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Impact of Tillage and Residue Management on Hydro-physical Properties of Clay Soil under Rice-wheat Cropping System in Indo-Gangetic Plains of India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SS designed the study and wrote the first draft of the manuscript. Author RK wrote the protocol, managed the editing of the manuscript and performed statistical analysis. Authors YKS and SKM managed the literature searches and analyses of study. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment on the residual impact of tillage operations and organic residues incorporation on hydro-physical properties of clay soil under the rice-wheat cropping system in split-plot design with three replications was carried out at the experimental farm of BAU, Sabour. The treatments of tillage operations and application of organic residues, along with their interactions, significantly decreased the soil strength/compaction and consequently bulk density of the soils over control. It was confirmed by the positive and highly significant correlation of soil strength with the bulk density (r = 0.802**). The maximum decrease was noted under T_3 (Mould board plough) and C_6 (GM + rice husk) and their interactions. A significant decrease in clod size was observed under treatments T_3 and C_6 and their interactions over control. The maximum increase in stable water-stable aggregates was estimated under treatments T_3 and C_6 and their interactions (T_3 x C_6) due to an increase in

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porosity and decrease in compaction of the soils which led to increasing in hydraulic conductivity. This was further confirmed by a positive and highly significant correlation of hydraulic conductivity with MWD (r = 0.788**) and negatively and highly significant correlation with compaction (r = -0.646**) and BD (r = -0.846**). It was revealed that the soil moisture content showed a variable increase with variable depth and observed their maximum values in T_4 (28%) and C_6 (29%) treatments at 45-60 cm depth of the soils. The increase in yield of wheat grain was highest under the influence of treatments (MB) T_3 and C_6 (GM + rice husk) and their interaction. These observations were further confirmed by the positive and highly significant correlation of yield of wheat grain with MWD (r = 0.514*) and HC (r = 0.482*) and negative and highly significant correlation with soil strength (r = -0.649**). The most effective treatments were T_3 and C_6 and their interactions, while minimum improvements were noted under T_1 (desi plough) and C_3 (paddy straw) and their interactions.

Keywords: Inceptisols; residue management; tillage; soil hydro-physical properties; rice; wheat.

1. INTRODUCTION

Rice–wheat cropping is dominant in the alluvial tract of Indo-Gangetic plains in South Asian countries like India, Pakistan, Nepal and Bangladesh, due to high productivity and profitability. Because of deteriorating, physical and hydraulic properties, and low organic carbon content of the soil under increasing intensification, the present productivity potential of the rice–wheat cropping system in this region is under threat. With decreasing per capita land area (currently <0.1 ha), the risk of degradation has greatly increased, posing a severe challenge to soil management for resource conservation, especially sustainable soil use [1,2,3].

Residue management systems improve soil quality by increasing soil organic carbon, fungal biomass, earthworm populations, and microbial enzyme activity [4,5,6]. Crop residues absorb rainfall energy, reduce splash effect, and prevent soil surface from crusting or sealing [7,8] and increase organic matter. An increase in organic matter improves aggregation, water-holding capacity, hydraulic conductivity, total porosity, resistance to water and wind erosion, and lowers bulk density and the degree of compaction [9, 10]. Organic carbon is responsible for 70 to 90% of the variability in water-stable aggregates in a clay loam soil [11]. Breakdown of soil aggregates and consequent poor soil structure often restrict plant root growth and consequently limit their ability to explore the soil profile for water and nutrients [12]. Organic matter retains water and helps soil particles to bind and resist against soil compaction. Preserving an adequate amount of organic matter in the soil stabilizes soil structure and makes the soil more resistant to degradation [13].

Population growth and unscientific land utilization incompatible with its carrying capacity have accelerated the process of land degradation in the country. Crop yield may vary significantly within a field due to natural variability (soil, topography), random variability (rainfall, wind), and soil management (soil tillage, seeding, fertilization).

The beneficial effects of reduced tillage on aggregate stability, soil C sequestration, and reduction in bulk density, have been widely reported [14,15,16]. The net effect of any tillage system depends on the integration of the system itself in relation to crop rotation and residue management. Indeed, surface residues accumulated due to any tillage were shown to promote higher soil organic C, microbial biomass N and C, potential N mineralization, and total N [17]. Incorporation of plant residues, coupled with appropriate tillage, increases soil organic carbon and if used as mulch, modifies soil temperature [18,19]. Tillage and crop residue management can influence soil physical properties as a direct result of altering the soil physical matrix or indirectly by altering surface energy partitioning, microbial activity, and soil chemical composition.

