Effect of conservation agriculture on soil organic carbon, soil physical properties and yield of different cropping systems in Vertisols of central India

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Effect of conservation agriculture on soil organic carbon, soil physical properties and yield of different cropping systems in Vertisols of central India

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Abstract

Intensive agriculture coupled with mechanization has become a threat to agricultural sustainability and hence, novel changes like conservation agriculture or regenerative agriculture are required to achieve desirable productivity and upkeep of natural assets. Around the world, conservation agriculture (CA), is gaining acceptance as an innovative and sustainable farming method that can improve the health of the soil, reduce the effect of climate change, enhance organic carbon in the soil, and increase agricultural production. The present research study examined the impact of conservation agriculture in the form of no-tillage on soil organic carbon (SOC), aggregate stability, soil penetration resistance (SPR), and yield of different cropping systems in terms of soybean grain equivalent yield (SGEY). The study was carried out in the Vertisols of central India during the kharif season (July-October) and rabi season (November-April) of 2022-23 on the existing long-term CRP-CA research project at the research farm of the ICAR-Indian Institute of Soil Science, Bhopal, (M.P.), India, initiated way back in 2010. The field experiment was set up using a factorial randomized block design with two tillage systems, no-tillage (NT) and conventional tillage (CT), and three cropping systems, namely, soybean-wheat, maize-gram, and maize-wheat with four replications. Results revealed that CA-based NT plots have significantly higher SOC (0.93%), mean weight diameter (1.29 mm), and water-stable aggregate (82.12%) compared to the CT plots on the surface soil (0-10 cm). Tillage had no significant impact on the surface of the soil (0-15 cm) to soil penetration resistance, but in lower depths (15-30 and 30-45 cm), SPR was significantly higher in CT compared to NT. The crop yield of NT in terms of SGEY (34.74 quintal ha^{-1}) is significantly higher than CT (32.28 quintal ha^{-1}). Thus, in the present era, CA techniques could be promoted as sustainable farming methods to increase agricultural yields and the physical health of the soil.

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Keywords conservation agriculture, conventional tillage, no-tillage, soil physical health, soybean grain equivalent yield

Introduction

To retard the pace of natural resource degradation in various agroecosystems, we need a more sustainable farming approach with components of regenerating soil health. Conservation agriculture (CA) is, at present, a sustainable and innovative farming approach that aims to enhance agricultural productivity and simultaneously mitigate climate change, conserve natural resources, increase organic carbon content in the soil, improve the physical health of the soil, and reduce GHG emissions. It is a self-sustaining system that provides an option for burning crop residue [1]. It represents a paradigm change from conventional agricultural methods by incorporating three fundamental principles: minimum disturbance of soil with reduced/no-tillage, permanent covering of the soil with crop residue, and varied crop rotations, including legume crops [2].

It has been discovered that CA activities have a major impact on the biological, chemical, and physical characteristics of soil. Increased carbon storage is one of the main long-term consequences of CA on soil dynamics [3]. When crop residues are left on the soil's surface, more organic matter is added to the soil. These organic compounds break down over time and build up as soil organic carbon (SOC). Conservation agriculture has been shown to promote soil organic carbon sequestration in several studies [4]. Under no-tillage techniques with residue retention, higher quantities of organic matter build on the soil surface, increasing the soil's organic carbon content [5-6]. As a result of sequestering carbon dioxide (CO_2) from the atmosphere, into soil in the form of organic carbon under CA helps to ameliorate climate change. The physical properties of soil, such as soil aggregation, are important for the retention and transmission of water, nutrients, temperature, and gases as well as for optimizing the soil environment for crop production. CA improves the physical properties of the soil [7-8], which stimulates root growth, recycling of nutrients, and sequestration of SOC [9-11]. SOC captured in the soil also improves soil aggregation, aggregate associate carbon (C), and aggregate stability [10-11], on account of biologically mediated processes, as organic material is available as a substrate.

