable to identify and address the root causes of the damage caused to land resources, the environment, and human health by the current agricultural paradigm. Such assessments are also decoupled from the human and ethical consequences of the demands and pressures placed upon agricultural production by the food and agriculture system as a whole, including consumer demand, diets, human health, industry, government, and the economy. These aspects are also important causes of unsustainability when it is considered that the world already produces more than twice the amount of food needed to feed its total population while wasting 30% of it, and yet mainstream scientists, global models, and multi-national corporations keep arguing the need for even greater production to meet the current and future demand. Ultimately, even ecologically sustainable production systems cannot continue to remain sustainable if they are driven by demand levels and lifestyles that are excessive, wasteful, unhealthy, and unjust, supported by national and global food distribution systems that are discriminatory and not accessible to all (Kassam and Kassam 2020). These aspects and issues of food system which are a major driver for agricultural intensification are outside the scope of this chapter which focuses mainly on the ecological sustainability of agricultural production.

Extent and Seriousness of Land Degradation

The seriousness of agricultural land degradation, and its end result of desertification has been receiving considerable attention from the international community for decades. A major reason for the slow progress in reversing the land degradation trends is the general lack of understanding and awareness about the root causes of land degradation and abandonment. Worldwide empirical and scientific evidence clearly shows that the root causes of soil degradation in agricultural land use and decreasing productivity – as seen in terms of loss of soil health and eventual abandonment of land – are closely related to the soil life-disrupting agricultural paradigm based on mechanical soil tillage, the agricultural methods of using mouldboard ploughs, disc harrows, tine, rotavators, hoes, and other mechanical tools to prepare the fields for crop establishment and weed control. This mechanical disturbance leads to losses in soil organic matter, soil structure, and soil health, and debilitates many important soil- and landscape-mediated ecosystem processes and functions.

For the most part, agricultural soils worldwide have been mechanically destructured, agricultural landscapes are kept exposed and unprotected, and soil life is starved of organic matter, thus being reduced in biological activity and deprived of habitat. The loss of soil biodiversity, damaged soil structure and its self-recuperating capacity or resilience, increased compaction of topsoil and subsoil, poor infiltration and increased water runoff and wind and water erosion, and greater infestation by insect pests, pathogens, and weeds indicate the current poor state of the health of most agricultural soils.

In the developing regions, a combination of all these elements is a major cause of low and stagnant/declining agricultural productivity and inadequate food and nutrition security, poor adaptation of agriculture to climate change, and a general lack of pro-poor development opportunities for smallholder farmers.

In industrialized countries, the poor condition of soils and sub-optimal yield ceilings due to excessive soil disturbance through mechanical tillage is being exacerbated by: (a) the over-reliance on the application of mineral fertilizers as the main source of plant nutrients and (b) reducing or doing away with crop diversity and rotations, including legumes. The situation is now leading to further problems of increased threats from insect-pests, pathogens, and weeds, against which farmers are forced to apply ever more pesticides including herbicides, and which further damages biodiversity and pollutes the environment.

It is reported that we have lost some 400 M ha of agricultural land from degradation since World War II (Montgomery 2007). This abandonment is due to the severe degradation and erosion arising from tillage-based agriculture systems in both industrialized and less industrialized countries. A recent study puts the annual global cost of land degradation due to land use and cover change at 300 billion USD, of which sub-Saharan Africa accounted for some 26%, Latin America and the Caribbean some 23%, and North America some 12% (Khonya et al. 2016). Other reports indicate much higher costs, and in cases where priceless ecosystem services are lost, it is argued that it is not possible to put a cost value. This shows that our agro-ecosystems globally are facing a serious challenge of reversing the trends and of rehabilitating abandoned lands into productive and regenerative agriculture. However, solutions for sustainable soil management in farming have been known for a long time, at least since the mid-1930s when the mid-west of the USA suffered massive dust storms and soil degradation due to a combination of intensive inversion ploughing of the prairies and multi-year drought.

The main purpose of tillage throughout ages has been two-fold, namely: to mechanically break and loosen the soil and to bury weeds in order to prepare a clean-looking seed-bed for sowing and crop establishment. Subsequently, during the season, the tillage operation is often used to control weeds. It is a commonly held belief by conventional non-organic and organic tillage farmers that the main benefit from tillage is to control or even eradicate weeds. However, in reality, tillage has been shown to increase weed infestation, and it has never been able to eliminate weed infestation.

