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Effect of tillage and weed management practices on soil physical and physico-chemical properties in rice under conservation agriculture

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Abstract

The present study was aimed to evaluate the effect of tillage and weed management practices on physical and physico-chemical properties of rice under conservation agriculture. The field experiment was conducted at AICRP on Weed Management, College of Agriculture, PJTAU, Rajendranagar, Hyderabad, initiated in 2014 with rice- maize-green manure cropping system conducted for five years before the current season. The experiment was laid out in split-plot design with three replications comprised of five tillage practices as main plots (T_1-CT (Conventional tillage)-CT, T_2-CT-ZT (Zero-tillage), T_3-CT (Direct seeded Rice)-CT, T_4-ZT-ZT and T_5-ZT+R (residue)-ZT+R and three weed management practices, W_1-Chemical weed management, W_2- Integrated weed management (IWM) amd W_3-Unweeded control in subplots. The results showed that under different tillage practices, soil bulk density (BD) was highest under ZT-ZT at 0–15 cm (1.35 $g\ cm^{-3}$) and at 15-30 cm, CT-CT(1.40) recorded higher BD. ZT treatments promoted larger macro-aggregates, Geometric Mean Diameter and Mean Weight Diameter, whereas CT treatments favoured micro-aggregates. Soil penetration resistance (SPR) was highest under ZT+R-ZT+R at 0–5 cm (1.28 MPa) and 5–10 cm (1.32 MPa), under CT(DSR)-CT at 10–15 cm (1.52 MPa), and under CT-CT at 15–30 cm. pH (8.46), CEC (30.23 Cmol (P^+) kg^{-1}), soil organic carbon (7.8 $g\ kg^{-1}$) were highest in ZT+R-ZT+R and in contrast EC was highest under CT-CT 0.57 $dS\ m^{-1}$. Weed management practices showed non significant effect on physical and physico chemical practices.

Keywords: Conventional tillage, conservation agriculture, residue, weed management, zero tillage

Introduction

Rice (*Oryza sativa* L.), a staple food crop, plays a critical role in global food security, particularly in Asia, where traditional cultivation methods relying on intensive tillage and unregulated weed control have contributed to soil health degradation and biodiversity loss. In India, rice is cultivated on approximately 47.8 million hectares, producing 137.8 million tonnes, while Telangana contributes 2.31 million hectares, producing 8.1 million tonnes at a productivity rate of 3.48 tonnes per hectare (2023–24) (Source: Ministry of Agriculture & Farmers Welfare, Govt. of India. (ON3960)).

Tillage practices significantly influence soil physical and physico-chemical properties such as bulk density, porosity, and organic carbon content. Conventional tillage accelerates the mineralization of soil organic matter (SOM), leading to nutrient loss, especially in sandy soils with limited organic matter protection (Feller and Beare, 1997) [5]. Conversely, zero tillage (ZT), a core component of conservation agriculture, preserves soil structure, enhances moisture retention, and promotes SOM accumulation (Lal, 2004) [15]. Conservation agriculture (CA) is a sustainable farming approach emphasizing minimal soil disturbance, permanent soil cover, and crop diversification to enhance resource efficiency and maintain productivity (Kassam *et al.*, 2009) [13]. However, tillage methods also impact weed control, as intensive tillage manages weeds effectively but risks soil compaction and organic matter depletion, while ZT requires integrated approaches to balance weed management and soil health (Zulu *et al.*, 2022) [27].

Weed management in rice cultivation directly affects productivity and soil health. Conventional chemical herbicide reliance can alter soil microbial activity and leave chemical residues, whereas integrated weed management combines mechanical, chemical, and cultural methods to minimize adverse impacts (Vishwakarma *et al.*, 2017) [23]. The interaction of tillage and weed management practices under CA is critical for improving soil health and ensuring sustainable rice production. This study investigates these interactions to develop practices that enhance soil quality, reduce environmental impacts, and maintain or improve yields, offering a path toward sustainable rice-based systems.

Materials and Methods

Field experiment was conducted at AICRP on Weed Management, College Farm, College of Agriculture, PJTAU, Rajendranagar, Hyderabad situated in Southern Telangana Zone with rice-maize-green manure system during *kharif* season. The experimental field is geographically situated at 17^0 19' 23" North latitude and 78^0 24' 29" East. Soil was sandy clay loam in texture with moderately alkaline pH, low in available N, medium in available P and high in available K.

