Conservation agriculture: Analysis and prioritization of socio-ecological factors operating at farm levels in Ohio, USA

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Conservation agriculture: Analysis and prioritization of socio-ecological factors operating at farm levels in Ohio, USA

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ABSTRACT

Conservation Agriculture (CA) has got the huge potential to address the issue of global food security with ecological resilience and replenishment. The present study was conducted across 40 counties of the state of Ohio in the United States of America to assess and prioritize the social-ecological factors operating at CA farms, using both qualitative and quantitative methods. It has been elucidated from the study that selected owner-farmers of the study area (n = 230) have no hesitation to consider CA as the future of farming to address food security in response to mitigate climate change effects. They have been applying the combination of the CA principles on their farms: 60% of the respondents do not till their field, 80% leave crop residues on the soil surface, and 97% follow crop rotations. Finally, the CA farmers have achieved 10 to > 40% fuel savings during farm operations, having farm soil salinity reduced in the case of 70% of respondents. Apart from this, grazing animals are also integrated to CA systems, adding animal manure to their farms. However, the study indicates that there is a need to encourage the use of conservation agriculture, which can minimize the negative impacts of dry spells in order to maximize crop production, and polish the strategies and policies in each and every sphere.

1. Introduction

Agricultural sustainability to address food security is critical to the socio-economic welfare of the society. Likewise, time extortion of the ecological resource pool to get handful of food is not justified. To maintain sustainability in the agriculture sector, several natural resource conservation programs have been initiated to benefit future farmers. This started from the era of the 1930′s "dust bowl, "which challenged the concept that conventional tillage was indispensable to make a friable working seedbed and better seed germination to support crop production (Camboni and Napier, 1993). Then time was taken to help farmers realize that unconventional ideas, like that seeds could be planted directly into residues of the earlier crop(s), leading to a U. S.-wide soil conservation movement that substantially aided in the development of NT farming practices that are being widely used today. However, adoption of NT in farmers' fields was slow even after its successful demonstration in the 1950 s. The type of NT planters, appropriate inputs, and adaptive knowledge and practical experience were the key factors for the adoption of NT farming. Then, the NT pioneers revolutionized existing agricultural systems with ecologically sound and resilient land management systems, along with the management of farm energy metabolism, labour, machinery inputs, and policy upgradations (Islam & Reeder, 2014).

Currently, the NT system (also referred to as zero tillage, conservation tillage, conservation agriculture, or direct-seeded agriculture system) is evolving into one of the primary strategies under the umbrella of modern farming techniques (conservation agriculture) that combats soil erosion, while concurrently providing sustained economic returns and resilient environmental benefits (Chatterjee and Acharya, 2021). A conservation agriculture (CA) system aims at sustaining crop production through the reduction in the amount of excessive tillage, maintenance of crop residue on the soil surface, and adoption of crop rotation or diversification practices to improve agro ecosystems functionality (Karki and Gyawaly, 2021).

In Ohio, agriculture is the leading sector that contributes farm gate receipts of about $10 billion and adding over $100 billion to the state

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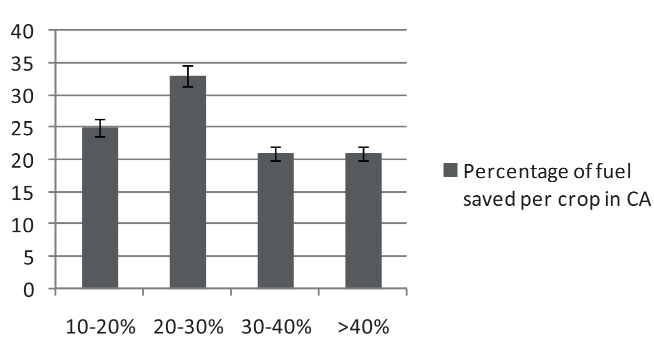
economy. Ohio has a total of 5.8 Mha of cultivable land (14.3 million acres), and about 75,000 farms, 90% of which are operated as family farms (Islam & Reeder, 2014). In addition, soil conservation technologies have been an integral part of the agricultural development of Ohio (Islam & Reeder 2014). However, Kuhlman (2020) reported that in a number of U.S. states, several of the agronomic crops were unable to be planted, leading to a substantial loss of farm income and stressful conditions for farmers. This situation resulted in a very dry, almost like a drought year. Hence, there must be an increase in federal investments in agriculture and food-related research to support and guide farmers in their transition to climate-smart agricultural practices, and incentives provided to increase on-farm renewable energy set-ups and reduction in farm energy consumption. It is reported that farms that adopt CA have increased soil fertility with an associated decrease in soil and water erosion, improved infiltration and water retention, and greater nutrient availability, which resulted in long-term economic crop yields worldwide (FAO, 2010). Similarly, Shrestha et al. (2018) indicated that grain yield of wheat increased by 6.3% in conservation or zero tillage over conventional tillage practices. greater adoption of CA is expected to be a win-win situation in mitigating the current and exiting challenges being faced by agricultural producers. Picture 1.