In 1943, Edward H. Faulkner wrote a book ‘Plowman’s Folly’ in which he provocatively stated that it can be said with considerable truth that the use of the plough has actually destroyed the productiveness of our soils. More recently, David Montgomery in his well-researched book ‘Dirt: The Erosion of Civilizations’ shows that in general, with any form of tillage, including non-inversion tillage, the rate of soil degradation (and loss of soil health) and soil erosion is generally by orders of magnitude greater than the rate of soil formation, rendering agro-ecosystems unsustainable (Montgomery 2007). Similar to Faulkner, Montgomery concluded that tillage has caused the destruction of the agricultural resource base and of its productive capacity nearly everywhere in the world and continues to do so.

Tillage-based production systems everywhere have converted our agricultural soils and landscapes into – for lack of a better term – ‘dirt’ and even worse in terms of excessive use of agrochemicals, seeds, water, and energy, whilst increasing production costs, decreasing factor productivity, and reducing overall resilience. These have led to degraded agro-ecosystems and dysfunctional societal ecosystem services, including poor water quality and quantity, disrupted water, nutrient, and carbon cycles, suboptimal water, nutrient, and carbon provisioning and regulatory water services, and loss of soil and landscape biodiversity.

Conservation Agriculture: A New Paradigm for Sustainable Production

In light of the above, the need for a new paradigm of agriculture has become increasingly clear. In recent decades, the situation of system unsustainability has begun to change, at least on the agricultural production side, as CA systems in rainfed and irrigated agriculture based on annual and perennial cropping systems, backed up by some 45–50 years of research and practical experience, have spread in all continents and in most agro-ecologies around the world.

CA has been defined as a production system based on the application of three interlinked principles, namely: (1) continuous no or minimum mechanical soil disturbance; (2) permanent maintenance of biomass mulch soil cover; and (3) diversification of crop species (Kassam et al. 2020). In a CA system, the core practices that would correspond to these principles would be complemented by practices related to integrated crop, soil, nutrient, pest, water, and energy management (Lal 2015).

However, even production systems such as CA ultimately also have their limits when they are linked to unconstrained food systems in which food demand seems to be growing at a rate far in excess to what is needed to achieve food security for the total population. Indeed, while farmers of the world already produce enough food to meet the global food needs of more than twice the global population, some 2 billion people remain poor and food insecure, and some 2 billion people are obese and overfed. In addition to the significant amount of food that is reported to go to waste, a significant portion of the food produced is fed to livestock to meet the increasing demand for livestock products by the population with higher incomes and urban lifestyles (Kassam and Kassam 2020). The inequity in the food distribution system due to income differentials cannot be addressed simply by adopting new production paradigm such as CA. It would also require structural changes in the political economy of the global food and agriculture system to make food more affordable by poorer sections of the population, the notion of food and land justice and food sovereignty to become more generally acceptable, a greater proportion of food from primary production being used for human consumption than used as livestock feed for secondary production, and a substantial move towards more healthy plant-based diets. These issues, although being beyond the scope of this chapter, are nonetheless of great importance if we are to minimize the unreasonable pressures currently being put on the natural resources and the environment as well as on the production systems and farmers, and on the food systems.

Making Sustainable Production Real Through CA

It would appear from the current scientific literature on sustainable production that we seem to have rediscovered the power of agro-ecology as a central element in helping us to understand what may constitute ecological sustainability of production systems and how it can be harnessed by all land-based agricultural producers globally. This time round we seem to have discovered which principles of agro-ecology constitute the foundation of ecological sustainability in production systems upon which to build overall economic, social, and environmental sustainability, and how to turn these principles into adapted CA systems and practices that are locally formulated and contextually robust or resilient. Unlike the struggling and vulnerable tillage production systems and food and agriculture systems built upon these, we appear to have come to realize that with CA production systems, we can achieve sustainable production intensification and potentially build sustainable food and agriculture systems provided some of the core elements of the unsustainable tillage agricultural production systems indicated above can be managed differently (Kassam 2016b).