The experiment was laid out in split plot design with five tillage practices as main plots and three weed management practices as sub-plots replicated thrice. Five tillage treatments consists of T_1-Conventional Tillage (CT)- Conventional Tillage (CT), T_2 - Conventional Tillage (CT)-Zero Tillage (ZT), T_3- Conventional Tillage (CT) (Direct Seeded Rice (DSR))- Conventional Tillage (CT), T_4-Zero Tillage (ZT)- Zero Tillage (ZT) and T_5 - Zero Tillage (ZT)+Residue(R)-Zero Tillage (ZT)+Residue (R). Weed management practices included chemical weed management *i.e.*, W_1-Chemical weed management (Bensulfuron methyl (0.6%) + pretilachlor (6%) 0.66 kg ha^{-1} as Pre Emergence (PE) at 3-5 Days After Transplanting (DAT) *followed by(fb)* bispyribac sodium 10% SC 25g ha^{-1} as Post Emergence (PoE) at 2-3 weed leaf stage for transplanted rice and Pendimethalin 30% EC 1000g ha^{-1} as PE *fb* bispyribac sodium 10% SC 25g ha^{-1} as PoE at 2-3 weed leaf stage for direct seeded rice), W_2-Integrated weed management (IWM) (Bispyribac sodium 10% SC 25 g ha^{-1} as early PoE at 2-3 weed leaf stage *fb* hand weeding at 40 DAT) and W_3-Unweeded control. For residue cover treatments previous season green manure was spread as mulch in between rows of current season crop.

Soil samples were collected from each plot before sowing/transplanting and at harvest of crop. The pH was measured using the glass electrode method (Jackson, 1973) [11], while electrical conductivity (EC) was determined using a conductivity meter (Jackson, 1973) [11]. Soil organic carbon (SOC) was analysed by wet oxidation method as described by Walkley and Black (1965) [24] and Core sampler method by Blake and Hartge (1986) [2] was used to determine Soil bulk density.

Soil aggregate analysis

Soil aggregate analysis was analysed using wet sieving method by Yoder (1936) [25]. Aggregates retained on 4.75 mm sieves were used for analysis after passing soil samples through 8 mm and 4.75 mm sieves. A 50 g retained soil sample was placed on a stack of six sieves (4.75, 2.0, 1.0, 0.5, 0.25, and 0.106 mm), submerged in water for 10 minutes and oscillated at 30–35 cycles per minute for 20 minutes. Aggregates from each sieve were oven-dried at 105°C and weighed. The water-stable aggregates were quantified as percentage aggregation.

The Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD) of aggregates was calculated as:

$$\text{MWD (mm)} = \Sigma X_i \times W_i$$

$$\text{GMD (mm)} = exp\frac{\sum_{i=1}^{n} Wi \log Xi}{\sum_{i=1}^{n} Wi}$$

Where, W_i -Proportion of each aggregate class in relation to the bulk soil and

X_i - mean diameter of the aggregate class (mm).

Soil Penetration resistance (SPR)

SPR was determined at 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-25cm and 25-30cm soil depths by using a proctor penetrometer. About five observations were made per plot at each depth for computing the average SPR (Anderson *et al.*, 1980) [1].

Results and Discussion

Bulk density (BD)

Tillage practices significantly influenced BD in both surface and sub-surface layers. The interaction of tillage and weed management practices on BD was non significant as showed in Table 1. At 0–15 cm, ZT treatments showed higher BD compared to CT. In contrast, CT treatments had higher BD in the 15–30 cm sub-surface layer than ZT treatments. The highest BD in the 0–15 cm layer was recorded under ZT-ZT (1.35 g cm^{-3}), while CT-ZT had the highest BD among CT treatments (1.29 g cm^{-3}). The highest BD in 15-30cm was observed in CT-CT (1.43 g cm^{-3}), followed by CT-ZT (1.41 g cm^{-3}). Weed management practices had no significant impact on BD, with unweeded control showing the highest BD at both depths.

