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Conservation agriculture, a farming approach to promote soil carbon storage and mitigate climate change

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Abstract

Conservation agriculture may have the ability to increase soil organic C content in comparison to conventional tillage-based methods. The traditional approach of intensive tillage modifies the soil environment, disrupts soil aggregates, depletes soil organic carbon (SOC), releases more carbon, demands greater energy, affects microbial activities, and ultimately harms soil health. To lessen these adverse impacts of conventional tillage (CT), conservation agricultural (CA) techniques such as reduced tillage (RT) and no-till (NT) with crop residue retention are promoted as sustainable approaches that can enhance soil health. The aim of this study was to examine the effects of varying tillage and cropping systems on SOC stocks and soil aggregation under different tillage and cropping systems in an Inceptisol. A field trial was carried out over eight years at the Agricultural farm of the University of Calcutta with four scenarios, namely scenario 1 (CT), where conventional tillage practices and complete residue removal were performed with transplanted rice followed by pigeon pea and wheat; scenario 2 (RT), where transplanted rice-zero till pigeon pea-zero till wheat were cultivated with partial residue removal; scenario 3 (NT), where rice-pigeon pea-wheat were grown with zero tillage and complete residue retention. Several key soil properties were analysed to calculate soil quality indices in each tillage system. The share of large macro-aggregates was greatest under NT compared to CT, while the micro-aggregates were most abundant under CT. The organic C associated with aggregates tended to diminish as the size of the aggregates decreased. Soil organic matter (SOM), soil organic carbon (SOC), and humic acids (HA) were extracted from soils collected from a depth of 0 to 15 cm in each scenario. Findings indicated that Scenario-3 had a significantly higher HA content. A lower E4/E6 ratio indicated greater stability and humification of humic acid carbon in CA-based scenarios. The overall SOC turnover was less in soil with residue retention than in soil without residues. It was observed that the NT system with residue retention is a practice with the potential to preserve organic carbon in the soil. CA enhances SOC stocks by contributing additional C inputs through increased biomass production and diminishing SOC losses due to surface soil cover and binding SOC in soil aggregates. This results in net sequestration of atmospheric C into the soil, contributing to climate change mitigation.

Keywords: conservational agriculture, conventional tillage, humic acid, E4/E6 ratio, soil organic carbon

