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A Study on Physio-chemical Changes in Soil as Influenced by Tillage and Crop Residue Management

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ABSTRACT: Tillage, undoubtedly, is one of the most crucial practices to ameliorate crop productivity and maintain soil health. The study was conducted at ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh. The experiment was laid out in split-plot design with three tillage systems (reduced tillage [RT], no-tillage [NT] with crop residue retention, and conventional tillage [CT] without residue), and four cropping systems: soybean + pigeon pea (2:1), soybean–wheat, maize + pigeon pea (1:1), and maize–chickpea. The soil samples were collected from 0-10, 10-20, 20-30 cm soil layer in 2022. The findings indicated that tillage had significant effect on soil bulk density and available water content after harvest of crop at 5% level of significance. RT reported maximum improvement in soil bulk density (1.13 Mg m^{-3}) at surface layer of 0-10 cm. Available water content, after harvesting the crop registered higher values under CT system (13.83%) compared to RT (13.4%) and NT (12.34%). Additionally, soil pH and electrical conductivity had no impact of tillage cropping system and soil depth. The interaction effects were also found no significant ($p<0.05$). Thus, continuous CA has been suggested for maximum improvement in soil properties.

Keywords: Tillage, soil properties, residue management, bulk density, available water.

INTRODUCTION

Intensity of tillage operations play crucial role in modifying the physical and chemical characteristics of soil. The prudent application of tillage techniques overcomes edaphic limitations, while inappropriate tillage can result in a number of unfavourable effects, such as the breakdown of soil structure, increased erosion, loss of organic matter and fertility, and disturbance of water, organic carbon, and plant nutrient cycles (Alam *et al*., 2014; Hati *et al*., 2021). No-tillage with surface residue, increases water infiltration, holds soil moisture and helps to prevent topsoil erosion, allows for more stable yields in the midst of weather extremes exacerbated by climate change (Verhulst *et al*., 2010; Kumar and Babalad 2018). The additional sources of organic matter help in improving soil structure, nutrient recycling and mobilize them in the soil profile in order to make them more readily available to the crops (Khursheed *et al*., 2019; Somasundaram *et al*., 2020; Roy *et al*., 2022). Conversely, frequent tilling compacts the soil and creates a hardpan layer beneath the plow layer alters the bulk density and moisture content of the soil. The combined use of minimum (RT) or no tillage (NT) with permanent soil cover and diversified crop species that include legumes together increase crop yields by enhancing several regulating and supporting ecosystem services.

Although significant research has been conducted on the effects of tillage practices and crop residue management on soil health, several knowledge gaps still exist that need to be addressed for a more comprehensive understanding. Soil types, climate conditions, and agricultural practices vary widely, and how tillage and crop residue management influence physio-chemical changes in soil across diverse ecosystems remains important. Soil reaction and soluble salts play a critical role in nutrient cycling and soil health; there is insufficient research on how different tillage and residue management practices affect soil activity. Much of the existing research is based on specific regions or soil types, and there is a need for studies that address regional variability.

MATERIALS AND METHODS

This study was conducted at ICAR-Indian Institute of Soil Science (ICAR-IISS), Bhopal, Madhya Pradesh, India (23° 18′N, 77°24′E). It is situated in the semi-arid region, an elevation of 485 m above sea level with average annual rainfall of 1133 mm, average air temperature of 25°C, and potential evapotranspiration of 1400 mm throughout the year. The soil was deep clayey vertisol, belonging to the montmorillonitic Isohyperthermic family of Typic Haplustert. The experiment included three tillage and four cropping systems with residue management. The experiment was carried out in a split plot design, with three replications. The tillage system involves conventional tillage (CT), reduced tillage (RT) and no-tillage (NT). In CT, 3-4 tillage operations are performed using a duck foot cultivator, a tins cultivator, or sweep tillage/planting, with residue burned during *Kharif*. For RT, one sweep tillage followed by sowing or planting, with more than 30% of residue retention. In NT plots direct sowing, with more than 30% residue retained on the field. The four cropping systems were {soybean (*Glycine max* L.) + pigeon pea (*Cajanus cajan* L.) (2:1), Soybean-wheat (*Titricum durum* L.), Maize (*Zea mays* L.) + pigeon pea (1:1), and Maize-chickpea (*Cicer arietinum* L.)}. Each allotment was 10 m × 5 m. Plots were separated by a buffer zone of 5 meters. All the necessary management practices were performed well in terms of nutrient, water, weed, and pest control. The nutrients were mostly supplied by urea (46% N), di-ammonium phosphate (18% N and 46% P), and muriate of potash (MoP: 60% K). Fertiliser doses of 30:26.4:24.9 for soya bean, 30:26.4:24.9 for pigeon pea, 120:24.6:33.2 for wheat, maize, and 40:26.4:24.9 for chickpea were applied to the soil throughout each cropping season.