Table 1: Effect of tillage and weed management practices on soil bulk density (g cm^{-3})

Treatments	Before sowing/transplanting of the crop		After harvest of crop	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Tillage practices				
T1 (CT-CT)	1.17	1.43	1.21	1.40
T2 (CT-ZT)	1.24	1.41	1.29	1.38
T3 (CT(DSR)-CT)	1.21	1.34	1.27	1.31
T4 (ZT-ZT)	1.34	1.36	1.35	1.33
T5 (ZT+R-ZT+R)	1.31	1.31	1.33	1.28
CD(*P=0.05*)	0.027	0.010	0.053	0.010
S.E(m)±	0.008	0.003	0.016	0.003
Weed management practices				
W1 -Chemical weed management	1.25	1.36	1.24	1.28
W2 -IWM	1.19	1.34	1.29	1.34
W3- Unweeded control	1.32	1.41	1.35	1.39
CD(*P=0.05*)	NS	NS	NS	NS
S.E(m)±	0.036	0.024	0.030	0.40
T×W	NS	NS	NS	NS

Similarly, Mondal *et al.* (2016) [19] and Manoj kumar *et al.* (2018) [16] also reported the higher BD in ZT treatments. The higher BD at 0-15cm in ZT treatments may be due to absence of tillage, leading to compaction and a lack of porosity (Hobson *et al.*, 2021) [10]. In contrast, CT often causes soil disturbance, breaking up aggregates and increasing pore space, which can reduce BD at the surface. The increased BD in CT at 15–30 cm layer is linked to compaction caused by puddling, which leads to (i) destruction of soil aggregates, (ii) filling of macropores with fine particles, and (iii) direct physical compaction from equipment and trampling (Hobbs and Gupta, 2000) [8]. Maximum soil compaction occurs when soil moisture is near saturation and decreases with reduced moisture content (Panayiotopoulos and Mullins, 1985) [20]. Wet tillage creates favourable conditions for compaction. In contrast, ZT seed drill operations performed in moist soil preserve soil aggregation, resulting in lower compaction and reduced BD compared to CT (puddled) plots.

Soil aggregate analysis

Significant impact of tillage practices was observed on soil aggregate size distribution, stability, and related physical properties. ZT treatments, particularly ZT+R-ZT+R, consistently promoted the formation and stability of larger soil aggregates compared to CT. ZT treatments exhibited a higher proportion of >4.75 mm and 4.75–2.00 mm aggregate size classes, while CT treatments had higher 2.00–0.5 mm and 0.5–0.25 mm fractions (as shown in Table 2 and Figure 1 and 2).

Among ZT treatments, ZT+R-ZT+R recorded the highest percentage of >4.75 mm aggregates (35.1%), while among CT treatments, CT (DSR)-CT had the highest percentage (13.2%). For the 4.75–2.00 mm size class, ZT-ZT (27.1%) and ZT+R-ZT+R (19.3%) showed higher values, whereas CT treatments had lower contributions. In the 2.00–0.5 mm aggregate class, CT-CT recorded the highest percentage (45.3%), and ZT-ZT contributed the least (24.4%). Larger water-stable macro aggregates (WsLMac), geometric mean diameter (GMD), and mean weight diameter (MWD) were significantly higher under ZT treatments, ZT+R-ZT+R having the highest GMD (1.123 mm) and MWD (2.268 mm). CT treatments showed higher water-stable microaggregates (WsMic) and small macroaggregates (WsSMac), with CT-CT recording the highest WsSMac (67.2%).

Weed management had no significant effect on aggregate size distribution or water-stable aggregates. However, unweeded control slightly increased 4.75–2.00 mm and 2.00–0.5 mm aggregates and had higher WsMic (10.4%) and MWD (1.538 mm). Integrated weed management (IWM) showed the highest WsLMac (36.3%) and GMD (0.909 mm). These findings highlight the significant influence of tillage on soil aggregate stability and minimal impact of weed management practices.