The innovations represented by the core practices of CA and how these integrate with conventionally defined good agricultural practices are of great importance to the future of agriculture and food systems globally. They can appear counter-intuitive, and they seem to question the very foundation of conventional tillage-based agriculture and the underlying assumptions of the industrial monolithic mind-set of the 'Green Revolution' agriculture. CA principles and systems have set in motion a global paradigm change in agriculture and food systems, benefitting all farmers and their rural communities who have adopted them seriously, as well as the greater society of which they are a part and the environment in general. They are providing solutions to global challenges such as local and global food insecurity, poverty alleviation, agricultural land degradation and soil erosion, loss of efficiency and resilience in conventional agriculture, loss of ecosystem services and biodiversity, stagnating yields and land productivity, and climate change adaptability and mitigation, as outlined below.

Since the mid-1990s, it has become apparent that climate change was upon us, and that it was necessary to develop climate-smart agriculture, defined as agriculture which is adapted to climate change and is able to mitigate climate change by decreasing the emissions of CO_2, CH_4, and N_2O. In recent years, CA has become accepted as being climate-smart and able to serve as the core of climate-smart agriculture.

In CA systems, all parts of the system function better and plants are larger and stronger, efficient, and resilient. Sometimes, CA has been referred to as being made up of three 'Rs' – Roots, Residues, and Rotations. The new knowledge being generated about CA systems is of global significance and provides evidence of the need to transform all land-based agriculture to CA so that they can more fully contribute to the future needs of the global society and of the planet. Conventional tillage-based agriculture is considered 'bad business as usual' and can no longer be relied upon to meet future needs.

Principles of CA described above, upon which to build sustainable production systems (Kassam, 2021), first and foremost, are functionally biological and ecological in nature, meaning that when put into practice, using locally formulated adapted practices, they provide a biologically active ecological foundation for sustainable production by maintaining as many of the ecosystem functions below and above the ground in space and time that are present in natural ecosystems.

The actual forms of core CA practices generally establish many interactive physical, biological, chemical, and hydrological processes that restore and maintain soil health and functions (Anderson 2015), and which together with other best agricultural practices, such as integrated crop, soil, nutrient, water, pest, energy, labour, and farm power management, lead to improved performance in terms of biological output, ecosystem services, efficiency, and resilience from all land-based production systems. The interlinked core practices provide the following ecological improvements that are regenerative and enhance land productivity potentials and enable the best phenotypic performance from any adapted traditional or modern genotype:

- *Continuous no or minimum mechanical soil disturbance*. Sow seed or plant crops directly into untilled soil and no-till weeding in order to maintain soil organic matter; promote soil biological processes; protect soil structure and porosity and overall soil health; and enhance productivity, system efficiency, resilience, and ecosystem services.
- *Permanent maintenance of biomass mulch soil cover.* Use crop biomass (including stubble) and cover crops to protect the soil surface; conserve water and nutrients; supply organic matter and carbon to the soil system; and promote soil biological activity to enhance and maintain soil health (including structure and aggregate stability), contribute to integrated weed, pest, and nutrient management, and enhance productivity, system efficiency, resilience, and ecosystem services.
- *Diversification of crop species*. Use diversified cropping systems with crops in associations, sequences, or rotations that will contribute to enhanced crop nutrition; crop protection; soil organic matter build-up; and productivity, system efficiency, resilience, and ecosystem services. Crops can include annuals, trees, shrubs, nitrogen-fixing legumes, and pasture, as appropriate, including cover crops.

Global empirical and scientific evidence in support of the above contributions to the key elements of sustainable production intensification is now overwhelming and continues to accumulate in all continents and agro-ecologies. One feature of soil health improvement is the enhancement of soil life and land's productivity potential due to increased soil organic matter. Soil life, comprising of all forms of microorganisms and mesofauna, generates advantages leading to a better soil environment that improves soil structure and functions, root growth, and the relationship with soil microorganisms, as well as improving above-ground crop growth and yield. A number of adaptability advantages begin to operate in CA systems, improving over time, leading to improved farm output, efficiency in input use, enhanced resilience to extreme events, and to harnessing of a range of ecosystem services (Kassam 2020a,b). Greater and more stable yields, minimum use of purchased inputs, and minimization of soil degradation and erosion, and increased livestock carrying capacity are some of the major benefits in CA systems that are not available under conventional tillage production systems.