Apart from this, Ohio agriculture has a glorious history of adopting CA (no-till). In 1962, Drs. Glover Triplett and David Van Doren established the world's first organized research projects on NT at several locations in Ohio, namely the Ohio Agricultural Research and Development Center (OARDC) at Wooster, North-West Branch of the Ohio Agricultural Research Center at Hoytville, and Western Branch of the Ohio Agricultural Research Center at Springfield, Ohio (Triplett et al., 1963, 1964) and the researchers are continuing the research even to this day (Triplett and Dick, 2008; Dick et al., 1991; Sundermeier et al., 2011; Rahman et al., 2021). This paper will elucidate a view on the holistic farming approaches using continuous no-till cropping diversity with or without cover crops, along with the agronomic, environmental, ecological, economic, and social perceptions and attitudes of CA farmers of the selected counties of Ohio (Stavi et al., 2012; Sundermeier et al., 2011; Islam et al., 2014; Islam et al., 2021).

Accordingly, this article aims to insight and prioritize the social-ecological factors influencing farmers' practices and attitudes towards conservation agriculture (CA) technology, as well as to delineate the present status of CA adopted farms of Ohio.

2. Theoretical construct

The theoretical perspective of the current study was constructed using diffusion of the farm-structure model (Camboni, 1984; Hooks et al., 1983; Napier et al., 1988; Rogers, 1983). While the diffusion component of the model accounts that psycho-social status of farmers influences their adoption behaviour and action, the farm- structure component asserts that adoption behaviour gets affected by the structural system of the farming and institutional-infrastructural systems of



Picture 1. World's first research project on no-till agriculture at the Ohio Agricultural Research and Development Center, Wooster, Ohio (*Personal communication with Professor Warren Dick).*

the farming enterprise. However, awareness is the most important aspect to consider before proceeding because farmers must be aware of their problem and should believe that an appropriate solution exists, before taking initiative to stay away from the situation. Another important factor to consider is the access to economic resources because land operators and/or managers will not come forward to adopt the conservation farming that demands different mindset, technologies, and inputs. Adopters must have adequate skills for a successful adoption of innovative and novel practices. The process must engage management skills to effectively run the farm operations. Incentives also play a critical role in this adoption process, as it has been seen that if farmers receive incentives for higher (but conventional) crop production, this can impede the adoption of conservation practices. However, encouraging land management with higher amounts of reactive nutrients and repetitive tillage operations to achieve higher crop production on a same parcel of land can sometimes cause exorbitant soil erosion and, consequently, soil health degradation. Hence, the theoretical aspect of the present study elucidates some of the most prominent diffusion factors like awareness of soil health degradation or observation on the detrimental effect of continuous tillage, indiscriminate groundwater extraction and use, on-farm adoption of environmentally resilient farming practices to curb environmental degradation involving farming experiences, formal or functional educational status of the respective farmer. Besides, farm-structure components like cropping diversity or rotations, livestock integration, farm size and ownership, and participation in proactive training programs are associated with conservation farming adoption-decision processes are also taken care (Camboni and Napier, 1993). However, farm stakeholders need proper conservation farming evidence-based knowledge, tools, and education. When farmers are acquainted with science-based knowledge on conservation practices and perceive their positive effects and outcomes on soil and water quality and crop productivity, then they will be motivated to adopt and involve themselves in the recommended methods (Coffey et al., 1998).

3. Method and materials

The study was undertaken to explore the key factors and issues related to farmers' perceptions and practices of CA in the state of Ohio, United States of America. Data to support the merits of the theoretical perspective elucidated in our study were collected from January to June 2020 across 40 counties of Ohio (Fig. 1).

3.1. Pilot survey and construction of interview schedule

Before taking up main work, a pilot study was conducted to understand the area, its people, organizations, communication and Extension system, and perceptions and practices of the people towards conservation farming technologies. An outline of the socio-economic background of the study areas, farmers' perception on natural resources, agro-ecology, and entrepreneurial activities helped in the construction of reformative working tools. In the final interview questionnaire, there were 30 questions asked to the respondents, from them both dependent and independent variables were pointed out after rigorous literature survey and expert opinions.

3.2. Sample selection and data collection and analysis

Data were collected using snowball sampling method. Owner-farmers engaged in conservation agriculture farming practices are taken as respondents. Respondents are asked to fill-out a survey questionnaire in both offline and online modes because of COVID-19 pandemic amidst the survey session. Majority of the respondents were > 35–65 years old (55%); 13% and 25% were 26–35 and > 65–85 years, respectively. They had an average farming experience of 25$\pm$ 2 years in conservation agriculture. Data analysis has been done using Microsoft-excel and SPSS version 24 softwares.

Fig. 1. Data collection from farmers in several counties of Ohio (marked with black dots).

4. Results

Data collected associated with conservation farming practices such as agricultural machinery, cropping diversity or rotation, irrigation management, practices followed for preventing or lessening soil compaction, and practices to reduce soil erosion in Ohio were collected (Tables 1–5).

Land operators traditionally used diverse equipment (Table 1) and specialized in the production of grain, viz. corn, soybean, wheat, and followed crop rotations (Table 2). The production of animals, viz. hogs and beef cattle play a secondary role in the farming system and in this study area. Farmers of the study counties use various farm machineries on their CA farms (Table 1), adopted good irrigation management practices (Table 3), soil compaction, and erosion reducing techniques (Tables 4 and 5). Average holding size in the study counties is 620.4$\pm$ 31 ha, average corn yield is 10.26$\pm$ 0.51 t/ha, average soybean yield is 3.77$\pm$ 0.18 t/ha, and average wheat yield is 13.52$\pm$ 0.67 t/ha (Fig. 2).