Soil samples were collected from 0-10, 10-20 and 20-30 cm soil depth after ten years of establishment in June, 2021 from middle in each plot. The samples were air-dried and crushed through a wooden hammer, passed through 2 mm sieve, and stored in plastic jars for analyzing soil pH, electrical conductivity and available water content. Soil pH and electrical conductivity (dSm^{-1}) were estimated by diluting the soil with distilled water in 1:2.5 and instantly taking the readings for pH using pH meter (Piper, 1950). The solution was allowed to rest to settle down completely and have a clear supernatant. The EC was recorded using conductivity meter (Black, 1965). Soil bulk density ($Mg\ m^{-3}$) of the soil was measured by the core method (Blake and Hartge 1986). Pressure plate apparatus was used to estimate moisture content at field capacity, permanent wilting point at different pressure (Richards and Fireman 1943). The data were subjected to analysis of variance (ANOVA) using Agricola package of the RStudio (Version 4.2.2).

RESULT AND DISCUSSION

A. Effect of tillage on soil pH

The tillage system had no significant effect on pH at 0-10, 10-20 and 20-30 cm soil depth (Fig. 1). There was a general trend of decreasing soil acidity with increasing depth from 0-10 cm to 20-30 cm. The results shows that reduced and no-tillage resulted higher soil pH compared to conventional tillage. At 0-10 cm soil depth, lowest soil pH (7.83) was recorded under CT at par with RT (7.96). Similarly, at the 10-20 cm depth, RT again reported highest active acidity (8.01) followed by NT (7.84) and CT (7.79). Similar trend was found for 20-30 cm soil depth. Further, cropping systems also indicated no significant influence on soil activity. The increase in soil pH due to addition of crop residue have been observed in other studies, probably due to decarboxylation of organic anions and release of OH^- or high concentrations of basic cations such as Ca, Mg, and K, released during the decomposition of plant residue. Butterly *et al*. (2013); Husson *et al.* (2018) also reported that conservation practices can enhance soil alkalinity and overall health. Umar *et al*. (2011); Diuker and Beegle (2006) suggested that upward changes in soil pH to the buffering effect of accumulated soil organic matter.

B. Effect of tillage on soil EC (dSm^{-1})

The result shows that tilling the soil with different intensities and frequencies had no influence on electrical conductivity of soil (Fig. 2). The surface soil layer of 0-10 cm registered higher EC (dSm^{-1}) which further decreased at 10-20 cm depth and increased at 20-30 cm soil depth. Reduced tillage resulted in lower (0.17, 0.16 and 0.17 dSm^{-1}, respectively) conductivity compared to other tillage. At 0-10 and 10-20 cm soil depth, similar higher (0.18 and 0.17 dSm^{-1}, respectively) electrical conductivity was recorded under no-tillage and conventional tillage. CT exhibited the highest EC at 20-30 cm soil depth. In addition to tillage system cropping systems also had no impact on electrical conductivity of soil. According to Kumar *et al*. (2017) tillage system influence soil properties suggested that the variations may be attributed to seasonal changes in rainfall, temperature, and other environmental factors affecting soil moisture and nutrient leaching, thereby impacting EC.