Thus, unlike conventional tillage agriculture where the focus is on intensive tillage and high application of mineral fertilizers and pesticides, the focus in CA is on soil health and system health aimed at obtaining more output from less input, and with stability and least environmental damage. The key to soil health has been the central role played by soil organic matter in building soil life and biodiversity, leading to improved soil structure and pore volume, aggregate stability, and establishing a symbiotic relationship between crop root systems and soil microorganisms, all leading to improved phenotypic expression in terms of growth, yield, efficiency, resilience, ecosystem services, and minimizing all inputs and maximizing outputs. The counter-intuitive element in CA is the fact that it calls for no mechanical tillage and establishing soil and cropping system health based on soil biology, crop diversity, and biological pest control.

Global Adoption and Spread of CA

The good news is that we now have a new agricultural paradigm staring us in the face. It is called Conservation Agriculture, and it offers research, education, and development opportunities to all stakeholders – public, private, and civil sectors – in the national and international food and agriculture systems to help accelerate the ongoing agricultural transformation. Since 2008–9, the annual rate of expansion of CA cropland area has been some 10 M ha. In 2008–9, CA covered some 107 M ha of annual rainfed and irrigated cropland, corresponding to 7.4% of global annual cropland, and in 2013–14 it covered some 160 M ha of annual cropland, corresponding to about 11% of global annual cropland. In 2015–16, CA covered more than 180 M ha of annual cropland, corresponding to 12.5% of global annual cropland (Kassam et al. 2019), and in 2018–19 CA covered more than 205 M ha, corresponding to 14.7% of global annual cropland (Kassam et al. 2021). Some 50% of CA land is in low-income countries, particularly in Latin America and Asia, and during the last decade it has begun to spread in west and central Asia and Africa as farmers and their communities learn how to overcome the constraints to adoption of CA. CA principles are also being applied to perennial crops in orchard systems involving olives, vines, and fruit trees, in plantation systems such as oil palm, cocoa, coffee, rubber, and coconut, and in agroforestry systems where CA systems with trees are being referred to as being part of 'evergreen agriculture'. This ongoing transformation is an illustration that farmers are willing to take greater control of their future by experimenting with radically new and innovative no-till CA principles and related practices in building sustainable and regenerative farming systems. Some 45–50 years of CA research in different parts of the world has shown that CA principles are universally applicable and that sustainable production and land management are possible for all farmers, small-scale and large-scale, rich and poor, men and women.

Thus, globally, agriculture is undergoing a fundamental change, a process that began in earnest around 1990 in response to unacceptable degradation that was being caused by all forms of tillage agriculture. The realization that tillage agriculture is inherently unsustainable came about as a result of the 'dust bowls' in the mid-West United States caused by the use of mouldboard ploughs to open up the prairies, accompanied by multi-year droughts. This disaster led to successful trials with no-till farming initially in the United States, United Kingdom, and parts of Africa, but it then took until around the end of the 1980s for no-till agriculture to take off, initially in the United States, Brazil, Argentina, Canada, and Australia, and later more generally in all continents, including in the last ten years in Asia, Europe, and Africa. The modern form of no-till agriculture has been referred to, since the mid-1990s, as Conservation Agriculture with its three interlinked principles, described above, of no or minimum mechanical soil disturbance (no-till seeding/crop establishment and weeding); maintenance of soil mulch cover with crop biomass, stubbles, and cover crops; and diversified cropping systems with annuals and perennials through rotations, sequences, and associations.

The no-till champions of the 1970s and 1980s, comprising of farmers and supported by a small number of research and extension agronomists and engineers, and no-till soil and water conservationists, led to globalization of the awareness of the severe soil and land degradation being caused by tillage agriculture and its inherent long-term ecological unsustainability. It also led to the awareness of the consequent loss of farm output and profit, of production efficiency, of resilience, and of ecosystem services (and total abandonment of agricultural land due to natural resources degradation including biodiversity and the environment). During this period, the transformation of tillage agriculture to CA was not driven by mainstream research, education, extension, and development systems, in fact, quite the contrary. Some national research systems openly opposed the spread of CA, and to some extent this is the case even today. As a result, the adoption and spread of CA has been very much a farmer-led phenomenon.