Table 1
List of agricultural machineries used in conservation agriculture farms of Ohio.

Item number	Name of the agricultural machinery
1	Tractor
2	Plough, chisel plough
3	Disc
4	Culti-mulcher
5	Corn-planter
6	Disc bine
7	Rake
8	Baler
9	Loader
10	Brush hog
11	No-till drill
12	Field cultivator
13	Ripper, disk ripper
14	Applicator
15	No-till planter, no-till planter with crimper/roller,16-row no-till planter
16	Harrow
17	Vertical tillage finisher
18	Combine harvester
19	Grain drill
20	Self-propelled sprayer
21	Grain wagons, grain dryer, grain bins, grain cart
22	Manure spreader
23	Skid- loader
24	Semi-truck and dump trailer
25	Anhydrous tool bar
26	Vertical tillage tool
27	Hay mower, square hay baler, round hay baler, hay bale wagons
28	Side-dress applicator
29	Air-seeder
30	Great plains twin row
31	Split row corn/bean planter
32	Turbo disc
33	In-line ripper

Table 2
Most popular crops in rotation in conservation agriculture farms of Ohio.

Item number	Crops in rotation
1	Hay-corn
2	Pasture mix
3	Corn-soybeans-wheat
4	Corn-soybeans-wheat (or rye cover crop)+ 10% alfalfa+grass hay crops
5	Corn-soybeans-wheat- cover crops
6	Corn-soybeans-wheat + continuous corn
7	Corn-beans-hay
8	Corn-beans-wheat-beans
9	Corn-soybeans and sometimes winter wheat
10	Corn-beans
11	Corn-soybeans-wheat-alfalfa
12	Corn-cover crop-soybeans-cover crop-wheat-cover crop
13	Beans-wheat (or cover crop)-corn
14	Corn-soybeans-soybeans
15	Soybean-corn-wheat
16	Corn-soy or corn-cover
17	Corn-soy-wheat-sorghum/Sudan-corn or corn-soy-wheat-sorghum/ Sudan-alfalfa/grass or corn-beans-triticale-oats-covers
18	Alfalfa+ clover + rye-corn-wheat-soybeans-popcorn
19	Corn-beans-triticale+ oats+ covers
20	Field corn-soybeans-wheat+ vegetables
21	Corn-beans+ cereal rye in between
22	Corn-cover crop-soybeans-cover crop

Table 3
Optimal points of good irrigation management that normally used by Ohio Conservation Agriculture farmers.

Item number	Optimal points of good irrigation management at farm level
1	Apply water only as needed. Surface "irrigation tape" makes best use of each gallon of water, though, it is most expensive.
2	Do not use any irrigation
3	Drainage water management
4	Monitors ET, and soil moisture
5	Rain-fed
6	Plant cover crops
7	Sub-irrigation
8	No-till
9	Get rid of excess water with tile
10	Fertigation

Table 4
Practices followed for preventing or lessening soil compaction by Ohio Conservation Agriculture farmers.

Item number	Practices followed for preventing or lessening soil compaction
1	Stay out of "too wet" fields
2	In-line ripper
3	Deep ripping
4	Sub-soiler
5	Wheel traffic management (or control traffic) depending upon soil moisture
6	Large tires and do not operate on wet soils
7	Crop rotation
8	At harvest time wait until the soil is fit to drive on
9	Trampolines and planning of operations
10	Use of alfalfa, beets
11	Legumes
12	Living roots
13	Partial loading equipment
14	Sacrifice paddocks, no vehicles use in critical times
15	Soil health practices
16	No till
17	Deep-rooted cover crops

Table 5
Practices to reduce soil erosion at the Conservation Agriculture farms in Ohio.

Item number	Practices to reduce soil erosion
1	Maintain crop residue
2	No-till and vertical till
3	Year-round soil cover (cover crops or crop residue)
4	Keep hay for years
5	Chisel ploughing
6	Contour strips
7	Grass buffer strips
8	Filter strips
9	Alternate strips
10	Maintain tile outlets
11	Seeded water ways
12	Grass waterways
13	Reduced tillage
14	Tile drainage
15	Cover crops and all types of tillage if needed done in the spring
16	Conservation tillage
17	Farm on contour
18	Creek buffers
19	Do not drive on wet soils
20	Drop boxes
21	Exclusion fencing
22	Stream crossing
23	Increase in below ground drainage

Some significant results were found in the study on the status of CA farms in Ohio. Among the respondent CA farmers, the primary occupation is farming for majority of the respondents (37±1.8%). 24± 1.2% of the respondents are CA educators, 13± 0.65% agency personnel, 10± 0.5% crop consultants, 1± 0.05% students, and rest 15± 0.75% others (Fig. 3), however, all of them are farmer-owner as well. Out of the total respondents, 84± 4.2% were male and 16± 0.8% were female (Fig. 4).

To Ohio CA farmers, the sources of farming related information are university Extension (41±2%) and some other sources (59±3%) like local and regional agriculture authorities, NGOs, crop consultancies, input dealers, or farm agencies (Fig. 5).

There was an attitude statement in the interview schedule: "Conservation farming is our future," and 52± 2.6% respondents were strongly agreed, 9± 0.4% agreed, 10± 0.5% were neutral with the statement, and13± 0.65% was strongly disagreed. Hence, still there is a gap in the universal acceptance of conservation agriculture technology (Fig. 6).