Thus, different tillage systems can change the number, shape, continuity, and size distribution of the pore network, which controls the ability of soil to store and transmit water and regulate aeration. In contrast, its influence on soil bulk density is variable. Therefore, the intent of this study was to document the residual impact of tillage and residue management on hydro-physical properties of clay soil under the rice-wheat cropping system.

2. MATERIALS AND METHODS

A field experiment was conducted during 2010-2012 to study the residual impact of tillage and residues under the paddy-wheat cropping system with wheat as a test crop (Tables 1 and 2). The experimental site is situated 25°15'40" North latitude and 87°21'42" East longitude with an altitude of 45.75 m above MSL (mean sea level). The sub-tropical climate of the area is characterised by desiccating summer and moderate rainfall. The total rainfall during the crop period was 78.6 mm. The distribution pattern of rainfall during the early period of crop growth was nil. The soil of experimental site was clay in texture with pH 8.3, EC 0.38 dSm^{-1} at 25°C, organic carbon 0.58 per cent, available nitrogen 311 kg/ha, available P_2O_5 36 kg/ha and available K_2O 205 kg/ha as estimated by alkaline $KMnO_4$, Olsen method, and neutral normal NH_4OAc, respectively and bulk density 1.48 Mg/m^3 by weight. Bulk density, hydraulic conductivity, Soil strength, Mean weight diameter, particle size distribution, and soil moisture were determined using standard procedures.

The experiment was conducted during Kharif season under irrigated conditions in split-plot design (SPD) replicated thrice and their residual effect was tested in Rabi wheat.

Table 1. Initial characteristics of the soil

		Soil characteristics
1	Location	Northern Section of Bihar Agricultural College Farm, Sabour
2	Family	Fine, mixed, hyperthermic, Vertic Haplustalf
3	Soil colour	Grey D 5 Y 6/1, Dark grey (M5Y4/1)
4	Parent material	Alluvium
5	Mechanical composition	
	a. Sand	24 %
	b. Silt	31 %
	c. Clay	45 %
6	Texture	Clay
7	pH	8.04
8	EC	0.33 dSm^{-1} at 25°C
9	Water stable aggregates	
	a. Mean weight diameter	0.478 mm
	b. Aggregate of size (>0.25 mm)	28.00 %
10	Hydraulic conductivity	0.148 cm hr^{-1}
11	Bulk density	1.44 Mg m^{-3}
12	Soil strength	9.10 MPa
13	Organic carbon	0.62 %
14	Available N	338.5 kg ha^{-1}
15	Available P_2O_5	48.0 kg ha^{-1}
16	Available K_2O	225.6 kg ha^{-1}

Chart 1. Main plot treatments comprising of tillage

T_1	Ploughing with desi plough twice (Cross) left for one week to decompose the weeds and residues and then planking in standing wheat (puddling) for paddy cultivation
T_2	Ploughing twice by cultivator, allowed to decompose weeds for a week then puddling by cross ploughing and planking
T_3	Summer ploughing onset of monsoon by mould board plough to invert the soil once in three years followed by subsequent ploughing by cultivator to puddle the soil.
T_4	Disc ploughing once in three years after the onset of monsoon to invert the soil. Residues were incorporated by cultivator, then puddling was done after one week.

Chart 2. Sub-plot treatments related to organic residues and green manuring

C_1	Control
C_2	FYM @ 50 q/ha
C_3	Paddy straw @ 50 q/ha
C_4	Green manuring with Dhaincha (incorporated 45 DAS)
C_5	GM + Paddy straw @ 50 q/ha
C_6	GM + Rice husk @ 50 q/ha

Table 2. Agro-management adopted for wheat crops

	Operation	Date of operation
1	Variety	Sonalika
2	Spacing	23 cm row to row
3	Seed rate	120 kg ha^{-1}
5	Fertilizer dose	100:60:40 N, P_2O_5 and K_2O

3. RESULTS AND DISCUSSION

3.1 Residual Effect of Tillage and Residues on Soil Strength/ Compaction (MPa)

The results (Table 3) indicated that the residual effect of different tillage and organic residues were effective significantly in reducing the soil strength after paddy harvest in all the treatments. Soil compactness was reduced significantly higher in treatments with summer ploughing by mould board plough (T_3) and Desi plough up to 9.33 MPa and 9.95 MPa, respectively, as compared to control.

Regarding the subplot treatments, green manuring + rice husk (C_6) had a maximum and statistically significant impact on the reduction of soil compaction (9.05 MPa) as against control (10.07 MPa). The effectiveness of other organic residues was in the following order.

Green manuring + paddy straw (C_5) > Green manuring (C_4) > Paddy straw (C_3) > FYM (C_2).