The globalization of CA began in earnest with the establishment, in 2001, of the process of holding a World Congress on Conservation Agriculture every two to three years, sponsored by the FAO and agricultural development bodies in Europe, Africa, Latin America, Australia, and North America along with some multi-national corporations involved in providing agricultural inputs to farmers. The first Congress was held in Spain (2001), the second in Brazil (2003), the third in Kenya (2006), the fourth in India (2009), the fifth in Australia (2011), the sixth in Canada (2014), the seventh in Argentina (2017), and the eighth in Switzerland (2021).

This ongoing transformation is an illustration that farmers are willing to take greater control of their future by experimenting with radically new and innovative no-till CA principles and related practices in building sustainable and regenerative farming systems. What is more exciting is the fact that CA principles are actually being applied to all land-based farming systems – rainfed systems, irrigated and partially irrigated systems, non-organic and organic systems, annual cropping systems including rice-based systems, perennial cropping systems including mixed-systems, horticultural systems, plantation and orchard systems, agroforestry systems, and crop–livestock systems, including with trees. Where purchased inputs are not available, the CA approach has shown that it is possible to intensify sustainably using local resources, including adapted traditional cultivars. Thus, there are many farmers, especially in Asia and Africa, who are practicing uncertified organic CA systems. No wonder, the certified organic tillage-based farming sector is taking a closer and serious look at CA and certified conventional tillage organic systems are also being converted to certified organic CA systems.

Despite the significant progress in CA adoption, and the fact that the world already produces far more food than is required to feed the global population, the world is being frightened by some of the multi-nationals and mainstream international research and development agencies who continue to push for the destructive industrial version of the Green Revolution agriculture. Many of our universities too, in all continents, have been far too slow when it comes to offering solutions in terms of sustainable production systems. One only has to watch the Massive Open Online Courses (MOOCs) being offered by some of the universities in Europe and America to appreciate how far behind the global education system is in preparing and equipping new graduates with the knowledge and management skills required to implement and sustain the required policy and institutional support to mainstream CA systems. Business as usual still prevails in nearly all our agricultural institutions, but we now have a fantastic opportunity to promote a radical transformation of agricultural land use systems worldwide.

Other Innovations

There are other innovations that are coming on stream through precision farming which is opening up possibilities for more efficient nutrient management, e.g., the 4R nutrient management approaches – right fertilizer, right rate, right place, and right time – as well through better understanding of the co-evolved relationship between the plant rhizosphere and soil microorganisms that can influence nutrient availability and uptake. Similarly, more efficient pest (weeds, insect pests, pathogens) management is becoming possible which brings together the power of CA along with precision farming and with co-evolved relationships between plants and natural enemies of pests such as those in push–pull systems, and also with a co-evolved relationship between the plant rhizosphere and soil microorganisms that can influence gene functions that can influence whether the plant is going to be attacked by pathogens or not. Allelopathy is another area which is offering opportunities for innovations that can help manage weeds without relying on herbicides.

Needs and Opportunities

It is clear that there is an urgent need and opportunities to facilitate and support the spread of CA. The following needs and opportunities exist globally, but particularly for the South Asia region, to accelerate the uptake and spread of CA:

- The science underlying the paradigm of CA needs to be established as a regular part of concern for managing a vibrant and innovative knowledge system that can help to generate new knowledge, new technologies, and associated practice, and new enabling social and institutional arrangements to support and sustain the spread and widest benefit sharing from the application of all rainfed and irrigated CA systems. This must include the urgent realignment of research, education, and development institutions, public and private, towards the adoption and spread of CA.