Fig. 7 elucidates that conservation farmers are saving either 10–20 (25±1.2% farmers), 20–30 (33±1.6% farmers), 30–40 (21±1% farmers,) or > 40 (21±1% farmers) percent of fuel per crop following

Fig. 2. Average crop yield.

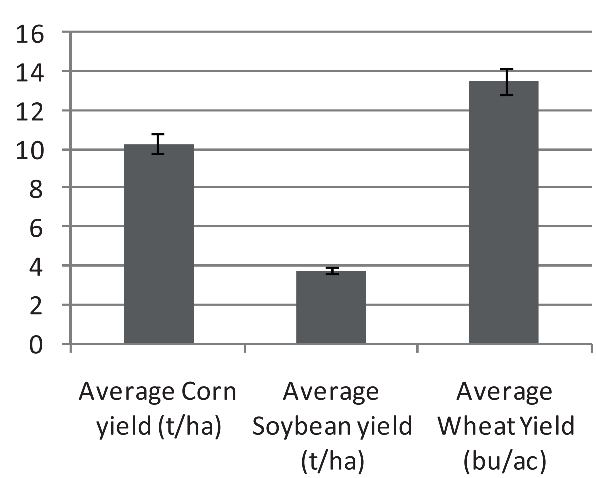


Fig. 3. Primary occupation of the respondents.

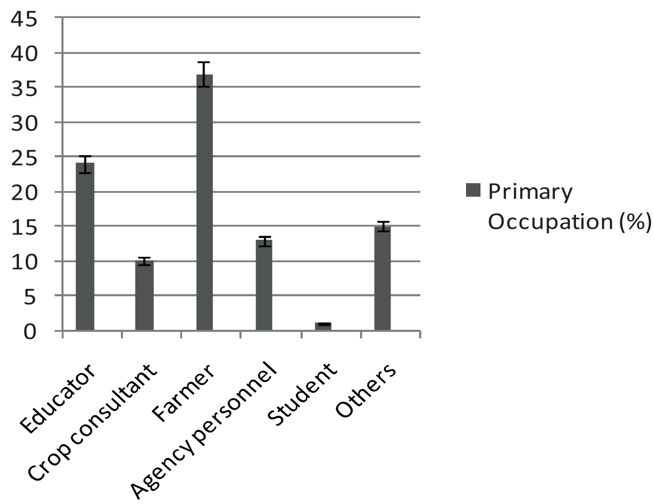


Fig. 4. Gender composition of the respondents.

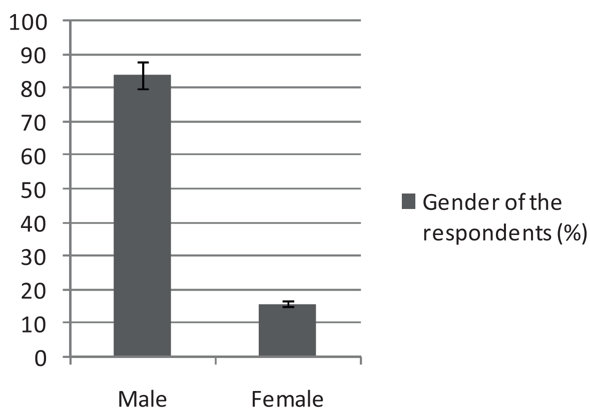


Fig. 5. Major sources of information on CA.

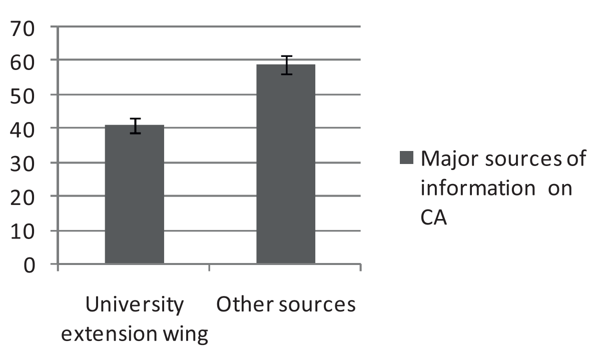


Fig. 6. Responses to attitude towards the following statement: Conservation farming is our future.

conservation agriculture practices.

Presented data is valid @ 5% level of significance (two-tailed).

In Table 6, the statement on farmers' feelings concerning burning of crop residues revealed that 177 farmers out of 230 (77%) feel that burning crop residues goes against the principles of conservation agriculture. It is better to leave the crop residues as mulch on the soil. More than 16% of the respondent farmers chose the option "burning crop residue is not recommended on conservation farms as it wastes vital carbon.""When maize stover (approx. 40% carbon content) is burnt, it makes greenhouse gas issues worse," – this option was chosen by 6% respondent farmers. Surprisingly, 1% of farmers feel very strongly in favour of burning crop residue, as they believe bio char provides a form of carbon that contributes handsomely toward passive pool or non-labile pool of soil organic carbon, coupled with residence of carbon in soil for a minimum of 50 years.