The effects of organic residues were found to be highly significant, while tillage had no significant effect on reduction of soil compactness after the harvest of wheat as compared to control. Green manuring + rice husk (C_6) had induced lowest soil compactness (8.72 MPa).

Both tillage operations and crop residues reduced soil strength significantly over control, but the effect of its interaction was found to be non-significant. The decrease in soil strength under both main plot treatments (Tillage operations: T_1 to T_4) and subplot treatments (Organic residues: C_1 to C_6) may be attributed to a decrease in bulk density and increase in aggregation, porosity, friability and aeration of the soils. This is further confirmed by the positive and highly significant correlation between soil strength and bulk density (r = 0.802**). This corroborates the findings of [20-23].

The maximum decrease in soil strength under the treatments T_3 (mouldboard ploughing) and C_6 (GM + rice husk) may be due to more development of aggregation and friability in comparison to other treatments. The magnitude of soil strength was higher after paddy harvest and lower after wheat harvest, which might be due to more compaction of soil after puddling for rice cultivation and more soil friability because of ploughing operations during wheat cultivation.

3.2 Residual Effect of Tillage and Residues on Bulk Density (BD)

The residual effect of tillage and organic residues, as well as its interaction on the bulk density of soil after harvest of paddy, was found to be highly significant as compared to control (Table 4). Bulk density (1.47 Mgm^{-3}) under Desi plough (T1) reduced significantly to 1.43 Mgm^{-3} under both the treatments i.e Mould board plough (T3) and Disc plough (T4). As regards the residual effect of organic residues, the bulk density under the control plot (1.48 Mgm^{-3}) was significantly reduced to 1.43 Mgm^{-3} both under green manuring + rice husk (C6) and green manuring + paddy straw (C5). Mould board plough either combined with green manuring + rice husk (T3C6) or green manuring + paddy straw (T3C5) had the lowest bulk density (1.40 Mgm^{-3}) while the maximum (1.51 Mgm^{-3}) was noted under the combination of desi plough with control (T1C1).

Table 3. Changes in soil strength/compaction (MPa)

Main plot treatments/Sub-plot treatments	After paddy harvest					After wheat harvest				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
C_1	10.27	10.11	9.87	10.01	10.07	9.96	9.69	9.63	9.90	9.80
C_2	10.20	9.72	9.63	9.84	9.95	9.71	9.53	9.36	9.46	9.52
C_3	10.02	9.43	9.42	9.72	9.65	9.56	9.22	9.10	9.33	9.30
C_4	9.92	9.34	9.13	9.50	9.47	9.38	9.07	8.98	9.13	9.13
C_5	9.64	9.02	9.01	9.37	9.26	9.20	8.66	8.80	8.83	8.87
C_6	9.23	8.91	8.92	9.13	9.05	8.96	8.68	8.59	8.65	8.72
Mean	9.95	9.42	9.33	9.60	9.58	9.46	9.14	9.08	9.22	9.23
		SE (±)		CD (5%)					SE (±)	CD (5%)
T	=	0.0879		0.2152		T		=	0.2325	NS
C	=	0.0803		0.1623		C		=	0.1513	0.3057
C at same T	=	0.1606		NS		C at same T		=	0.3025	NS
T at same C	=	0.1710		NS		T at same C		=	0.3610	NS

Main plot treatments:
T_1 = Cross ploughing (desi plough) + after one week puddling (planking)
T_2 = Ploughing (Cultivator) + after one week puddling (Cross ploughing & planking)
T_3 = Summer ploughing (mould board plough) after onset of monsoon in three years followed by subsequent ploughing by cultivator to puddle the soil.
T_4 = Disc ploughing in three years after onset of monsoon + puddling after one week

Sub- plot treatments:
C_1 = Control
C_2 = FYM (50 Q ha^{-1})
C_3 = Paddy straw (50 Q ha^{-1})
C_4 = Green manuring (Dhaincha incorporated after 45 DAS)
C_5 = GM + Paddy straw (50 Q ha^{-1})
C_6 = GM + Rice husk (50 Q ha^{-1})

Table 4. Change in bulk density (BD) of the soil (Mgm^{-3})