C. Effect of tillage on soil bulk density ($Mg\ m^{-3}$)

The results revealed that BD was significantly different under tillage system at varying soil depths (Table 1 and Fig. 3). Mean BD values varied from 1.14 to 1.26, 1.10 to 1.25 and 1.08 to 1.30 $Mg\ m^{-3}$ under CT, RT and NT, respectively. The lowest soil bulk density (1.13 $Mg\ m^{-3}$) was recorded under RT at the surface, 0-10 cm depth. There was a general trend of increasing soil bulk density across all cropping systems and tillage practices as depth increased. For 10-20 and 20-30 cm soil depth, NT displayed the highest BD (1.24 and 1.26 $Mg\ m^{-3}$) followed by CT. For, cropping systems, no significant variation in bulk density were observed. The lowest bulk density in soybean + p. pea (2:1) under reduced tillage (1.14 $Mg\ m^{-3}$), while the highest was found in the same under no-tillage (1.26 $Mg\ m^{-3}$). Higher bulk density under NT due to the lack of soil disturbance which leads to gradual compaction were documented by many researchers (Schwen *et al*., 2011; Vyas *et al*., 2013; Somasundaram *et al.*, 2019). In addition, lower BD under RT at the surface soil suggests that reducing tillage enhances soil structure and reduces compaction in the uppermost soil layer, likely due to better incorporation of organic matter and reduced mechanical pressure. The general increase in BD with soil depth was also reported by Jat *et al*. (2018); Choudhary *et al*. (2018). Further, continuous use of conservation agriculture (CA) practices reduces BD over extended periods (Muchabi *et al*., 2014; Bhattacharyya *et al*., 2009).

D. Effect of tillage on Available water content (%, wt/wt)

The findings stated significant difference in available water content under tillage system at various soil depths (Table 2 and Fig. 4). At 0-10 cm depth, CT reported highest available water content (13.83%), at par with RT (13.40%) after harvest of crop. However, lowest available water content (12.34%) was reported under NT. Similarly, at 10-20 cm and 20-30 cm soil layers CT had higher available water over RT and NT, decreased with increasing soil depth. In contrast to tillage, cropping systems had no significance on available water. The interactions of tillage and cropping system (T×CS), tillage and depth (T×D), cropping system and depth (CS×D) and among tillage, cropping system and soil depth (T×CS×D) had significant effect on available water. Our research findings corroborated with Bekele (2020), reported higher soil moisture in NT and RT at the time of sowing and in the early stages of vegetation lowered as time progressed. Lili *et al.* (2023) also reported significant increase in water content under CT in the tillage layer.

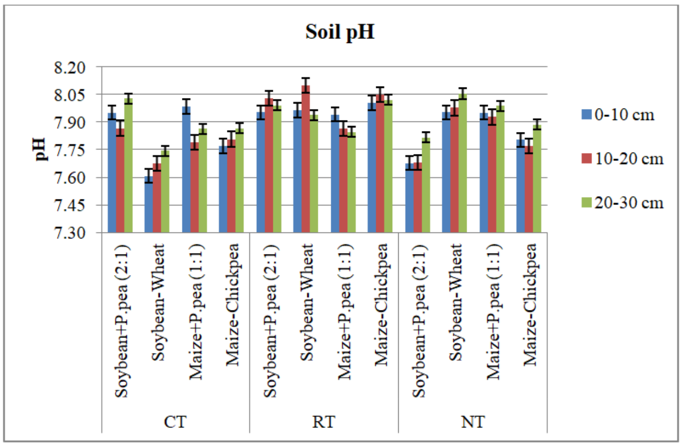

Fig. 1. Effect of tillage and residue management on soil pH under different cropping system at different soil depth.