- The damage that has been caused by modern and traditional tillage-based agriculture worldwide must not be underestimated. The rate of land degradation and abandonment must be stopped and reversed, so that they are restored based on the application of the principles of CA.
- There are exciting opportunities for the agriculture sector as a whole to deliver its full range of ecosystem services – supporting, regulating, provisioning, and cultural – through CA-based agricultural land and landscape management. Ecosystem services are also societal services, and farmers, land managers, food and agricultural service sectors, and policy and supporting institutions, all have a duty and a responsibility to minimize or avoid the degradation of agro-ecosystems and ecosystem services and to restore them to their ecologically desirable state.
- There is an opportunity for everyone, but particularly the youth, to feel excited and confident about the future of food and agriculture, and land use management in general, and their role and responsibility in particular, in creating a rewarding and ethically responsible post-modern food and agriculture sector.
- There is a need and to promote incentive-based agricultural development and stop subsidy-based agricultural development strategies. Farmers should be awarded and rewarded for adopting systems and practices of CA that provide ecosystem services to society.
- There is a need to promote the formation of national CA associations to promote and establish farmer-driven processes of adoption and spread of CA, and to access and attract the institutional support required to maintain a competitive and innovative CA-based food and agriculture sector.
- There is a need and an opportunity to create multi-stakeholder national platforms for CA development and dissemination in the Asia region and to facilitate information sharing and communication, and to monitor CA adoption, its contribution to agriculture and rural development, and to promote the mainstreaming of CA on farms and in all the supporting public, private, and civil sectors.

For Whom Are We Working? Whose Voices Do We Represent and Amplify? Is There a Future for the Youth in Agriculture?

The question must be asked: For whom are we working? Clearly, the answer is first and foremost, we are speaking for sustainable development of the national, regional, and international food and agriculture system. This means we are working for all the farmers, men and women, small-scale and large-scale, and rich and poor. However, in the development context, we must represent the voices and the needs of the poor smallholder farmers, their households and livelihoods, and their well-being. We must also represent the voices of the urban poor who cannot afford to buy food because they are not gainfully employed. Additionally, we must represent the global agricultural land use community in order that all agricultural land use worldwide is eventually brought under sustainable use and management.

CA systems have shown that the ecological foundation of sustainability in agricultural land use can be provided by CA systems for all farmers, in all land-based agro-ecologies to improve their biological, economic, and environmental performance. For poor farmers and their families in particular, CA systems offer something uniquely special – the ability to achieve sustainable production intensification with minimum or no purchased inputs to build local food security, strengthen livelihoods, and restore the flow of ecosystem services. They make their agriculture climate-smart and offer confidence and hope for the future for themselves and for their children, many of whom may not remain in farming once they have had an opportunity to educate themselves.

Ultimately, no amount of ecological sustainability in a production system such as CA can withstand the unlimited demand for food and non-food commodities placed upon the global land resource base. The world already produces enough food to feed more than its current population, but a significant proportion of it is wasted or fed to livestock. Thus, in general, mainstream approaches to agricultural assessments regarding national and international food security appear to be simplistic and limited in scope. As a result, they are unable to identify and address the root causes of the damage caused to land resources, the environment, and human health by the current agricultural paradigm. Such assessments are also decoupled from the human and ethical consequences of the demands and pressures placed upon agricultural production and farmers by the food and agriculture system as a whole which has continuously failed to achieve global food security for all. A number of recent analyses show that the global food system is broken, along with a number of other global chronic crisis. Increasingly, it appears that the overly dominant global capitalist economic system and the associated multi-national corporate sector that is driven by the goals of infinite growth for profit in a finite planet is not capable of solving the global burden of crises. It is not capable of protecting and meeting the food, seed, and land sovereignty needs of the smallholder farmers worldwide, nor is it capable of meeting the human nutrition and health needs of society and the planet (Kassam and Kassam 2020).

Prospects for a Brighter Future

In light of the above, we take the view that agriculture and all the related sectors have a bright future. The global transformation of agricultural land use towards CA gives us hope and confidence that we can establish and maintain development pathways for sustainable production intensification and sustainable land management. The really exciting part is that we have rediscovered that this can be done provided we respect and understand how nature works in its ecosystems and how we can build upon this understanding of sustainable land-based agro-ecosystems everywhere for all. Therefore, there is much to be excited about the for future of agriculture and land management broadly defined, and this is particularly relevant for youths, males and females, who can and must consider farming, agricultural sciences, and all the agricultural and land management professions to be respectable areas of opportunity to serve personal, national, and international ambitions.