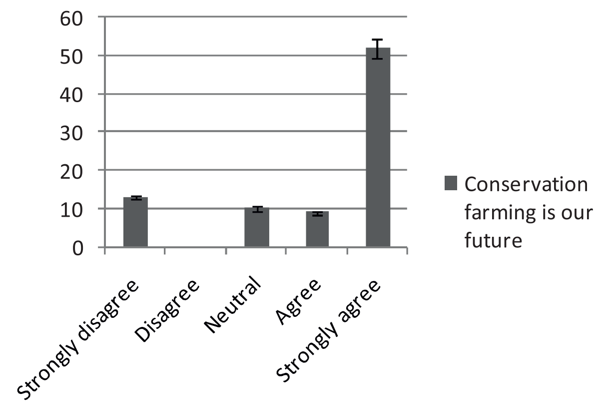


Fig. 7. Percentage of fuel saved per crop following conservation agriculture practices in Ohio.

Table 6
Responses to the question "which of these statements most accurately describes your feelings concerning burning crop residues?" (N = 230).

Item number	Statement	Percentage
1	a) I feel very strongly in favour of burning crop residue, since bio char provides a form of carbon that contributes handsomely toward passive pool or non-labile pool of soil organic carbon, coupled with residence of carbon in soil for minimum of 50 years.	1
	b) Burning crop residue is not recommended on conservation farms as it wastes vital carbon.	16
	c) When maize stover (approx. 40% carbon content) is burnt, it makes greenhouse gas issues worse.	6
	d) Burning crop residues goes against the principles of conservation agriculture. It is better to leave the crop residues as mulch on the soil.	77

Presented data is valid @ 5% level of significance (two- tailed)

In the case of the above-mentioned opinion statement (Table 7), respondents' feelings towards the statement on conservation agriculture versus organic farming, 34% farmers cast their opinion against two statements, viz. the first one, "conservation farming follows both chemical and organic modes in a sustainable combination." and the second, "both types of farming have many aspects in common, but in

Table 7
Statement on the question "which of these statements most accurately describes yours feeling concerning conservation agriculture versus organic farming?" (N = 230).

Item number	Statement	Percentage
1	a) Conservative farming follows both chemical and organic modes in a sustainable combination.	37
	b) Both types of farming have many aspects in common, but in practical view, conservation agriculture is more acceptable by farmers.	37
	c) Conservation agriculture (CA) is more used in cereal and grain legume crops in an open field without an irrigation system. Organic agriculture (OA) is a whole system that is certified from the field to the fork. OA is a holistic system that deals with both animal and crop production along with processing and marketing; so we cannot properly compare OA with CA.	17
	d) Other	9

Presented data is valid @ 5% level of significance (two- tailed) practical view, conservation agriculture is more acceptable by farmers."

Half of the respondents found traditional or conventional practices as the most powerful barrier against the adoption of conservation agriculture practices. Land ownership and policy aspects are not heavily influencing factors here. Financial risk and limited knowledge on CA are pointed out as two other important obstacles in the path of success of CA (Table 8). Though, the respondents find out some important policy issues must be considered in relation to CA adoption, viz. (i) developing solutions and practices to improve soil, land, and water conservation; (ii) increasing knowledge and awareness of the links between conservation agriculture and environmental health; (iii) access to advice for soil/land management; and (iv) incentives for changes (e.g., financial incentives, legislation, policies) (Table 8).

Table 9 depicts statements based on three principles of CA being practiced by Ohio farmers on their conservation agriculture fields. It has been elucidated that most of the farmers (60%) practice no-till agriculture: 80% of conservation farmers leave their crop residue on the soil, some of them use crop residues as livestock feed (6%), sell it off (2%), and only 1% of them are still burning residues. Among the Ohio farmer respondents, 97% follow crop rotation practices in their fields. Altogether, Ohio conservation farmers adapted the following practices in their farms: (i) crop rotation; (ii) maintain and manage a permanent soil cover; (iii) minimum soil disturbance, zero tillage and direct planting; and (iv) pest, weed, and fertility management. They are also very good at attending Extension meetings, conferences, or workshops on CA; over half of the farmers (55%) attended more than 10 meetings. Finally, the CA farmers of Ohio are running their CA farms at a good pace.

It is also clear from the data presented in Table 10 that 83% farmers include grazing animals into their crop rotations, with the majority of them having a maximum of 10 livestock, while 11% still have higher than 200 livestock on their farms. Out of 230 farmer respondents, 25% of them used animal manure or compost once in a year in their fields, 12% used manure in every season, 3% respondents used manure on every crop, and 32% respondents used manure for other purposes, while 28% reported never using manure on their conservation fields.

In a question asking which management systems are important for soil quality improvement, agricultural sustainability, and mitigating climate change, 105 farmers selected cover crops as the best option, followed by conservation tillage (33% farmers), crop rotation and crop residue management (14%), and soil amendments (6%). According to the respondents (93% farmers), the defining factors of fertilizer management under CA are (i) minimal disturbance to the soil for crop cultivation; (ii) retaining and managing crop residues in the current crop for soil temperature moderation, soil moisture conservation, and nutrient addition through decomposition; (iii) crop diversification for restoring soil fertility, which is done through the inclusion of a legume crop or short duration pulse crop in the existing cropping system; and (iv) carbon sequestration (Table 11).

From the statement No. 3 (Table 11), it has been found that 60% of CA farmers think repeated tillage is the most predominant cause of on-farm soil health/quality degradation. Other causes pointed out include repeated cultivation of one crop in the same field (20%), followed by excessive use of chemicals (11%), industrial and air pollution, and climate change (2% each). Three percent of respondents do not know the actual cause, and another 2% found some other factors responsible.