Main plot treatments/Sub-plot treatments	After paddy harvest					At wheat sowing					After wheat harvest				
	T_1	**T_2**	**T_3**	**T_4**	**Mean**	**T_1**	**T_2**	**T_3**	**T_4**	**Mean**	**T_1**	**T_2**	**T_3**	**T_4**	**Mean**
C_1	1.51	1.48	1.46	1.45	1.48	1.47	1.44	1.42	1.41	1.44	1.50	1.47	1.45	1.44	1.47
C_2	1.48	1.46	1.45	1.43	1.46	1.44	1.42	1.41	1.39	1.42	1.47	1.45	1.44	1.42	1.45
C_3	1.47	1.45	1.44	1.44	1.45	1.43	1.41	1.40	1.40	1.41	1.46	1.44	1.43	1.43	1.44
C_4	1.46	1.43	1.44	1.42	1.44	1.42	1.39	1.40	1.38	1.40	1.45	1.42	1.43	1.41	1.43
C_5	1.45	1.44	1.40	1.43	1.43	1.41	1.40	1.36	1.39	1.39	1.44	1.43	1.39	1.42	1.42
C_6	1.45	1.43	1.40	1.42	1.43	1.41	1.39	1.36	1.37	1.38	1.44	1.42	1.39	1.40	1.41
Mean	1.47	1.45	1.43	1.43	1.45	1.43	1.41	1.39	1.39	1.41	1.46	1.44	1.42	1.42	1.44
		SE (±)		CD (5%)					SE (±)	CD (5%)				SE (±)	CD (5%)
T	=	0.0066		0.0162		T		=	0.0064	0.0158	T		=	0.0063	0.0153
C	=	0.0039		0.0078		C		=	0.0037	0.0076	C		=	0.0039	0.0078
C at same T	=	0.0077		0.0171		C at same T		=	0.0075	0.0166	C at same T		=	0.0077	0.0170
T at same C	=	0.0097		0.0215		T at same C		=	0.0095	0.0209	T at same C		=	0.0094	0.0208

Before the sowing of wheat, bulk density (1.43 Mgm^{-3}) under desi plough treatment (T1) significantly reduced to 1.39 Mgm-3 due to ploughing by Disc plough (T4) (Table 4). Bulk density of soil in other treatments was also significantly reduced to 1.39 and 1.41 Mgm-3 under mouldboard plough (T3) and cultivator (T2), respectively as compared to desi plough (1.43 Mgm^{-3}). The bulk density (1.44 Mgm^{-3}) under the control (C1) plot was significantly reduced to 1.38 Mgm^{-3} due to green manuring + rice husk @ 50q/ha (C6). The minimum reduction of 0.02 unit was observed under FYM treated plots while the maximum reduction of 0.06 unit was noted under the influence of green manuring + rice husk. Mouldboard plough (T3) + paddy straw (C5) and rice husk (C6) had the minimum bulk density (1.36 Mgm^{-3}) in the soil at sowing time of wheat crop as against the maximum under Desi plough and the control (T1C1).

Further, bulk density of soil after harvest of wheat as influenced by treatments (Table 4) indicated that differences due to the residual effect of tillage (T), organic residues (C) and their interactions (T x C) were statistically significant. The residual effect of green manuring + rice husk (C6) had shown a maximum reduction in bulk density (1.41 Mgm^{-3}), which was at par with green manuring + paddy straw (1.42 Mgm^{-3}) (C5). The effect of other treatments on bulk density reduction may be arranged in the following orders: green manuring > paddy straw > FYM. Mould board plough along with green manuring + rice husk and green manuring + paddy straw had the minimum bulk density (1.39 Mgm^{-3}) in the soil after harvest of wheat as against the maximum (1.50 Mgm^{-3}) under desi plough with no organic residues (T1C1).

Based on general observation, it was observed that a maximum decrease in bulk density was found under treatment T3 (mouldboard plough) and T4 (Disc plough) and C5 (GM + paddy straw) and C6 (GM + rice husk). This might be attributed to more aggregation and friability developed under these treatments in comparison to other treatments. The findings were in conformity with the findings of [24,25] in which they reported that the tillage reduced the bulk density by increasing soil volume while [10,26, 27] reported a decrease in bulk density of the soils on the application of organic residues. It was also reported that a decrease in bulk density may be ascribed to soil disturbances by ploughing due to more increase in volume by loosening the soils under deep ploughing by mould board plough and slow rate of decomposition of rice husk and paddy straw [28]. The result was further confirmed by the positive and significant correlation of compaction with the bulk density of the soils (r = 0.802**). The maximum decrease in bulk density was at wheat sowing followed by after wheat and paddy harvest attributed to more friability of the soils at the time of wheat sowing. The relationship between bulk density and consequent increase in compaction seemed to be possible as also reported by [29,30].

3.3 Residual Effect of Tillage and Residues on Clod Size Distribution

The treatments of Desi plough (T1) has shown mean weight diameter (MWD) of clod distribution (1.45 cm) which was significantly higher in value and at par with (T2) cultivator (1.40 cm) whereas minimum clod size (1.26 cm) was observed in Mould board plough (T3) which was at par with (T4) Disc plough (1.29 cm) (Table 5).