1. Introduction

Conservation Agriculture (CA) represents a farming method that helps avert the loss of cultivable land while restoring damaged lands. It encourages minimal disruption of soil, upkeep of a continuous soil cover, and variety in plant species. It boosts biodiversity and natural biological activities above and beneath the soil surface, which aids in enhancing water and nutrient efficiency and promotes better and sustained crop yield (FAO, Retrieved 26, 2020). In CA, practicing minimal soil disturbance is crucial for preserving minerals in the soil, preventing erosion, and stopping water loss from occurring in the soil. Historically, agriculture has viewed soil tillage as a primary method for introducing new crops to a region. It was thought that tilling the soil would enhance soil fertility through the mineralization process occurring in the soil. Furthermore, tilling can lead to significant erosion and crust formation, resulting in decreased soil fertility. Nowadays, tillage is regarded as damaging the organic matter present in soil cover. No-till farming has emerged as a method that can maintain soil organic levels for an extended duration, while still enabling the soil to remain productive for prolonged periods (FAO, 2007). In addition, the tilling process can increase time and labour required for crop production. Minimal soil disturbance also minimizes the destruction of soil micro and macro-organism habitats, which is typical in conventional ploughing methods. (FAO, retrieved 24, 2020) By adhering to no-till practices, the producer experiences a decrease in production costs for a specific crop. Tilling the land necessitates higher expenses for fuelling tractors or for providing feed for animals used to pull the plough. The producer observes a reduction in labour since they do not have to spend as much time in the fields compared to a conventional farmer. The second essential principle in CA is quite similar to the first regarding the safeguarding of the soil. The principle of managing the topsoil to establish a lasting organic soil cover facilitates the growth of organisms within the soil structure. The use of mulch similarly diminishes the speed of runoff and the effect of raindrops, thereby mitigating soil erosion and runoff. (FAO Retrieved 26, 2020) The third principle involves practicing diverse crop rotation or crop interactions. Implementing a rotational cropping system permits an extensive buildup of rooting zones that enhances water infiltration (Hobbs et al. 2007) (FAO Retrieved 26, 2020). Organic substances in the soil decompose into phosphates, nitrates, and other advantageous elements, which are consequently better absorbed by plants. Tilling raises the oxygen content in the soil and boosts aerobic processes, speeding up the decomposition of organic matter. Therefore, an increased number of nutrients are accessible for the upcoming crop; however, concurrently, the soil's nutrient reserves are depleted more rapidly. An excessive depletion of soil organic carbon (SOC), changes in microbiological functions, and disintegration of soil aggregates combined with the rising climate change have jeopardized the sustainable food manufacturing under intensive farming. The depletion of SOC happens when perennial plants are transformed into agricultural land that entails intensive tillage. These traditional tillage methods may compromise soil quality (the soil's natural ability to perform to ensure crop productivity) and soil health (the equilibrium among the soil organisms within the soil ecosystem and between the soil organisms and their surroundings). The implementation of conservation agriculture (CA) is endorsed by FAO as a reaction to sustainable land stewardship, environmental conservation, and climate change adaptation and mitigation (Pisante et al. 2012; 2015). Per the FAO definition, CA is a farming system that encourages the maintenance of (1) minimal soil disturbance preventing soil inversion (i. e. no-tillage or minimum tillage), (2) a continuous soil cover with crop residues and/or cover crops, and (3) diversification of plant species through varied crop sequences and associations that include at least three distinct crops (FAO, 2017). The application of CA-based techniques has transitioned into an official state policy for agriculture in Kazakhstan. In fact, since 2008, the government of Kazakhstan has been providing subsidies to farmers who implement CA-based technologies. Italy is among the European nations where the use of no-tillage and minimum tillage has been increasing lately (Kassam et al., 2019). Aside from the no-tillage method, additional details regarding the conservation agriculture practices they employ are not available. Finland stands as the northernmost country utilizing no-tillage, featuring the highest implementation rate of 10% (200,000 ha) in Europe (González-Sánchez et al., 2017). Conservation agriculture offers numerous advantages, including improved biodiversity and natural biological activities both above and below the soil layer, aiding in enhanced water and nutrient efficiency and fostering improved and sustained crop yields. Additionally, rises in soil organic carbon (SOC) may lead to higher crop yields (Zhao et al., 2017) and diminished yield variability since SOC accumulation not only traps atmospheric CO2 but also boosts soil fertility and water retention capacity (Franzluebbers, 2002). Robust soils are essential for developing sustainable cropping systems that can withstand the impacts of climate change. High-residue crops are likely to capture more carbon compared to those with low residue outputs. Intensifying cropping systems, such as increasing the number of crops per season, double cropping, and introducing cover crops can lead to heightened soil carbon storage under no-tillage practices (West and Post, 2002).Cover crops can increase C concentration and stocks, potentially offsetting residue removal-induced losses to SOC and harm to other soil properties (Ruis and Blanco-Canqui, 2017). Thus, CA involves complex and interactive processes that ultimately determine soil C storage making it difficult to identify clear patterns, particularly when the results originate from a large number of independent studies. To solve these problems, a model approach can be useful to assess the contribution of each principle of CA in soil C sequestration. The three sites are very contrasting for soil texture and organic C contents, climates, crops used and management intensity. To assess the feasibility of options, allowing for C sequestration in soils in future years, and simulations under a short-term future climate scenario were carried out.

The primary aim of this research was to examine the impacts of various tillage and cropping systems on SOC stocks, soil aggregation, and GHG emissions in an Inceptisol. This document will offer a detailed overview of our understanding of the influence of CA.