The study reinforced the impact of tillage practices on soil structure and aggregate distribution. Intensive tillage disrupts macroaggregates, exposes soil organic matter to microbial decomposition, and increases erosion susceptibility, as reported by Zotarelli *et al.* (2007) [26]. Conventional tillage accelerates aggregate destruction, while puddling in rice compacts soil and hinders root growth. In contrast, reduced tillage practices like zero tillage preserve soil organic carbon, promote aggregate stability, and support long-term soil health. Conservation tillage enhances aggregation, and surface residue retention reduces erosion and protects aggregates from rain impact (Boogar *et al.*, 2014) [3]. Choudhury *et al.* (2014) [4] stated that polysaccharides released during crop residue decomposition act as cementing agents, playing a vital role in macroaggregate formation. These practices underscore the benefits of sustainable tillage systems in maintaining soil health.

Table 2: Effect of tillage and weed management practices on soil aggregate distribution (%), GMD and MWD after harvest of the crop

Treatments	**>4.75 mm**	**4.75-2.00 mm**	**2.00-0.50 mm**	**0.5-0.25 mm**	**<0.25 Mm**	**GMD (mm)**	**MWD (mm)**
	Percent of the aggregate classes						
Tillage practices							
T1 (CT-CT)	9.7	10.3	45.3	21.9	12.8	0.751	0.974
T2 (CT-ZT)	10.6	11.6	41.2	22.3	14.2	0.760	0.923
T3 (CT(DSR)-CT)	13.2	10.6	34.9	28.7	12.6	0.769	1.123
T4 (ZT-ZT)	31.5	27.1	24.4	10.2	6.7	1.122	2.236
T5 (ZT+R-ZT+R)	35.1	19.3	32.5	8.8	4.3	1.123	2.268
CD (*P=0.05*)	2.215	1.885	3.990	3.331	1.355	0.072	0.111
S.E(m)±	0.669	0.648	1.205	1.006	0.409	0.022	0.034
Weed management practices							
W1 -Chemical weed management	19.3	15.9	35.7	18.6	10.4	0.899	1.495
W2 -IWM	20.7	15.6	35.4	18.8	9.5	0.909	1.482
W3- Unweeded control	20.1	15.9	35.8	17.7	10.4	0.908	1.538
CD (*P=0.05*)	NS	NS	NS	NS	NS	NS	NS
S.E(m)±	0.550	0.502	0.774	0.512	0.493	0.013	0.035
T×W	NS	NS	NS	NS	NS	NS	NS

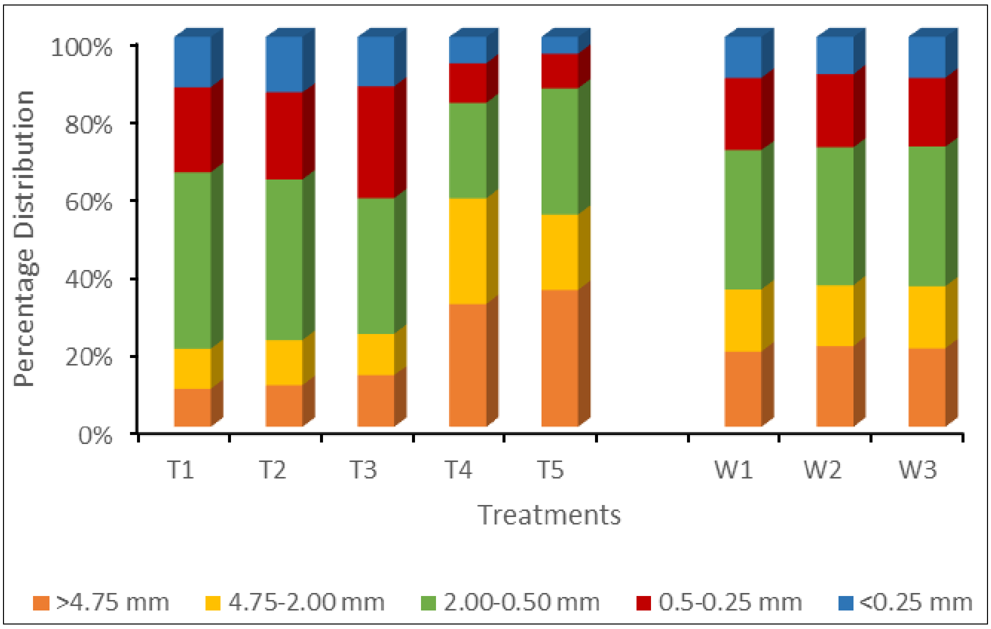
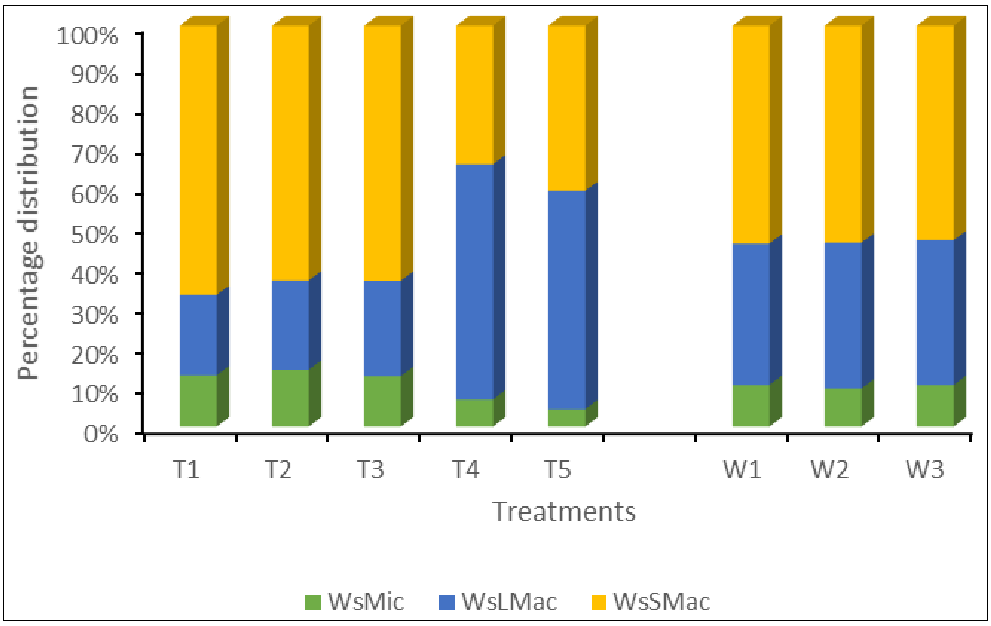