The maximum reduction in clod size was noted under the treatments of GM + rice husk (C6) and Mould board ploughing (T3) while the lowest reduction was observed under paddy straw (C3) and Desi plough (T1). The reduction in clod size might be attributed to the breaking down of the big sized clods under ploughing and reorientation of the soil particles forming clods under influence of the binding effects of the organic residues. Here, it will be essential to mention that the organic residues create a line of cleavage of the clods. These lines of cleavage were the lines of weakness along which the clods were broken resulting into the smaller sized clods. It might further be supported by the fact that organic residues increased the friability of the soils.

3.4 Residual Effect of Tillage and Residues on Soil Aggregate (>0.25 mm)

Percentage of aggregate (> 0.25 mm diameter) after paddy harvest presented in Table 6 indicated that the residual effect of tillage and organic residues were highly significant in improving aggregation. In the case of tillage practices, the aggregates due to Disc plough (T_4) increased significantly from 36.17 to 38.75% as compared to Desi plough (T_1). While in sub-plot treatments green manure + rice husk (C_6) showed maximum aggregation (44.5%) as against the control plot (30.0%).

Table 5. Changes in clod size of the soils (cm) before wheat sowing

Main plot treatments/Sub-plot treatments	T_1	T_2	T_3	T_4	Mean
C_1	1.85	1.80	1.61	1.65	1.73
C_2	1.48	1.38	1.21	1.25	1.33
C_3	1.54	1.46	1.29	1.34	1.41
C_4	1.38	1.38	1.20	1.22	1.30
C_5	1.30	1.26	1.15	1.20	1.23
C_6	1.15	1.12	1.10	1.08	1.11
Mean	1.45	1.40	1.26	1.29	1.35
		SE (±)		CD (5%)	
T	=	0.0167		0.0409	
C	=	0.0402		0.0812	
C at same T	=	0.0804		NS	
T at same C	=	0.0753		NS	

Table 6. Changes in percentage of aggregates (>0.25 mm)

Main plot treatments/ Sub-plot treatments	After paddy harvest					After wheat harvest				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
C_1	28.00	29.50	30.50	32.00	30.00	30.50	32.00	31.00	33.50	31.75
C_2	33.00	35.00	36.00	36.50	35.15	35.00	37.00	38.00	38.00	37.00
C_3	36.50	37.00	37.50	38.00	37.25	38.00	39.00	39.00	39.00	38.75
C_4	38.00	39.50	39.00	39.00	38.88	39.00	41.00	41.00	40.00	40.25
C_5	39.50	41.00	40.50	41.00	40.50	41.00	42.00	43.00	42.00	42.00
C_6	42.00	44.00	46.00	46.00	44.50	44.00	46.00	48.00	48.00	46.50
Mean	36.17	37.67	38.25	38.75	37.71	37.92	39.50	40.00	40.08	39.38
		SE (±)		CD (5%)					SE (±)	CD (5%)
T	=	0.2556		0.6256		T		=	0.0010	NS
C	=	0.4935		0.9974		C		=	0.5590	1.1298
C at same T	=	0.9871		NS		C at same T		=	1.1180	NS
T at same C	=	0.1366		NS		T at same C		=	1.4295	NS

Percentage aggregation (> 0.25 mm) after harvest of wheat (Table 6) revealed that treatments were significantly effective in improving soil aggregation over control. The percentage of aggregates under control (31.75%) significantly increased to 46.5% under green manuring + rice husk (C_6), while it was 42.0% under green manuring + paddy straw (C_5). The maximum increase was noted under the treatments T_4 (Discing) and C_6 (GM + rice husk). Amongst treatment interactions, T_3 and T_4 in combination with C_6 were found to be superior to others in increasing aggregates. The increase in aggregates might be attributed to the role of paddy roots and organic residues in building up aggregates. Further, the variation in aggregate content under different treatments of organic residues might be due to their degree of decomposition and content of organic matter. The results are in close agreement with the findings reported by [31,32,33]. Further, the impact of tillage operations on increasing water-stable aggregates was reported by some workers like [34].

Tillage treatments after wheat harvest were found non-significant over control in increasing the percentage of aggregates while it was found significant after paddy harvest. This might be further attributed to the effect of rice roots under the influence of different tillage treatments in increasing soil aggregation. Higher values of aggregates after wheat harvest might be due to frequent wetting and drying cycle followed in wheat cultivation and also due to the fast decomposition of organic residues resulting in formation of more stable compounds to form better soil aggregation under aerobic condition of the soil.