Conservation agriculture thus minimizes excessive soil disturbance and avoids soil degradation, prevents soil erosion, compaction, and aggregate breakdown, and also minimizes the loss of soil organic matter (SOM) and nutrient leaching. Additionally, it also reduces the tillage cost, saves time, uses less energy (reduces diesel consumption), gives higher net returns, and reduces greenhouse gas emissions [12-13]. CA with maintaining residue on the soil surface has been observed to enhance crop productivity and water and nutrient use efficiency [14-15] due to related benefits such as timely planting and seeding, decreased pests and diseases by promoting biological variety, prevented soil degradation, enhanced soil fertility, improved soil moisture regime, and advantages of crop rotation.

In India, the implementation of CA is still in its early stages and is mostly practiced on 5 million hectares in the Indo-Gangetic region [16]. However, Indian soils, particularly Vertisols, have huge potential for soil carbon storage due to their high clay content (58%) and climatic conditions, which support good vegetation. However, in the black soil (Vertisols) of semi-arid central India, such information on the dominant cropping system is very scanty. Therefore, this research article describes the effect of conservation agriculture in the form of no-tillage on soil physical health, soil organic carbon, and crop yield in the Vertisols of central India.

Methodology

Location of experiment

The experiment was conducted during the kharif season (July–October) and rabi season (November–April) of 2022-23 on Vertisols of Central India (Figure 1) in the existing long-term CRP-CA research project established during June 2010 at the research farm of the ICAR-Indian Institute of Soil Science, Bhopal, India. The geographical coordinates of the research farm are approximately 23°18′N, 77°24′E, with an elevation of 485 meters above sea level. The study location has a hot, sub-humid climate with a mean annual air temperature of 25 °C a mean annual rainfall of 1130 mm, and a potential evapotranspiration of 1400 mm. The soil of the experimental field is classified as deep clayey Vertisols. Meteorological data for the study period, from June 2022 to May 2023, including total rainfall and average minimum and maximum temperatures, were recorded at ICAR-IISS, Bhopal, as illustrated in Figure 2.