Fig 1: Effect of tillage and weed management practices on soil aggregate distribution (%) after the harvest of crop



WsLMac (%)>4.75 mm & 2.00 mm to 4.75 mm sized aggregates, WsSMac >0.25 mm and < 2 mm sized aggregates, WsMic -<0.25 mm sized aggregate

Fig 2: Effect of tillage and weed management practices on water-stable aggregates (WsMic, WsLMac and WsSMac) after the harvest of crop

Soil Penetration Resistance (SPR)

SPR was significantly influenced by tillage, while weed management showed no significant impact. In surface layers (0–10 cm), ZT treatments exhibited higher SPR, with ZT+R-ZT+R recording the highest values (1.28 MPa at 0–5 cm and 1.32 MPa at 5–10 cm). In subsurface layers (10–30 cm), CT treatments showed higher SPR, with CT-CT recording the highest values at 15–20 cm (2.06 MPa), 20–25 cm (2.52 MPa), and 25–30 cm (2.56 MPa). ZT treatments consistently showed lower SPR in subsurface layers.

Among the weed management practices, unweeded control (1.02 MPa) recorded the highest SPR value followed by IWM (0.97M Pa) and chemical weed management practice (0.89 M Pa) recorded lowest value in 0-5 cm. A similar trend was observed at all depths (5-10, 10-15, 15-20, 20-25 and 25-30 cm).

Jug *et al.* (2024) [12] stated that conventional tillage practices, including repeated tillage and puddling, can lead to increased SPR in subsurface layers due to soil compaction, which may hinder root penetration and water infiltration. The present study also aligns with findings by Gathala *et al.* (2011) [6], who reported that intensive tillage disrupts soil aggregates and increases compaction, leading to higher SPR. Conservation tillage enhances soil health by conserving water, reducing environmental footprints, and minimizing soil disturbance, thereby maintaining lower SPR and preserving soil structure. Adopting conservation tillage practices helps to maintain soil integrity and promote sustainable agricultural systems.