3.5 Residual Effect of Tillage and Residues on Mean Weight Diameter (MWD) of Soil Aggregates

Mean weight diameter of soil aggregates after paddy harvest (Table 7) indicated that differences were significant only due to the residual effect of organic residues applied before planting rice in the plots. The lowest MWD of soil aggregates (0.495 mm) was noted in the case of control plots. It increased significantly with green manuring, green manuring + paddy straw and green manuring + rice husk, which had statistical parity among themselves. FYM and paddy straw incorporation did not cause MWD to increase significantly.

However, after the harvest of the wheat crop, the mean weight diameter of control plot (0.51 mm) (Table 7) significantly increased to 0.572 mm under green manure + rice husk and 0.556 mm, 0.546 mm and 0.528 mm under green manure + paddy straw (C5), Green manuring with dhaincha (C4) and FYM (C2), respectively. The percent change of MWD value from that of the control plot varied from a minimum increase noted in FYM (3.53%) to a maximum increase of 12.16% observed under green manure + rice husk treatment. [14,35] Reported larger MWD values primarily due to the occurrence of oxides of Fe, Al, and Mn in soils that resisted their breakdown.

The treatments T_4 (Discing) and C_6 (GM + rice husk) were found most effective among all the treatments in increasing the mean weight diameter of the soils. The increase in MWD of the soils might be due to an increase in aggregation and looseness. This was further confirmed by the negative and highly significant correlation of MWD with compaction (r = 0.773**) and bulk density (r = -0.805**). The result was in conformity with the findings of [36,37].

3.6 Residual Effect of Tillage and Residues on Hydraulic Conductivity of Soil

From Table 8, it is evident that the residual effect of different tillage and organic residues and their interactions were highly significant. Mould board plough in combination with green manuring + rice husk (T3C6) had maximum hydraulic conductivity (0.218 cm/hr) as against the minimum (0.124 cm/hr) observed under the plots of Desi plough and no organic residues (T1C1).

It was observed that after the harvest of wheat, Disc plough (T4) had significantly high hydraulic conductivity (0.211 cm/hr), whereas low hydraulic conductivity was observed in the case of Desi plough (0.152 cm/hr) (Table 8). The trend of effect may be as follows: Disc plough > Mould board plough > Cultivator > Desi plough. Organic residues had a significant residual effect on the improvement of hydraulic conductivity in comparison with the control plot. After wheat harvest, green manure + rice husk had significantly high hydraulic conductivity of soil (0.212 cm/hr) as against control (0.160 cm/hr). Mould board plough (T3) combined with green manuring + rice husk had significantly higher hydraulic conductivity (0.263 cm/hr) as against Desi plough and Control (T1C1) (0.143 cm/hr).

In clayey soil, with dominance of montmorillonite group of clay minerals, there is formation of compact layer just below the plough sole restricting the movement of water down the depth. The soil under investigation was compact and had high bulk density, which results in reduced hydraulic conductivity.

There was a significant increase in HC over control under both the sets of treatments i.e tillage and organic residue application. The maximum increase in HC was observed in the case of treatments T3, T4 and C6 and their interactions, while minimum in T1 and C2 and their interactions. The treatments of organic residues would have improved aggregation and porosity, which ultimately might have increased the HC of the soils. The increase in HC under the influence of different tillage treatments might be attributed to an increase in friability and pore spaces of the soils by disturbing the hard layers. This was further confirmed by negative and highly significant correlation of HC with that of compaction (r = -0.646**) and bulk density (r= -0.846**). Similar impacts of organic residues on HC were also reported by some workers like [32, 38] while the impacts of tillage treatments were in conformity with the findings of [39,40]. Hydraulic conductivity after wheat harvest was higher than the values after paddy harvest. The lower values after paddy harvest might be accentuated to the compaction due to puddling, while higher values after wheat harvest might be due to more loosened soils. This result was in close agreement with the findings of [41].

Table 7. Changes in mean weight diameter (mm)

Main plot treatments/ Sub-plot treatments	After paddy harvest					After wheat harvest				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
C_1	0.476	0.494	0.512	0.495	0.495	0.494	0.503	0.521	0.521	0.510
C_2	0.494	0.504	0.530	0.530	0.515	0.512	0.512	0.539	0.548	0.528
C_3	0.504	0.513	0.539	0.539	0.524	0.521	0.513	0.548	0.568	0.538
C_4	0.508	0.504	0.540	0.553	0.526	0.530	0.530	0.557	0.566	0.546
C_5	0.517	0.531	0.549	0.567	0.541	0.539	0.557	0.549	0.575	0.556
C_6	0.549	0.548	0.549	0.557	0.551	0.576	0.568	0.558	0.584	0.572
Mean	0.508	0.516	0.537	0.540	0.525	0.529	0.531	0.545	0.560	0.542
		SE (±)		CD (5%)					SE (±)	CD (5%)
T	=	0.015		NS		T		=	0.0129	NS
C	=	0.0147		0.0297		C		=	0.0058	0.0117
C at same T	=	0.0294		NS		C at same T		=	0.0115	NS
T at same C	=	0.0292		NS		T at same C		=	0.0167	NS