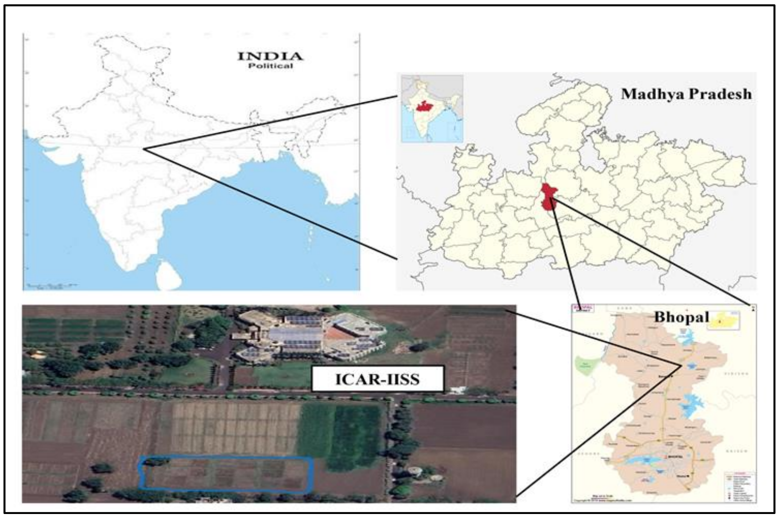

Figure 1. Location of the experiment

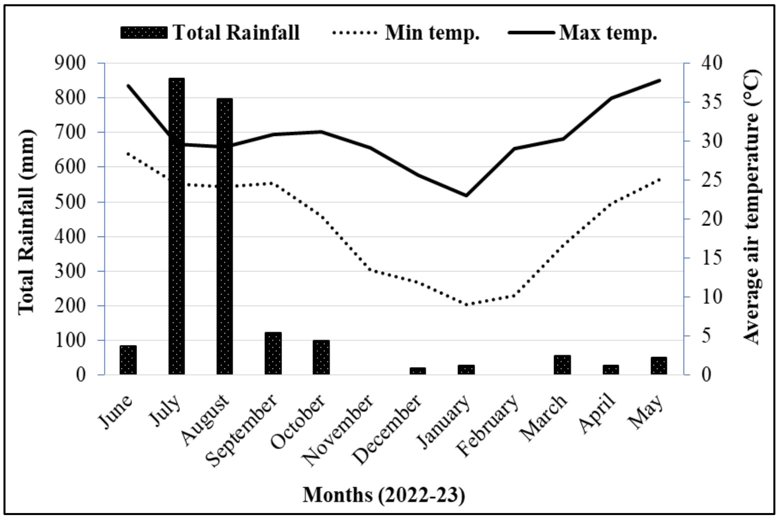

Figure 2. Monthly weather data for the year 2022-23

Experimental details

The field trial was structured as a factorial randomized block design, incorporating two main factors: tillage systems and cropping systems. The two tillage systems were no-tillage (NT) with residue retention and conventional tillage (CT) involving residue removal and ploughing to a depth of 0-15 cm. The three cropping systems under investigation were: Soybean-wheat, Maize-wheat, and Maize-gram. This design resulted in six treatment combinations: (T1: soybean-wheat in CT; T2: maize-wheat in CT; T3: maize-gram in CT; T4: maize-gram in NT; T5: maize-wheat in NT; and T6: soybean-wheat in NT). Each treatment was replicated four times. The plot size for each treatment was 10 x 10 meters, and the plots were situated on flat land. Nutrient requirements for the crops were met by applying recommended doses of fertilizers, which varied according to the crop: (30:60:30 for soybeans, 120:60:40 for wheat, 120:60:40 for maize, and 40:60:30 for grams of $N\text{-}P_2O_5\text{-}K_2O$ kg ha^{-1}, respectively).

Collection and processing of soil samples

Samples of soil were taken at three distinct depths (0-10 cm, 10-20 cm, and 20-30 cm) from each treatment plot after the *rabi* crop harvest. The collected soil samples were air-dried in the shade to remove moisture from the soil. Soil lumps or clods were gently broken up using a wooden pestle. The soil was then sieved through a 0.5-mm sieve to estimate soil organic carbon content. The soil samples were retained on a 4-mm sieve after passing through the 8-mm sieve, used for aggregate analysis.

Methods of soil analysis

Soil organic carbon

The wet digestion method described is a common technique used to quantify organic carbon in soil samples [17]. One gram soil sample (0.5 mm in size) is placed in a 500 ml conical flask and mixed with 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$) and 20 ml of concentrated sulfuric acid (H_2SO_4). This mixture is then digested for 30 minutes. The purpose of this step is to oxidize the organic carbon in the soil to carbon dioxide (CO_2). After digestion, the excess potassium dichromate is titrated with ferrous ammonium sulphate [$Fe(NH_4)$ $(SO_4)_2.6H_2O$] after adding 10 ml of conc. H_3PO_4 using a diphenylamine indicator. This titration is used to measure the amount of unreacted potassium dichromate, indirectly indicating the amount of organic carbon present in the soil sample. A blank sample (containing all reagents except the soil) is treated in the same manner as the soil sample. The amount of potassium dichromate used in the blank sample is subtracted from the amount used in the soil sample. The following formula was used to determine organic carbon (%):

$$\%\ \mathrm{OC}\ = 10 \times \frac{\text{Blank reading } - \text{Sample reading}}{\text{Blank reading} \times \text{wt. of sample}} \times 0.003 \times 100$$

Aggregate stability

The process of wet sieving soil samples to evaluate their aggregate stability [18-19]. The Yoder apparatus, which had a 38 mm vertical stroke, was used, and it ran for 10 minutes at a rate of 28-30 strokes per minute. Six sieves with varying sizes (ranging from 4, 2, 1, 0.5, 0.25, and 0.125 mm) were used in a set and placed in descending order. The soil samples (4 mm in size) were placed on top of each set and submerged in room-temperature water for ten minutes. The oscillation of the sieves vertically and continuously forces water to flow up and down through the screens and the aggregate assembly. The nest of sieves was carefully withdrawn from the water after ten minutes had passed.