Table 3: Effect of tillage and weed management practices on soil penetration resistance (M Pa) after harvest of crop

Treatments	0-5 cm	5-10 cm	10-15 cm	15-20 cm	20-25 cm	25-30 cm
Tillage practices						
T1(CT-CT)	0.73	1.11	1.42	2.06	2.52	2.56
T2(CT-ZT)	0.78	1.13	1.35	1.82	2.45	2.49
T3(CT(DSR)-CT)	0.85	1.14	1.52	1.54	1.62	1.62
T4(ZT-ZT)	1.18	1.25	1.43	1.46	1.57	1.64
T5(ZT+R-ZT+R)	1.28	1.32	1.44	1.49	1.60	1.63
CD($P=0.05$)	0.167	0.108	0.100	0.121	0.112	0.149
S.E(m)±	0.050	0.033	0.030	0.037	0.034	0.045
Weed management practices						
W1 -Chemical management	0.89	1.11	1.35	1.63	1.89	1.91
W2 -IWM	0.97	1.19	1.44	1.70	1.99	2.00
W3- Unweeded control	1.02	1.27	1.50	1.74	2.05	2.06
CD($P=0.05$)	NS	NS	NS	NS	NS	NS
S.E(m)±	0.042	0.041	0.044	0.029	0.042	0.040
T×W	NS	NS	NS	NS	NS	NS

Soil physico-chemical properties

Soil physico-chemical properties, including pH, EC, and CEC, were not significantly influenced by tillage or weed management practices.

Soil pH was highest under ZT+R-ZT+R (8.46), followed by ZT-ZT (8.42), and lowest under CT-ZT (8.32). The higher soil pH under ZT+R-ZT+R and ZT-ZT was due to reduced soil disturbance, which minimizes the oxidation of soil organic matter and the subsequent release of hydrogen ions that lower pH. Residue retention under ZT+R-ZT+R may also contribute to increased decomposition of organic residues, releasing basic cations such as calcium, magnesium, and potassium, which can buffer soil acidity and increase pH. Conversely, CT-ZT recorded the lowest pH (8.32), likely due to enhanced oxidation and acidification from repeated soil tillage (Lal, 2004) [15].

The highest EC in CT-CT(0.57) and the lowest in ZT+R-ZT+R (0.50). Redistribution of soluble salts within the soil profile. Tillage operations can disrupt soil structure, leading to the upward movement of salts and increased EC in surface layers. On the other hand, reduced disturbance in ZT systems helps stabilize salt distribution, maintaining a lower EC. Additionally, residue retention under ZT may improve water infiltration and leaching, further reducing salt accumulation at the surface (Hobbs *et al.*, 2008) [9].

ZT+R-ZT+R recorded the highest CEC (30.23 (Cmol(P+) kg-1)), attributed to increased SOC, which enhances the availability of exchange sites for cations. Organic matter decomposition from retained residues under ZT+R-ZT+R likely played a key role in increasing SOC levels and, subsequently, the soil's capacity to retain essential nutrients. In contrast, CT practices recorded the lowest CEC (28.94 (Cmol(P+) kg-1)), as tillage accelerates organic matter decomposition and disrupts aggregate stability, reducing SOC and exchange capacity (Six *et al.*, 2000) [21]. Kumar *et al.* (2018) [14] reported a 10.3% increase in CEC with residue incorporation under zero tillage compared to conventional tillage.

Over five years of experimentation, different tillage practices significantly influenced soil organic carbon (SOC) content, while weed management practices had no significant effect (Table 4). SOC was highest under ZT+R-ZT+R (7.80 g kg^{-1}), followed by ZT-ZT (7.38 g kg^{-1}), and lowest under CT (DSR)-CT (5.57 g kg^{-1}). Among weed management practices, unweeded control showed higher SOC. Higher SOC was observed under zero tillage (ZT) compared to conventional tillage (CT), as conservation agriculture typically retains more SOC due to reduced soil disturbance, residue retention, and improved aggregation, as noted by Mohanty *et al.* (2015) [18]. Haddaway *et al.* (2017) [7] further concluded that reduced and no-tillage practices contribute to SOC preservation by minimizing soil disturbance, thus enhancing overall soil quality. Zero tillage (ZT), improve soil carbon content by maintaining soil structure and reducing erosion (Steponavičienė *et al.*, 2024) [22]. In contrast, conventional tillage (CT) disrupts soil aggregates, accelerates organic matter oxidation, and reduces SOC levels. Additionally, puddled soils experience further SOC loss due to chemical changes and limited oxygen availability in flooded condition (Mihelic *et al.*, 2024) [17].