Table 8. Changes in hydraulic conductivity (cm/hr) of the soils

Main plot treatments/ Sub-plot treatments	After paddy harvest					After wheat harvest				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
C_1	0.124	0.133	0.159	0.163	0.145	0.143	0.145	0.178	0.173	0.160
C_2	0.137	0.138	0.167	0.165	0.152	0.148	0.148	0.183	0.188	0.167
C_3	0.139	0.143	0.169	0.173	0.156	0.149	0.159	0.201	0.203	0.178
C_4	0.140	0.148	0.183	0.178	0.162	0.153	0.163	0.203	0.213	0.183
C_5	0.143	0.153	0.193	0.183	0.168	0.157	0.168	0.213	0.243	0.195
C_6	0.148	0.159	0.218	0.203	0.182	0.163	0.173	0.263	0.248	0.212
Mean	0.139	0.146	0.182	0.178	0.161	0.152	0.159	0.207	0.211	0.183
		SE (±)		CD (5%)					SE (±)	CD (5%)
T	=	0.0016		0.0039		T		=	0.0007	0.0016
C	=	0.0008		0.0016		C		=	0.0009	0.0018
C at same T	=	0.0017		0.0038		C at same T		=	0.0018	0.0038
T at same C	=	0.0022		0.0049		T at same C		=	0.0018	0.0037

3.7 Soil Moisture in Relation to Tillage versus Soil Depth and Time Interval

Soil moisture content in relation to tillage vs soil depth with respect to time interval is presented in Table 9. It was noted that different tillage operations brought about an increase in soil moisture content at a deeper depth of soil sampling. The trend was more conspicuous in the case of organic residues as compared to soil depth with respect to time interval. At shallow depth (0-15 cm), mould board plough (T3) appeared to be more useful in increasing soil moisture content, while at deeper depth (45-60 cm), Disc plough (T4) had the tendency to increase soil moisture content at 0 DAS and Desi plough (T1) at each of 14 and 21 DAS. There was a clear indication that moisture utilization by wheat was maximum in T3 followed by T4, T2 and T1 treatments.

3.8 Soil Moisture in Relation to Organic Residues versus Soil Depth and Time Interval

Soil moisture content in relation to organic residues vs soil depth with respect to time interval (Table 9) decreases at each depth with advancement in age of seeding on account of application of organic residues. Further, the difference in organic residues brought about an increase in soil moisture content at deeper depth (45-60 cm) on contrary to shallow depth (0-15 cm). Green manuring + paddy straw (C5) appears to be more useful in increasing soil moisture content at shallow depth, while at deeper depth green manuring + rice husk (C6) was proved to be better in increasing soil moisture content irrespective of the time interval.

Table 9. Changes in moisture content (%) of the soils

Soil depth/Time/ Treatment mean	0-15 cm				15-30 cm				30-45 cm				45-60 cm			
	0 DAS	7 DAS	14 DAS	21 DAS	0 DAS	7 DAS	14 DAS	21 DAS	0 DAS	7 DAS	14 DAS	21 DAS	0 DAS	7 DAS	14 DAS	21 DAS
T_1	24.5	19.0	15.5	11.0	26.0	21.0	17.0	12.5	27.0	24.5	22.0	20.0	27.0	26.0	25.0	22.0
T_2	24.0	18.5	14.0	12.5	26.5	20.0	16.0	14.0	26.0	25.0	23.5	21.0	27.0	25.0	24.0	21.0
T_3	26.0	20.0	15.0	13.5	27.0	21.0	14.0	10.0	25.0	24.5	20.0	21.5	26.5	24.0	22.0	18.0
T_4	25.0	19.0	15.0	13.0	26.0	20.0	13.0	11.0	27.5	25.0	21.0	22.0	28.0	26.0	23.0	19.5
C_1	24.0	20.0	15.5	12.0	25.0	20.5	11.0	10.0	28.0	23.5	19.0	19.0	26.5	25.0	23.0	19.0
C_2	25.0	21.0	15.0	13.0	26.0	22.0	15.0	12.0	27.0	24.0	21.0	20.5	26.0	24.5	23.5	20.5
C_3	24.0	19.0	15.0	13.5	27.0	21.0	13.0	11.0	25.0	24.5	20.5	19.5	25.0	24.0	22.5	21.0
C_4	25.5	20.5	16.0	13.0	27.0	20.0	13.0	11.0	28.0	25.0	19.5	19.0	28.0	26.0	21.5	21.5
C_5	26.0	21.5	16.5	14.0	28.5	21.0	13.5	12.0	29.0	25.5	21.0	20.0	28.0	27.0	22.5	22.0
C_6	26.0	20.0	16.0	13.0	28.5	22.0	14.0	12.5	28.0	24.0	21.5	20.5	29.0	27.5	23.5	22.5