Aggregates remaining on each sieve are backwashed in an aluminum cane and dried for twenty-four hours at 105 °C in an oven. After drying, a weight measurement was taken of the particles remaining on each filter. The dry material was once again dispersed using a solution of sodium hexa-meta phosphate, churned, and run through a sieve of the same size to eliminate the sand and stone fractions. The sand and stone retained are weighted after oven drying and corrections are made. Sum up the percentages of aggregates retained on sieves larger than 0.25 mm. This sum represents the proportion of water-stable aggregates (WSA) in the soil sample.

The mean weight diameter (MWD) is calculated to represent soil aggregation-

$$\mathrm{MWD}\ = \sum_{k=1}^{n} \mathrm{di\ wi}$$

Where-

n= number of size fraction

Di = diameter of the sieve (in mm) through which the soil particles passed.

Wi = weight of the soil retained on each sieve (in grams).

Soil penetration resistance (SPR)

Soil penetration resistance (SPR) measurement helps assess the soil's compaction, which can affect root growth. SPR was measured using a digital cone penetrometer (Eijkelkamp) at the harvesting stage of the *rabi* crop. The penetrometer measures the soil penetration resistance in megapascal (MPa) which indicates the force required to penetrate the soil to a certain depth. SPR was measured at depths ranging from 0 to 60 cm under the experimental plots, likely to capture variations in compaction throughout the soil profile.

Soybean grain equivalent yield (SGEY)

As the crops grew mature, they were harvested, and the yield was recorded. Yields required to be converted into SGEY (quintal ha^{-1}) to compare the various crops engaged in the experiment in terms of economic productivity. The minimum support price (MSP) of 2022-2023 (in Indian rupees (INR) quintal^{-1} for soybeans (4300), maize (1962), grammes (5230), and wheat (2015) was taken into consideration in order to determine SGEY (quintal ha^{-1}).
As an example, in the case of maize yield conversion-

$$\text{SGEY of Maize} = \frac{\text{Yield of maize grain x MSP of maize}}{\text{MSP of soybean}}$$

Statistical analysis

Experimental results were analyzed by using standard statistical methods of analysis of variance (ANOVA) [20]. Only for the characters that are statistically significant at the five percent level, the critical difference (C.D.) value was computed.

Results and Discussion

Soil organic carbon

In the depth of 0–10 cm, the soil organic carbon (SOC) concentration under NT (0.93%) was considerably greater than for CT (0.78%); however, tillage had no significant effect at 10–20 and 20-30 cm (Table 1 and Figure 3). Therefore, the favorable result of NT on SOC content was only observed at the soil's 0-10 cm layer-not at the inlays below. The amount of residue and tillage had a significant impact on the accumulation of soil organic carbon in the upper layers (0-15 cm),

Table 1. Effects of conservation agriculture at various depths on soil organic carbon (%)

Soil organic carbon (%)				
Tillage System	**Cropping System**	**0-10 cm**	**10-20 cm**	**20-30 cm**
CT	Soybean-Wheat	0.84	0.58	0.50
	Maize-Wheat	0.76	0.58	0.49
	Maize -Gram	0.73	0.57	0.50
	Mean	**0.78**	**0.58**	**0.50**
NT	Soybean-Wheat	0.90	0.59	0.50
	Maize-Wheat	1.02	0.61	0.48
	Maize -Gram	0.87	0.61	0.48
	Mean	0.93	0.60	0.49
CD (p= 0.05)	TS	0.06*	N.S.	N.S.
	CS	0.07*	N.S.	N.S.
	TS x CS	0.10*	N.S.	N.S.