Table 4: Effect of tillage and weed management practices on soil physico-chemical properties before sowing and after harvest of crop

Treatments	Before sowing/transplanting of crop				After harvest of crop			
	pH	EC (dS m^{-1})	CEC (Cmol(P+) kg^{-1})	Organic carbon (g kg^{-1})	pH	EC (dS m^{-1})	CEC (Cmol(P+) kg^{-1})	Organic carbon (g kg^{-1})
Tillage treatments								
T1 (CT-CT)	8.37	0.6	28.75	5.65	8.38	0.57	28.94	5.78
T2 (CT-ZT)	8.32	0.58	28.81	6.45	8.34	0.55	29.02	6.83
T3 (CT(DSR)-CT)	8.38	0.57	28.57	5.40	8.4	0.51	29.42	5.57
T4 (ZT-ZT)	8.42	0.55	29.8	7.06	8.46	0.53	30.11	7.38
T5 (ZT+R-ZT+R)	8.46	0.56	30.04	7.55	8.51	0.5	30.23	7.80
CD($P=0.05$)	NS	NS	NS	0.321	0.039	NS	NS	0.324
S.E(m)±	0.031	0.015	0.444	0.097	0.012	0.01	0.472	0.098
Weed management practices								
W1-chemical weed management	8.41	0.6	27.96	6.40	8.45	0.55	29.05	6.41
W2-IWM	8.37	0.57	29.32	6.20	8.41	0.53	29.65	6.75
W3-Unweeded control	8.38	0.55	30.31	6.60	8.41	0.52	29.93	6.86
CD($P=0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
S.E(m)±	0.017	0.015	0.66	0.209	0.017	0.009	0.375	0.14
T×W	NS	NS	NS	NS	NS	NS	NS	NS

Conclusion

The study demonstrates that adopting ZT over five years significantly enhanced soil physical, physicochemical, and chemical properties. ZT treatments showed higher soil bulk density and soil penetration resistance due to reduced tillage and subsurface compaction. Soil aggregation improved under ZT compared to conventional tillage, primarily due to crop residue retention. Weed management practices had no notable effect on soil physical or physicochemical properties. Zero tillage with residue retention notably increased soil organic carbon in the 0–15 cm layer compared to CT, as conservation agriculture practices such as minimal soil disturbance and residue retention reduced oxidation and enhanced carbon retention. These findings highlight conservation agriculture ability to improve SOC and soil health, supporting sustainable land management practices.