2. Materials and methods

2.1. Study area and treatment details

Samples were collected in March, 2024, at location 88°4355'E, 22°3744'N, University of Calcutta agricultural farm, Baruipur, Kolkata, India. Average rainfall of the area 1700mm, 70% of which occurred during monsoon, soil is silty-loamy alluvial and soil order is Inceptisol. The area was split up into fully randomized experimental units of $40m^2$ (5m*8m) with three replicates per treatment. A field experiment was conducted for eight years in Agricultural farm of University of Calcutta with four scenarios namely scenario 1(CT) where conventional tillage practice and all residue removal were done with transplanted rice-pigeon pea-wheat, scenario 2(RT) where transplanted rice-zero till pigeon pea-zero till wheat were cultivated with partial residue removal, scenario 3(NT) where rice-pigeon pea-wheat were cultivated with zero tillage and all residue retention. Recommended doses of fertilizers (rice 120:60:60, wheat 120:60:40, pigeon pea 30:60:60 of $N:P_2O_5:K_2O$ kg ha^{-1}) were applied during each cropping season.

2.2. Sampling

Each plot was flat and uniform and soil sampling was done using a grid. The field was divided into cells by means of a coarse grid. A horizontal coarse cell was selected in the top row and kept the X coordinate the same but randomly select a new Y coordinate. The soil samples were placed in cold boxes and transported to the laboratory for analysis.

2.3. Physico-chemical analysis

2.3.1. pH: Soil pH was determined from soil water suspension in 1:2.5 ratio with the help of Systronics pH meter model no: 324(Sparks, 1996).

2.3.2. EC: Electrical conductance (EC) was determined from soil water suspension with 1:5 ratio with the help of Systronics conductivity bridge model 305(Barker and Khalili, 2003).

2.3.3. CEC: Cation exchange capacity (CEC) of soil was determined by the $BaCl_2$ compulsive exchange procedure (Sparks, 1996).

2.3.4. Soil texture: Texture also affects water permeability, and heavier finer soil can suffer from drainage problems, if soil structure is poor. Soil texture is determined by international pipette methods in order to characterise the particle size composition of the soil.

2.3.5. SOC: The determination of soil organic carbon (SOC) is based on the Walkley-Black chromic acid wet oxidation method. Oxidizable matter in the soil is oxidised by 1 N $K_2Cr_2O_7$ solution. The reaction is assisted by the heat generated when two volumes of H_2SO_4 are mixed with one volume of the dichromate. The remaining dichromate is titrated with ferrous sulphate. The titre is inversely related to the amount of C present in the soil sample (Anonymous, 1992).

2.4. Aggregate associated carbon

A wet sieving method was used to determine the water-stable aggregates. The soil retained in the sieves of different diameters were divided into four types, i.e., large macro-aggregates (LM) >2000µm, small macro-aggregates (SM) >250-2000µm, micro-aggregates (MI) >53-250µm, silt+clay (S+C) <53 µm. Soil and aggregate fractions were dried at 45°C and SOC concentration of soils and aggregates were measured by wet digestion method (Walkley and Black, 1934).

2.5. Isolation and purification of humic Acid

The HA was extracted using a 0.5 mol L-1 238 NaOH solution in a proportion 1:10 (soil: solution), followed by shaking for 3h @150 rpm (de Souza and Bragança, 2018). For the removal of inorganic contaminants from the HA, purification was carried out by parchment paper then repeatedly washed with deionized water. The purified HA was dried at 40°C (de Souza and Bragança, 2018).

2.5.1. Yield of HA measurement: Yields of humic acids were measured.

2.5.2. E4/E6 ratio of HA measurement: E4/E6 ratio was determined by dissolving 1 mg of HA in 5 ml of 0.05 M NaHCO3 and pH was adjusted to 8.3 with NaOH. The absorbance at 465 and 665 nm was measured on a UV3000 spectrophotometer (Chen et al. 1977).

2.6. Statistical analysis

Data were processed for significance test of treatments by one way ANOVA. Duncan multiple range test at significance level of 5% ($p<0.05$) were performed using R software to separate treatments means.

3. Results and discussion

3.1. Basic soil properties: Some relevant physical and chemical characteristics of the soils are presented in Table 1. Soils samples were slightly acidic to neutral in nature (pH ranged from 5.85-6.17). The electrical conductivity (EC) of soils ranged widely from 98.6 to 103 µs/cm. Organic matter is an important source of cation exchange capacity in these soils (Carvalho et al., 2009). The cation exchange capacity (CEC) of soils varied from 14.6 to 17.8 cmolkg^{-1}. After 8 years of conservation practices pH and EC decreases to some extent, but CEC increases than CT. Higher CEC value favours carbon sequestration because organic matter colloids have higher quantity of negative charge which can hold cations strongly. The soil is silty clay in texture, based on morphological, physical and chemical characteristics, soils were classified as Inceptisols.