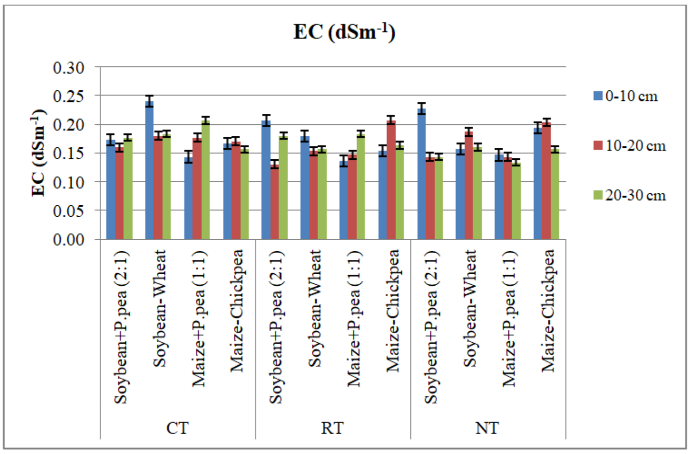

Fig. 2. Effect of tillage and residue management on soil EC (dSm^{-1}) under different cropping system at different soil depth.

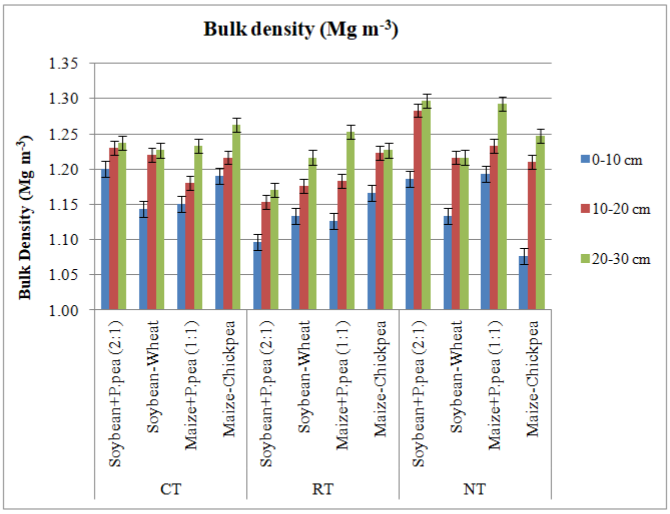

Fig. 3. Effect of tillage and residue management on soil bulk density (Mgm^{-3}) under different cropping system at different soil depth.

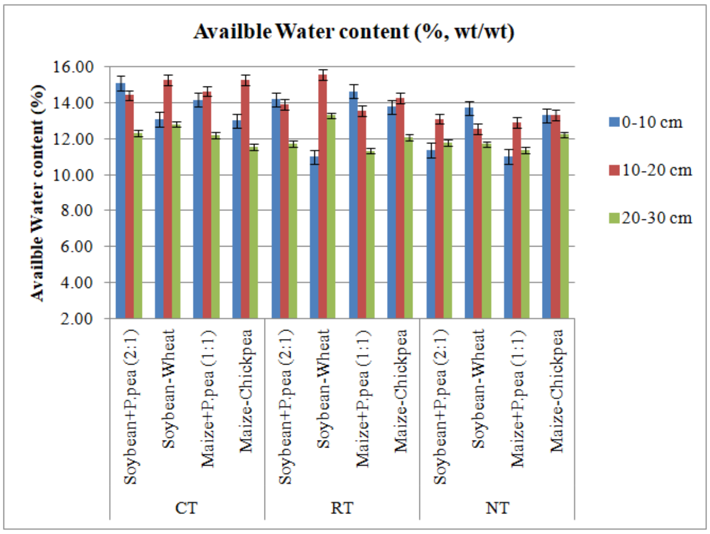

Fig. 4. Effect of tillage and residue management on available water content (%, wt/wt) under different cropping system at different soil depth.

Table 1: Effect of tillage and residue management on bulk density (Mg m^{-3}) under different cropping system at different soil depth.