Farmer respondents (77%) also consider conservation farming a means of soil salinity reduction (Table 11).

Table 8
CA farmers' perceived responses on issues related to adoption barrier and policy statements (N = 230).

Item number	Statements	Percentage
1	What are the perceived barriers to farmers' adoption of conservation farming practices?	
	a) Tradition	49
	b)Policy	3
	c)Financial risk	25
	d)Lease/land owner	3
	e)Lack of knowledge	17
	f)Other	3
2	Which of these policies do you feel would most encourage the adoption of conservation farming?	
	a) Develop solutions and practices to improve soil, land, and water conservation	8
	b) Increase knowledge and awareness on the links between conservation agriculture and environmental health	10
	c) Having access to advice for soil/land management	13
	d) Incentives for changes (e.g. financial incentives, legislation, policies)	20
	e) All of the above	45
	f) Other	4

Table 9
CA farmers' responses on the three principles being practiced in Ohio (N = 230).

Item number	Statements based on three principles of Conservation Agriculture	Percentage
1	How frequently do you till your field?	
	a) No-till	60
	b) Once per year	8
	c) Twice per year	3
	d) Other	29
2	How do you use crop residue on your own farm?	
	a) Leave on the soil	80
	b) Livestock feed	6
	c) Sell	2
	d) Burn it off	1
	e) Other	11
3	Do you follow crop rotation practices?	
	a) Yes	97
	b) No	3
4	How do you practice Conservation Agriculture?	
	a) Crop rotation	18
	b) Maintaining and managing a permanent soil cover	10
	c) Minimum soil disturbance, zero tillage and direct planting	22
	d) Pest, weed, and fertility management	17
	e) All of above	29
	f) None of the above	4
5	How many meetings on Conservation Agriculture have you attended thus far?	
	a)0–3	19
	b)4–7	13
	c)8–10	13
	d)> 10	55

Presented data is valid @ 5% level of significance (two- tailed)

Table 10
Farmers' response on inclusion of animal in conservation agriculture system in Ohio (N = 230).

Item number	Statements	Percentage
1	Do your crop rotations include grazing animals?	
	a) Yes	83
	b) No	17
2	Total number of livestock you currently own:	
	a) 0–10	69
	b)10–50	12
	c)50–200	8
	d)> 200	11
3	How often do you use animal manure or compost as a part of conservation farming?	
	a) In every season	12
	b) With every crop	3
	c) Once in a year	25
	d) Never	28
	e) Other	32

Presented data is valid @ 5% level of significance (two-tailed)

Table 11
Farmers' response on soil health management in their conservation agriculture farms (N = 230).

Item number	Statements	Percentage
1	Which of these management systems are important for soil quality improvement, agricultural sustainability, and mitigating climate change?	
	a) Conservation tillage	33
	b) Soil amendments	6
	c) Cover crops	46
	d) Crop rotation	7
	e) Crop residue management and use	7
	f) Other	1
2	Which of these are the defining factors of fertilizer management under Conservation Agriculture?	
	a) Minimal disturbance to the soil for crop cultivation	5
	b) Retaining and managing crop residues in the current crop for soil temperature moderation, soil moisture conservation, and nutrient addition through decomposition	5
	c) Crop diversification for restoring soil fertility, which is done through the inclusion of a legume crop or short duration pulse crop in the existing cropping system.	11
	d) Carbon sequestration	10
	e) All of the above	62
	f) Other	7
3	What do you think are the main causes of soil health/ quality degradation?	
	a) Repeated tillage	60
	b) Excessive use of chemicals	11
	c) Repeated cultivation of one crop in the same field	20
	d) Industrial and air pollution	2
	e) Climate change	2
	f) I do not know	3
	g) Others	2
4	Can soil salinity be reduced by practicing Conservation Agriculture?	
	a) Yes	77
	b) No	23

Presented data is valid @ 5% level of significance (two- tailed)

Weed management is a conundrum in CA. Hence, there was a question presented to the farmers that asked how they are managing weeds in their no-till fields. The majority of the respondents follow an integrated weed management program (36%), 16% follow all the management practices mentioned in the interview schedule viz. plant mulches to suppress weeds (15%), plant cover leguminous crops intercropped with other crops (9%), non-chemical weed control (6%), residue maintained at the field (9%), and some other methods (9%) are also being followed (Table 12).

Finally, from the survey in the study counties of Ohio, respondent farm farmers shared their experiences, observations, and what changes they have witnessed after a few years of practice of conservation agriculture on their farms (Table 13).

Table 12
Weed management in conservation agriculture farms of Ohio (N = 230).

Item number	Statements	Percentage
1	How do you manage weeds in conservation agriculture?	
	a) Plant mulches to suppress weeds	15
	b) Plant cover leguminous crops intercropped with other crops	9
	c) Follow an integrated weed management program	36
	d) Non-chemical weed control	6
	e) Residue is maintained at the field	9
	f) All of the above	16
	g) Others	9

Presented data is valid @ 5% level of significance (two- tailed)

Table 13
Visible changes in farmers' land since they first began conservation farming.