Tillage System (TS), Cropping System (CS), Conventional Tillage (CT), No Tillage (NT),
*Statistically Significant, N.S.- Statistically Insignificant

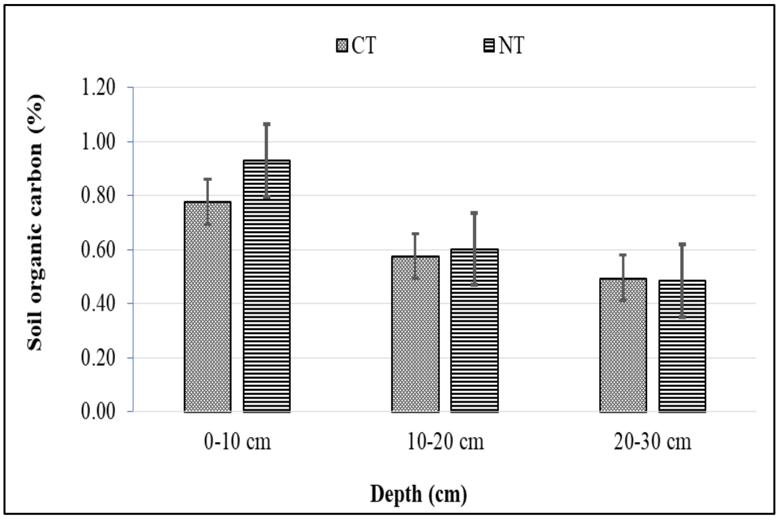

Figure 3. Effects of conservation agriculture at various depths on soil organic carbon (%)

but not in the lower levels (15-30 cm) [21]. CA is associated with higher SOC levels in the surface layer of soil because of a rise in the amount of crop residue [22] and less soil disturbance, which lowers organic matter oxidation and enhances SOC storage [23]. Cropping systems and the interactions between cropping and tillage systems had significant effects on SOC only at a depth of 0-15 cm. Compared to other crop rotations in the NT the maize-wheat cropping system had a greater SOC at 0-10 cm; this might be due to higher residue retention on the surface of the soil. The concentration of SOC decreased with increasing depth in both tillage systems [24].

Aggregate Stability

Mean weight diameter (MWD)

Tillage and cropping regimes had a substantial impact on the mean weight diameter (MWD) of aggregates at 0-10 cm and 10-20 cm depth. The MWD was higher in NT (1.29 mm) than in CT (0.97 mm) at 0-10 cm (Table 2). The higher value of MWD indicates improved soil aggregation in NT compared with CT [25]. Significantly higher MWD under NT (1.05 mm) compared to CT (0.71 mm) was reported on the top 15 cm of soil [26-27].

Table 2. Effect of conservation agriculture at different depths on water stable aggregate (WSA %) and mean weight diameter (MWD mm)

Tillage System	Cropping System	Mean weight diameter (mm)			Water stable aggregate (%)		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
CT	Soybean-Wheat	0.98	0.75	0.74	76.58	73.02	73.43
	Maize-Wheat	1.13	0.89	0.87	78.16	72.99	72.48
	Maize -Gram	0.80	0.86	0.80	79.07	73.75	72.58
	Mean	**0.97**	**0.83**	**0.81**	**77.94**	**73.25**	**72.83**
NT	Soybean-Wheat	1.04	0.77	0.83	81.31	77.96	74.55
	Maize-Wheat	1.53	1.09	0.81	82.47	75.72	74.53
	Maize-Gram	1.30	0.87	0.71	82.57	78.43	73.29
	Mean	1.29	0.91	0.78	82.12	77.37	74.12
CD(p=0.05)	TS	0.19*	0.08*	N.S.	3.70*	2.71*	N.S.
	CS	0.23*	0.09*	N.S.	N.S.	N.S.	N.S.
	TS x CS	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Tillage System (TS), Cropping System (CS), Conventional Tillage (CT), No Tillage (NT),
*Statistically Significant, N.S.- Statistically Insignificant

The addition of crop residue, increased SOC, and minimal soil disturbances were the reasons for the significant MWD seen under the NT practice [27]. Lower MWD is a reflection of lower SOC under CT, which has been associated with a greater chance of physical breakdown of soil aggregates that could result in a higher rate of SOC oxidation [27].