Tillage	**Cropping System**	**Bulk density (Mg m^{-3}) Soil depth (cm)**		
		0-10	**10-20**	**20-30**
Conventional tillage	Soybean+ Pigeon pea (2:1)	1.20	1.23	1.24
	Soybean -Wheat	1.14	1.22	1.23
	Maize + Pigeon pea (1:1)	1.15	1.18	1.23
	Maize – Gram	1.19	1.22	1.26
	Mean	**1.17**	**1.21**	**1.24**
Reduced tillage	Soybean+ Pigeon pea (2:1)	1.10	1.15	1.17
	Soybean -Wheat	1.13	1.18	1.22
	Maize + Pigeon pea (1:1)	1.13	1.18	1.25
	Maize – Gram	1.17	1.22	1.23
	Mean	**1.13**	**1.18**	**1.22**
No-tillage	Soybean+ Pigeon pea (2:1)	1.19	1.28	1.30
	Soybean -Wheat	1.13	1.22	1.22
	Maize + Pigeon pea (1:1)	1.19	1.23	1.29
	Maize – Gram	1.08	1.21	1.25
	Mean	**1.15**	**1.24**	**1.26**
	Grand Mean	1.15	1.21	1.24
Tillage System(T)	*			
Cropping system(CS)	**NS**			
Soil depth(D)	***			
T × CS	***			
T × D	**			
CS × D	*			
T × CS × D	*			
LSD $_{TS (0.05)}$	**0.02**			
LSD $_{CS (0.05)}$	**0.02**			
LSD $_{D (0.05)}$	**0.01**			

'.' Significant at 10% level; *Significant at 5% level; **Significant at 1% level; ***Significant at 0.1% level

Table 2: Effect of tillage and residue management on available water (%, wt/wt) content under different cropping system at different soil depth.

Tillage	Cropping System	Available water (%, wt/wt) Soil depth (cm)		
		0-10	**10-20**	**20-30**
Conventional tillage	Soybean+ Pigeon pea (2:1)	15.09	14.41	12.30
	Soybean -Wheat	13.08	15.26	12.81
	Maize + Pigeon pea (1:1)	14.17	14.64	12.20
	Maize – Gram	12.99	15.25	11.53
	Mean	**13.83**	**14.89**	**12.21**
Reduced tillage	Soybean+ Pigeon pea (2:1)	14.19	13.93	11.71
	Soybean -Wheat	10.99	15.55	13.29
	Maize + Pigeon pea (1:1)	14.65	13.53	11.33
	Maize – Gram	13.77	14.28	12.06
	Mean	**13.40**	**14.32**	**12.10**
No-tillage	Soybean+ Pigeon pea (2:1)	11.36	13.11	11.78
	Soybean -Wheat	13.71	12.53	11.69
	Maize + Pigeon pea (1:1)	10.99	12.91	11.35
	Maize – Gram	13.30	13.33	12.23
	Mean	**12.34**	**12.97**	**11.76**
	Grand Mean	**13.19**	**14.06**	**12.02**
Tillage System(T)	**			
Cropping system(CS)	**NS**			
Soil depth(D)	***			
T × CS	**NS**			
T × D	**			
CS × D	**			
T × CS × D	***			
LSD $_{TS (0.05)}$	**0.49**			
LSD $_{CS (0.05)}$	**0.66**			
LSD $_{D (0.05)}$	**0.32**			

'.' Significant at 10% level; *Significant at 5% level; **Significant at 1% level; ***Significant at 0.1% level

CONCLUSIONS

In conclusion, the study highlights the significant impact of tillage and residue management on soil bulk density and available water content. These factors were found to play a crucial role in influencing soil structure and moisture retention, which are vital for crop growth and soil health. However, the study also revealed no significant effect on soil pH and electrical conductivity, suggesting that these factors may not be as responsive to changes in tillage practices and residue management. These findings emphasize the importance of appropriate tillage and residue management strategies in optimizing soil physical properties while maintaining stable soil chemical conditions.

FUTURE SCOPE

Future studies could explore the long-term effects of various tillage and residue management practices on soil health and crop productivity, including their potential to improve soil fertility and resilience to climate change. Research could also investigate the combined impact of different tillage systems with varying residue management strategies across diverse soil types and climatic conditions to develop region-specific recommendations.

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Conflict of Interest. None.

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