Item number	Visible changes in farmers' land
1	Accumulation of more organic matter in the soil (Specifically in case one farmer, after 10 years of continuous no tillage and cover cropping organic matter has increased one full percentage point)
2	Increase in soil fertility (The farmer has done soil test and then applied lime and fertilizer as per need)
3	Higher Soil pH
4	Restoration of natural drainage
5	Improved yield
6	CA works better on some land than other land
7	Soil became softer
8	Improved tilth
9	Improved soil health
10	Easier weed management (Specifically in case one farmer, Marestail and water hemp are very much controlled)
11	Better soil structure
12	Improved water infiltration
13	Better earthworm populations
14	Healthier crops
15	Definite improvement in water holding capacity
16	Improved dirt quality
17	Reduced soil erosion
18	More oxygen in soil
19	More grass
20	Better soil drainage
21	Higher biological activity in soil
22	Greater net profits

5. Discussion

Current high-input agriculture produces greater amounts of food, feed, and fiber, but effect of these farming practices, together with climate change, are adversely affecting soil quality with increased agro ecosystem disservices. By 2050, agricultural production may need to double to provide food security, which will make existing farmland increasingly dependent on agrochemicals, freshwater, and energy inputs. Such intensification of farming will have consequences on agro ecosystems that are expected to be detrimental. However, the challenges and opportunities are emerging with the advent of expanding science-based knowledge, technology, and information systems that are encouraging us to envision CA in the 21st century. Thus, adoption of CA should be the goal (Hobbs et al., 2007), as CA technology is sustainable in the long run since it promotes the appropriate combinations of minimum tillage, residue management, and crop diversification or rotation, equipment and machines, and inputs.

CA is a farming system that involves maintenance of extended soil cover, minimum soil disturbance, and diversification or rotation of crops. Worldwide, the global area under CA is about 180 M ha, i.e., about 12.5% of the total global cropland in 2015–16 (Kassam et al., 2019). Farmers are practicing CA around the globe, as it has become an eco-friendly agricultural approach and is gradually being recognized as the greenest farming system, even over the organic farming (Layton, 2021; Marla, 2018). Though both cultivation systems are aimed to maintain a delicate balance between agriculture and natural resources, organic farmers have the practices of continuous soil tilling, while CA is said to be no-tilled (Layton, 2021). Batte et al. (1990) reported that in Ohio, the farm size, farm farmers' age, and the source of farming-related information are some of the most important factors in on-farm resource management. Extension is a source of technical information that is accessible in most of the counties. However, Extension educators are not always available in all counties in most U.S. states. Besides, the format of their information may not be readily understood by the farming community due to technical jargon (Sundermeier et al., 2009). Esri (2019) conducted a study in Iowa, where the existing crop management system is transformed from conventional tillage to no-till conservation farming along with cover crops in farmers' fields. The farmers started seeing improved water infiltration with record crop yields; hence they considered CA to be "farming for the future" (Esri, 2019; Lang, 2021).

For decades, farmers have burned crop stubbles in their lands as an economically viable way of removing excess crop residue accumulation from the surface and perceived it as a method of workable and improved soil tilth; controlling weeds, insects, and diseases; and recycling nutrients such as calcium, magnesium, and potassium. However, more strict government regulations have helped farmers make the transition from burning to leaving residue on the surface that engages best management practices. Best management practices like crop residue management, no-till, mulching, cover crops, crop rotation, and other conservation practices are the most promising alternatives to stubble or residue burning (Israelsen, 1982).

Crop residues play an important role in protecting surface soil from rainfall impact, controlling water and wind erosion, improving biodiversity, and recycling nutrients, thus removing them comes at an economic and ecological cost (Islam et al., 2013). In the United States, most of the corn stover is either turned over by ploughing, or left in the field (Nelson, 2002). In Ohio, the total amount of corn stover and wheat straw is estimated to be 4.6 and 0.7 million dry tons per year, respectively. Of these, 85% of crop residues management are in 43 counties in the north-western and west-central regions of Ohio (Li and Keener, 2011). Depending on the amount of crop residue returned to the soil, a large number of farmers converting from ploughing to no-till farming systems in the U.S. Corn Belt could help make the agro-ecosystem function as a net sink for tropospheric CO_2 (Duiker and Lal, 1999; Sundermeier et al., 2011). As conservation practices proactively help to sequester excess carbon within the soil and curb greenhouse gas emissions, it should be the part of the future of climate-smart agriculture.

It has been found that no-till or shallow tillage not only provides effective control against soil erosion, but also enhances soil, water, and fertilizer-use efficiency with a same or comparatively better crop yield (Islam and Reeder, 2014; Lavrenko et al., 2021). Similar benefits of no-till, as part of CA in the United States, were reported (Dick et al., 1998; Reeder, 2000; Owens, 2001; Triplett and Dick, 2008; Huggins and Reganold, 2008; Reicosky et al., 2011; Sundermeier et al., 2014). However, it takes a long time (5–7 years) to improve soil functionality and higher crop yields by no-till alone. Cover crops integration improves no-till functionality by minimizing transitional effects.