Water stable aggregate (WSA)

Tillage had a major effect on the water stable aggregate (WSA). It was shown that in the upper 10 cm of soil, the WSA of the NT was much greater (82.12%) than that of the CT (77.94%). The water stability of aggregates (WSA) was higher in NT than in CT [28]. The soil's structural stability is indicated by a higher WSA [29]. Tillage practices and cropping system interactions did not significantly alter water-stable aggregates. In comparison to the CT, where the soil was more disturbed by ploughing and crop residue was removed, better aggregate stability under the NT was defined as less soil disturbance and accumulation of crop residues on the surface of the soil [1, 26, 30].

Soil penetration resistance (SPR)

For a quick assessment of soil strength, soil penetration resistance (SPR) is a reliable and practical measure [31]. Tillage had no significant effect on soil penetration resistance on the upper soil depth (0-15 cm), but in lower depths (15-30 and 30-45 cm), SPR was significantly higher in CT (3.45 MPa and 4.16 MPa) compared to NT (2.52 MPa and 3.39 MPa) (Table 3 and Figure 4).

Table 3. Effect of conservation agriculture at different depths on soil penetration resistance (MPa)

Soil Penetration resistance (MPa)					
Tillage System	**Cropping System**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**
CT	Soybean-Wheat	1.44	3.85	4.31	4.37
	Maize-Wheat	1.81	3.76	4.29	4.25
	Maize-Gram	1.80	2.74	3.87	4.17
	Mean	**1.68**	**3.45**	**4.16**	**4.26**
NT	Soybean-Wheat	1.38	2.79	3.36	3.68
	Maize-Wheat	1.89	2.93	3.67	5.14
	Maize-Gram	1.26	1.84	3.15	4.11
	Mean	**1.51**	**2.52**	**3.39**	**4.31**
CD (p= 0.05)	TS	N.S.	0.68*	0.76*	N.S.
	CS	N.S.	0.83*	N.S.	N.S.
	TS x CS	N.S.	N.S.	N.S.	N.S.

Tillage System (TS), Cropping System (CS), Conventional Tillage (CT), No Tillage (NT),
*Statistically Significant, N.S.- Statistically Insignificant

CA scenarios reduced soil penetration resistance at 15 to 45 cm soil depth over farmer's practices (CT) [32-33]. The plough pan development enhances the soil penetration resistance in lower depths of soil under conventionally tilled plots [34]. In our study, maximum SPR (5.14 MPa) was recorded at 45–60 cm depth under a maize-wheat cropping system.

Soybean grain equivalent yield (SGEY)

The crop yield of both the *kharif* and *rabi* seasons and its soybean grain equivalent yield (SGEY) are presented in Table 4 and Figure 5. The SGEY of NT (34.74 quintal ha^{-1}) is significantly higher than CT (32.28 quintal ha^{-1}) [23]. Also, SGEY had been significantly affected by the cropping system. Between the cropping systems, maize-gram noted the highest yield, then maize-wheat and soybean-wheat in both tillage systems. There was not a significant effect of cropping systems and tillage interaction on

SGEY. No-till farming increased yields while lowering production costs because of the savings in fuel, time, labour costs, and other physical and intangible benefits [12-13].