3.2. SOC: The SOC content showed significant variation among the scenarios in Table 1. The SOC content of these soils varied from 0.56 to 1.00 %. Highest SOC was observed in scenario 3(1.00%) followed by scenario 2(0.82%), scenario 1(0.56%). Scenario 1 showed lower TOC compared to initial (0.64%). Higher SOC levels in surface soil under conservation practices arise from greater amounts of residue inputs and zero tillage with minimal soil disruption (Jat et al. , 2019a). Different tillage methods significantly influence SOC levels. This research shows that CA methods had a notably beneficial impact on SOC levels compared to conventional tillage (CT) methods. Increased SOC in CA-based practices resulted from the long-term application of crop residue on the soil surface, which contributes carbon to the soil following decomposition.

3.3. Aggregate associated carbon: Aggregate associated carbon content under various tillage practices is displayed in Table 2. Carbon concentration increased with the size of aggregates, that is, LM > SM > MI > S+C. Tillage significantly influenced the carbon concentration associated with aggregates, as greater aggregate associated carbon indicates more carbon storage in the soil. After 8 years, NT plots had a greater proportion of large macro-aggregates carbon (LM-C) than CT plots. In contrast to CT, CA promoted macro-aggregation, especially within the surface soil layer. Favourable effects of NT on soil structural properties may also be partly due to higher activity of earthworms and more microbial biomass than in CT plots (Nyamadzawo et al. 2009). Soil aggregate related carbon rose under NT and RT due to reduced soil disturbance and the preservation of crop residue compared to CT. The retention of crop residue offers a carbon source for microbial activity and supports the binding of residue and soil particles into larger aggregates (Swanepoel et al., 2018).

3.4. Yield of HA: HA as a reactive component of soil humic substances, plays a major role in soil fertility preservation and nutrient supplying power (Zhang et al., 2019). Higher HA content improves soil aggregate stabilization along with soil fertility (Jat et al., 2019b). Significant variation in HA yield is observed under different tillage practices shown in Table 3. No tillage practice (scenario 3) showed highest HA content (2.97 g 100 g soil$^{-1)}$. Reduced tillage practice (scenario 2) recorded higher HA concentration (1.71 g 100 g soil^{-1}) compared to initial (1.21 g 100 g soil^{-1}). Conventional practice showed lowest HA yield 0.92 g 100 g soil^{-1} (scenario 1). Long term conservation agriculture enhanced stable humic acid content in soil. CA based system promotes humic acid content in soil with more humification and aromatic structures.

3.5. E4/E6 ratio: The E4/E6 ratio (the relationship between the absorbance at 465 and 665 nm) is regarded as inversely related to the levels of condensation and aromaticity in humic substances as well as their degrees of humification (Chen et al. , 1977). The absorbance measured at 465 nm signifies the organic material present in the early stages of humification, while the absorbance at 665 nm reflects the highly condensed humified material that contains a higher proportion of aromatic components (Albrecht et al. , 2011). The E4/E6 ratio of HA, presented in Table 3, indicates the lowest value for scenario 3 (4. 2), followed by scenario 2 (4. 5), the initial state (4. 8), and the highest for scenario 1 (5. 1). NT displayed the greatest level of humification among the tillage methods. RT also enhances the degree of condensation compared to the initial soil condition, but after 8 years of CT practice, the soil humic substances deteriorated and the degree of humification declined.

3.6. Yield of crops: Crop production varied with time under different tillage practices shown in Table 4.

3.6.1. Rice: In CT, the output of rice during the first four years saw an increase, reaching the highest level among the three scenarios. Starting in the fifth year, production began to decline, and by the seventh year, rice production in RT and CT was identical (3. 1t/ha), which was lower than NT (3.6t/ha). After the eighth year, the production peaked for NT (4. 0t/ha), followed by RT (3. 1t/ha) and CT (0. 6t/ha).