Cover cropping is the one of the economically viable, environmentally compatible, and socially acceptable components of CA worldwide (Friedrich et al., 2012; Islam and Sherman, 2021). In Ohio, farmers use different types of both summer and winter cover crops like oilseed radish, sun hemp, hairy vetch, crimson clover, cowpeas, cereal rye, pearl millet, and Sudan-sorghum in their corn-soybean or corn-soybean-wheat systems. It is reported that a cover crop cocktail (i.e., the mixture of 5–10 species of cover crops) is also gaining popularity to improve soil health, increase crop productivity, and minimize fertilizer cost (Islam and Reeder, 2014). Moreover, the integration of cereal rye as a winter cover crop in a corn-soybean rotation has become a routine operating component of CA.

In addition to the most usually recognized ecological benefit of improving soil health, reduction in operating cost, farmers are willing to continue adapting CA as it significantly reduces fuel consumption and thus emissions from agricultural operations. About 35% of the total fuel consumption and emissions reduced were from where continuous no-till has been adopted. The Corn Belt and northern plains of the United States account for almost 58% (~29% each) of the total fuel and emission reductions (NRCS- CEAP, 2016; Sundermeier et al., 2009).

Though, in some climatic conditions and landscapes, disintegrating livestock from crops and trees can be considered as an important cause for the delinking in agro-ecological diversity with the adverse impacts on terrestrial environments (Lal, 2010). Nitrogen and carbon cycles are closely coupled to on-farm livestock's role in land use systems (Steinfeld et al., 2006); however, greenhouse gases like methane are exacerbated when ruminants are concentrated in conventional ways. This can be minimized by integrating livestock with crops and trees as part of regenerative agriculture by establishing on-farm vegetation buffers that will improve biodiversity and conserve soil and water, which is a strategy to reduce the environmental footprint of livestock raised alone on the same lands (Goldstein et al., 2012). Additionally, livestock manure can be recycled to minimize fertilizer use and increase soil organic carbon to improve the soil health of croplands (Petersen et al., 2007).

In contrast, weeds are the major biotic constraints in CA fields that compete with agronomic crops for space, nutrients, water, and light, and pose a significant threat to the greater adoption of CA in the agro ecosystems. With transitional no-till in CA, weed seeds stratified at the surface soil cause robust weed infestation, and thus farmers use herbicides in greater amounts and more frequently as the only answer to deal with this problem (Singh et al., 2015). Most of the Ohio farmers have selected Glyphosate as their desired herbicide that is used in an estimated 60% of total no-till soybean production. Herbicide application increases with an increase in no-till acreage worldwide, including Ohio. As herbicides require far less energy in manufacturing and use than that of tillage; hence, they provide an important economic benefit with increasing energy costs (Nalewaja, 2003). Farmers of Ohio mainly rely on those herbicides that have worked in the past, knowledge on the time of emergence and type of weed, and the labour-intensiveness act as the most important determinants in making a weed management decision, followed by the latest soil health and crop yield research and Extension recommendations. Zwickle et al. (2012) reported that most of the farmers still rely heavily on tillage, mowing, and herbicides, though a small percentage of farmers have started using crop rotations, mulching, cover crops, and hand weeding in their fields.

In the end, extension personnel must explain the wide range of ecological and economic benefits of CA and there is a need for custom studies concentrating on the interest of farmers (Drost et al., 1996). Often, initial costs for new equipment and financial risks associated with making the transition serve as roadblocks or barriers for many farmers considering adoption of CA (Al-Kaisi et al., 2000; Drost et al., 1996). While they often thought of soil conservation as the primary reason for adoption, many farmers do not believe that agricultural farms cause non-point sources of soil and water pollution associated with public health, especially harmful algal blooms and associated cyanotoxins (Hua et al., 2004; Rahman et al., 2021). If the pathways for adoption of CA are to be evaluated, these determinants will simmer up: (i) the trade-offs between crop residues and animal feed; (ii) breaking the stereotyped mindset of the farmers; (iii) on-farm demonstration of the technology (Karki and Gyawaly, 2021); (iv) policy and institutional support like providing incentives to CA farmers (Lang, 2021); (v) farmers' network; and (vi) availability of farm machinery (Karki and Gyawaly, 2021).

6. Conclusions

The present study indicated the status of CA in the state of Ohio in the United States. The CA farmers who were quite aware of the diverse benefits associated with CA, but had some departures in the knowledge and practice to effectively employ the combination of CA. The farmers desired to be knowledgeable on soil health and soil conservation aspects associated with CA; however, a positive attitude towards best management practices was noticed among the CA farmers due to a reduction in practicing conventional agricultural practices that pose threat to the farm income stability and environmental functionality. Breaking with conventional agricultural practices, a potential financial risk after transition and lack of proper evidence-based knowledge on CA were identified to be major constraints for farmers adopting CA in Ohio. However, proper training and removal of roadblocks on recommended perceptions on CA principles, along with incentives can be the game-changing factors for the greater adoption of CA. The involvement of various stakeholders like the university Extension, state and federal authorities, environmental agencies, farmers' organizations, and agrobusiness sectors should be actively involved to motivate farmers to adapt CA. Further, the key constraints need to be addressed if CA has to be adopted in holistic and novel approaches. Most of the studies have, so far, been conducted at the research plot level, thus more on-farm level studies across different agro-ecosystems are needed to generate the knowledge pool to bridge the gap between labs and farm land management.

Ethical approval

For non-interventional studies (e.g. surveys), ethical approval is not required and the current work neither involved human participants directly in their study nor applied any treatment on them and did not disclose their identity.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Supporting data can be available from the corresponding author on request.

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