References

1. Anderson G, Pidgeon JD, Spencer HB, Parks R. A new hand-held recording penetrometer for soil studies. J Soil Sci. 1980;31(2):279-296.
2. Blake GR, Hartge KH. Bulk density. In: Methods of soil analysis: Part 1 Physical and mineralogical methods. 1986;5:363-375.
3. Boogar AM, Jahansouz MR, Reza M. Soil aggregate size distribution and stability following conventional-till, minimum-till and no-till systems. Int J Far Allied Sci. 2014;3:512-517.
4. Choudhury SG, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK, *et al*. Tillage and residue management effects on soil aggregation, organic carbon dynamics, and yield attribute in rice–wheat cropping system under reclaimed sodic soil. Soil Till Res. 2014;136:76-83.
5. Feller C, Beare MH. Physical control of soil organic matter dynamics in the tropics. Geoderma. 1997;79(1-4):69-116.
6. Gathala MK, Ladha JK, Saharawat YS, Kumar V, Kumar V, Sharma PK. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice–wheat rotation. Soil Sci Soc Am J. 2011;75(5):1851-1862.
7. Haddaway NR, Hedlund K, Jackson LE, Kätterer T, Lugato E, Thomsen IK, *et al*. How does tillage intensity affect soil organic carbon? A systematic review. Enviro Evidence. 2017;6:1-48.
8. Hobbs PR, Gupta RK. Sustainable resource management in intensively cultivated irrigated rice-wheat cropping systems of Indo-Gangetic plains of South Asia: Strategies and adoption. In: Singh AK, editor. Proc. of the Int. Conf on managing natural resources for sustainable production in 21st century. New Delhi, India: J Indian Soc Soil Sci; 2000. p. 584-592.
9. Hobbs PR, Sayre K, Gupta R. The role of conservation agriculture in sustainable agriculture. Philos Trans R Soc B Biol Sci. 2008;363(1491):543-555.
10. Hobson D, Harty M, Tracy S, McDonnell K. The effect of tillage depth and traffic management on soil properties and root development during two growth stages of winter wheat (*Triticum aestivum* L.). SOIL Discuss. 2021:1-32.
11. Jackson ML. Soil chemical analysis: An advanced course. 2nd ed. Madison (WI): University of Wisconsin; 1973.
12. Jug D, Jug I, Radočaj D, Wilczewski E, Đurđević B, Jurišić M, *et al*. Spatio-temporal dynamics of soil penetration resistance depending on different conservation tillage systems. Agronomy. 2024;14(9):2168.
13. Kassam A, Friedrich T, Shaxson F, Pretty J. The spread of conservation agriculture: justification, sustainability and uptake. Int J Agri Sust. 2009;7(4):292-320.
14. Kumar V, Naresh RK, Satendra Kumar SK, Sunil Kumar V, Singh SP, Mahajan NC. Tillage, crop residue, and nitrogen levels on dynamics of soil labile organic carbon fractions, productivity, and grain quality of wheat crop in Typic Ustochrept soil. J Pharmacogn Phytochem. 2018;7(1):598-609.
15. Lal R. Soil carbon sequestration to mitigate climate change. Geoderma. 2004;123(1-2).
16. Manoj Kumar, Verma SK, Priyadarshani A, Khambalkar A, Arora A, Singh N. Influence of tillage practices and weed control methods on organic carbon pools and physical properties of sandy clay loam soil in North Central India. Int J Chem Stud. 2018;6(6):1699-1705.
17. Mihelič R, Pintarič S, Eler K, Suhadolc M. Effects of transitioning from conventional to organic farming on soil organic carbon and microbial community: a comparison of long-term non-inversion minimum tillage and conventional tillage. Biol Fertil Soils. 2024;60(3):341-355.
18. Mohanty SK, Singh AK, Jat SL, Parihar CM, Pooniya V, Sharma S, *et al*. Precision nitrogen management practices influence growth and yield of wheat (*Triticum aestivum*) under conservation agriculture. Indian J Agronomy. 2015;60(4):617-621.
19. Mondal S, Kumar S, Haris A, Dwivedi S, Bhatt B, Mishra J. Effect of different rice establishment methods on soil physical properties in drought-prone rainfed lowlands of Bihar, India. Soil Res. 2016;54:997-1006. doi:10.1071/SR15346.
20. Panayiotopoulos KP, Mullins CE. Packing of sands. J Soil Sci. 1985;7(6):129-139. doi:10.1111/j.1365-2389.1985.tb00318.x.
21. Six J, Feller C, Denef K, Ogle SM, de Moraes Sa JC, Albrecht A. Soil organic matter, biota, and aggregation in temperate and tropical soils—effects of no-tillage. Agronomy. 2000;220(3-4):137-149.
22. Steponavičienė V, Žiūraitis G, Rudinskienė A, Jackevičienė K, Bogužas V. Long-term effects of different tillage systems and their impact on soil properties and crop yields. Agronomy. 2024;14(4):870.
23. Vishwakarma AK, Wanjari RH, Gopal R. Weed management in conservation agriculture: A brief review. J Pharmacogn Phytochem. 2017;6(6S):502-506.
24. Walkley A, Black CA. Estimation of organic carbon by chromic acid titration method. Soil Sci. 1934;37:29-38.
25. Yoder RE. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. J Am Soc Agron. 1936;28:337-351.
26. Zotarelli L, Alves BJR, Urquiaga S, Boddey RM, Six J. Impact of tillage and crop rotation on light fraction and intra-aggregate soil organic matter in two Oxisols. Soil Till Res. 2007;95(1-2):196-206.
27. Zulu SG, Magwaza LS, Motsa NM, Sithole NJ, Ncama K. Long-term no-till conservation agriculture and nitrogen fertilization on soil micronutrients in a semi-arid region of South Africa. Agronomy. 2022;12(6):1411.