It is particularly encouraging that the CA Global Community at the 8th World Congress on Conservation Agriculture set a notional goal of transforming 50% of the global cropland area into CA by 2050 (WCCA 2021). They have suggested a global plan of action to be developed by the CA Community at the national and regional level calling for all stakeholders to become involved. We therefore commend everyone, irrespective of whether they are in the public sector, private sector, or civil sector, whether they are plant breeders, agronomists, or plant protection professionals, agricultural engineers or crop physiologists, microbiologists or economists, rural sociologists or anthropologists, or irrigation and water management experts or those keen on gender, communication, ecosystem services, or climate change, or any of the food and agricultural and land use management disciplines, to respond fully and with confidence to the potentials and opportunities offered by the new agricultural paradigm of CA. Farmers, large and small, rich and poor, men and women, throughout the world are seizing this opportunity. They, more than anyone else, deserve your help, support, and trust because the future of our planet and of humankind is in their hands. How well they perform their custodian role and feed the population of the future will depend on how much we all care for them and how much we do to give them an effective voice in sustainable development.

There is a hopeful and exciting future emerging in post-modern agriculture based on the CA paradigm. Solutions are now available to manage agriculture sustainably and anyone who wishes to serve the farmers and agriculture development must understand and protect its ecological foundations. This also applies to farmers who wish to farm sustainably, and to those who wish to take care of the agricultural land resources and the environment on behalf of society and nature. This is the grand challenge to the education and research system globally, to ensure that new knowledge for innovative technologies is generated and transmitted appropriately to future generations. Equally important will be the need to maintain an enabling policy environment that will help to transform and build institutions and human capacity for innovations to serve the food and agriculture sector broadly defined.

Where to Look for More Information?

A general source of information on CA is the FAO website (www.fao.org/conservation-agriculture) and also the websites of the European Conservation Agriculture Federation (ECAF) (https://ecaf.org/), the Africa Conservation Tillage Network

(ACTN) (www.act-africa.org/) and the Conservation Agriculture Alliance for Asia and Pacific (CAAAP) (www.caa-ap.org/). More information regarding the development of CA systems globally can be found in books and journals, and on websites of national and regional CA organizations.

Books include Goddard et al. (2006), Baker et al. (2007), FAO (2011, 2016), Jat et al. (2014), Farooq and Siddique (2014), Chan and Fantle-Lepczyk (2015), and Dang et al. (2020). Nationally oriented information on CA development is available for several countries including Australia (Crabtree 2010), Canada (Lindwall and Sonntag 2010), Brazil (Junior et al. 2012; de Freitas and Landers 2014), Argentina (Peiretti and Dumanski 2014), and United States (Lessiter 2018).The three-volume book on Advances in Conservation Agriculture (Kassam 2020a,b, 2021) is a global source of information on Systems and Science (Volume 1), Practice and Benefits (Volume 2), and Adoption and Spread (Volume 3).

Lessiter (2011) provides a narrative on 40 legends of the past in no-till farming in North America. The International Soil and Water Conservation Research published a special issue on Pioneers in soil conservation and Conservation Agriculture which provides good information on the adoption of CA in several countries (Dumanski et al. 2014).

The Proceedings of World Congresses on CA are a good source of historical and current information on CA research and adoption. Similarly, proceedings of Africa Congresses on CA provide good information on research and development work in Africa (Kassam et al. 2017; Mkomwa and Kassam 2021). Websites of national and regional CA associations are a good source of CA information on adoption and spread as well as on research.

Conclusion and Future Outlook

CA systems are leading to a paradigm change in the food and agriculture system globally. The resulting impact is the opening up of new and more profitable ways of managing agricultural lands and improving livelihoods, investing in agricultural land for commercial purposes, and enhancing and being rewarded for ecosystem services. Agriculture is no longer the sector to employ the poor and the uneducated. It is a place where greater technical and managerial skills are going to be demanded in order to save the human race and the planet. Agriculture has become a calling for many, especially the youth, to reengage and double their efforts to achieve and sustain food security, address agricultural land degradation, achieve more from less, and respond to climate change. We must concentrate on promoting all aspects of CA for the benefit of farmers, wherever he or she may be farming, however poor or rich, small or large, as well for society and the planet. All disciplines and people have a role to play because the option and opportunity, which we all must seize, is at the level of a paradigm change – like moving from a flat Earth mindset to a round reaching mindset. All aspects of the food and agriculture systems must be realigned to the new paradigm over the coming decades across the world to achieve an attainable target of 700 M ha of cropland under CA (50% of cropped area) by 2050.

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