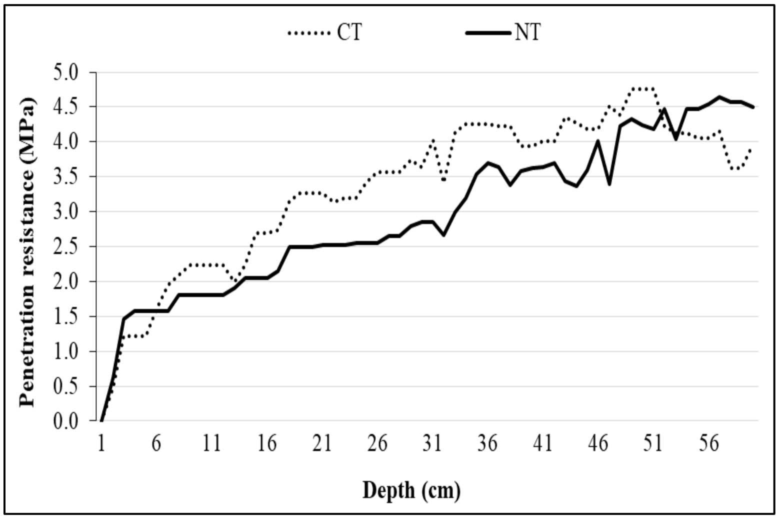

Figure 4. Effect of conservation agriculture on soil penetration resistance (MPa) at different depths
{Conventional Tillage (CT), No Tillage (NT)}

Table 4. Effect of conservation agriculture on crop productivity in the form of soybean grain equivalent yield (quintal ha^{-1})

Grain yield and Soybean grain equivalent yield (quintal ha^{-1})				
Tillage System	**Cropping System**	**Grain yield (Kharif)**	**Grain yield (Rabi)**	**SGEY (Kharif+Rabi)**
CT	Soybean-Wheat	9.55	36.58	26.70
	Maize-Wheat	35.93	37.68	34.05
	Maize -Gram	40.17	14.72	36.08
	Mean	**28.55**	**29.66**	**32.28**
NT	Soybean-Wheat	10.69	41.60	30.19
	Maize-Wheat	39.37	38.83	36.27
	Maize -Gram	42.95	14.75	37.76
	Mean	**31.00**	**31.73**	**34.74**
CD (p= 0.05)	TS	2.18*	1.18*	0.73*
	CS	2.66*	1.45*	0.89*
	TS x CS	N.S.	2.05*	N.S.

Tillage System (TS), Cropping System (CS), Conventional Tillage (CT), No Tillage (NT),
*Statistically Significant, N.S.- Statistically Insignificant

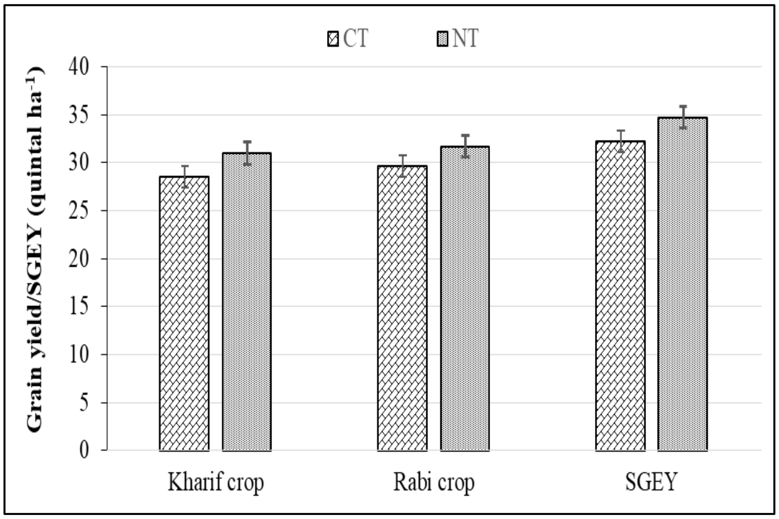

Figure 5. Effect of conservation agriculture on crop productivity in the form of soybean grain equivalent yield (quintal ha^{-1})
{Conventional Tillage (CT), No Tillage (NT), (Error bars indicate standard error)}

Conclusion

The study of the effects of conservation agriculture on aggregate stability, soil organic carbon, and soil penetration resistance is very significant because of the dynamics of these parameters in influencing crop production. In comparison to conventional farming methods, the current study's results indicate that CA-based cropping systems enhance soil organic carbon and the stability of aggregates in the upper surface of the soil layer. In terms of MWD and WSA, soil aggregation was greater under the CA-based NT plots, which indicates better soil physical condition than CT plots. Our conclusion was that, in comparison to traditional tillage methods, CA-based management strategies are more effective and sustainable for long-term crop production that preserves the physical health of the soil.

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