3.6.2. Wheat: Wheat production in CT was increased with years, highest in 5th year (4.0t/ha), after that production started decrease and lowest in 8th year, where in RT change in production increased up to 4th year, after that yield declined with years but higher than CT. in NT production was low for first three years and from 4th year yield increased and highest among all scenarios in 8th year (4.1 t/ha).

3.6.3. Pigeon pea: Yield of pigeon pea in 1st four years was highest for CT followed by RT and NT. Increase in production for NT was continuous over time but yield declined from 4th year in case of CT and from 7th year in case of RT.

4. Conclusion

Study reveals that conservation agricultural methods such as no tillage with complete residue retention (NT) and reduced tillage (RT) with partial residue retention positively influenced SOC, soil aggregate associated carbon, and humic acid under the same cropping pattern (rice-pigeon pea-wheat) compared to conventional tillage practice with complete residue removal (CT). NT helps to prevent soil degradation through the formation of non-labile HA. Crop yield is lower for the first 4-5 years in the case of RT and NT than in CT, but after that, production shows a significant increase in the case of NT. Therefore, long-term conservation agriculture (beyond 5 years) should enhance SOC storage to counter climate change while boosting crop productivity to guarantee long-term profitability and sustainability.

Conflict of Interest

The authors declared no conflict of interest.

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Table 1

Physico-chemical analysis of soils

Sample sites	pH (1:2.5)	EC (µs/cm)	CEC (Cmolc/ Kg)	SOC (%)	Sand, silt, clay (%)
Scenario 1 (after 8years)	6.17a	103.0a	14.6b	0.56a	33,48,19
Scenario 2 (after 8years)	6.01a	98.6c	17.3c	0.82b	33,48,19
Scenario 3 (after 8years)	5.85c	98.9a	17.8b	1.00c	33,48,19
Initial	6.10b	100.3c	15.0c	0.64a	33,48,19

Different letters indicated statistically significant differences among treatments ($p<0.05$) (Duncan multiple range test for separation)

Table 2

Effect of different tillage on aggregate associated carbon concentration (%)

Tillage Practices	LM-C(0-15cm)	SM-C(0-15cm)	MI-C(0-15cm)	S+C-C(0-15cm)
Scenario 1	0.62a	0.36c	0.30b	0.24b
Scenario 2	0.68a	0.38b	0.34a	0.32b
Scenario 3	0.71b	0.42c	0.39c	0.37a

Different letters indicated statistically significant differences among treatments ($p<0.05$) (Duncan multiple range test for separation)

Table 3

Yield of Humic acid (g/100g soil) and E4/E6.

Scenarios	Yield of HA(g/100g)	E4/E6
Initial	1.21a	4.8c
Scenario 1	0.92c	5.1b
Scenario 2	1.71c	4.5a
Scenario 3	2.97c	4.2b

Different letters indicated statistically significant differences among treatments ($p<0.05$) (Duncan multiple range test for separation)

Table 4

Yield of crops under different tillage practices

Scenario	Crop	Year wise production (t/ha)							
		1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year
Scenario 1	Rice	3.2	3.3	3.8	4.2	4.1	3.9	3.1	2.6
	Wheat	2.9	3.3	3.6	3.9	4.0	3.6	3.2	3.0
	Pigeon pea	2.6	2.8	2.9	3.0	2.8	2.5	2.4	2.4
Scenario 2	Rice	3.0	3.1	3.4	3.6	3.6	3.5	3.1	3.1
	Wheat	2.9	2.9	3.3	3.4	3.8	3.7	3.9	3.8
	Pigeon Pea	2.4	2.3	2.6	2.9	3.2	3.5	3.1	2.9
Scenario 3	Rice	2.1	2.3	2.2	2.4	2.8	3.4	3.6	4.0
	Wheat	2.0	2.2	2.1	2.5	2.9	3.2	4.0	4.1
	Pigeon Pea	1.3	1.5	1.9	1.8	2.1	2.3	2.8	3.0
	CD at 5%	0.96	1.30	0.66	0.59	1.01	0.78	0.69	1.20