**DAS – Days after sowing of wheat*

There was an increase in soil moisture content under the influence of the treatments of tillage operation and application of organic residues and their interactions. The maximum value of soil moisture content was observed in T4 (28.0%) and C6 (29.0%) treatments at 45-60 cm depth of the soils. Here, it might be accentuated that the moisture content of the soils was more associated with organic matter content and porosity of the soils. This corroborates the findings of [42,43,44]. Due to the incorporation of green manure +paddy straw and green manure + rice husk (C6) in combination with deep tillage T3 and T4, there was better storage as well as efficient utilization of profile moisture which might be due to improved soil physical as well as fertility status.

It was further observed that there was no pronounced effect of tillage operations on the increase in soil moisture content. This might be attributed to the increase in macropores, destruction of aggregation, and increase in infiltration and hydraulic conductivity of the soils due to tillage. This is in conformity with the findings of [45].

3.9 Residual Effect of Tillage and Residues on Yield of Wheat Crop

The residual effect of tillage and organic residues revealed that Mould board plough along with green manuring + rice husk (T3C6) has given the maximum grain yield (21.99 Q/ha) (Table 10). The increase in yields might be ascribed chiefly to the effect of tillage and organic residues treatments on the improvement of soils properties alongwith the availability of nutrients. These observations were further confirmed by positive and highly significant correlation of yield of wheat grain with MWD (r = 0.514*) and HC (r = 0.482*) and negative and highly significant correlation with soil strength/compaction (r = -0.649**). It was supported by the previous findings of [46,47] who were of the opinion that the tillage methods were known to favourably moderate soil physical environment for efficient water management and higher grain yield of rice. Further, increase in yield of wheat under influence of organic residues was reported by a number of workers like [48,49,50] while the impact of tillage operations on increasing wheat yield was reported by [49,51,52].

3.10 Correlation Coefficient (r) between Soil Parameter and Yield of Wheat

A perusal of correlation coefficient matrix amongst yield of wheat and soil physical characteristics presented in Table 11 indicated that MWD and HC were positively and significantly correlated with the yield of wheat whereas compaction and BD were negatively and significantly correlated with the yield. It is also clear from the correlation matrix that compaction was negatively and significantly associated with the MWD and HC whereas it was positively and significantly associated with BD. It was also noticed that MWD had positive association with HC but negative association with BD. It was further observed that BD too was negatively associated with HC.

Table 10. Yield of wheat (Q/ha)

Main Plot/Sub-plot	T_1	T_2	T_3	T_4	Mean
C_1	15.02	15.13	15.00	16.03	15.30
C_2	16.69	17.14	19.76	17.30	17.72
C_3	16.85	17.36	18.08	16.97	17.32
C_4	16.08	17.47	18.64	18.56	17.69
C_5	17.05	17.42	19.47	18.86	18.32
C_6	18.82	19.76	21.99	21.26	20.46
Mean	16.75	17.46	18.82	18.96	17.80
		SE (±)		CD (5%)	
T	=	0.3135		0.7672	
C	=	0.2532		0.5117	
C at same T	=	0.5064		1.0913	
T at same C	=	0.5585		1.2038	

Table 11. Correlation coefficient amongst yield of wheat and various soil properties

	Compaction (Soil strength)	MWD	HC	BD	Yield
Compaction (soil strength)	1	-0.773**	-0.646**	0.802**	-0.649**
MWD		1	0.788**	-0.805**	0.514*
HC			1	-0.846**	0.422*
BD				1	-0.507*

**5% level of significance, **1% level of significance*

4. CONCLUSIONS

The result indicated a significant improvement in soil properties along with yields of grain over control under influence of these treatments of tillage operations (T) and application of different organic residues (C) and their interactions (T x C). Deep ploughing and green manuring treatments were found superior over ploughing by Desi plough (T_1) and application of paddy straw (C_3) and their interactions (T_1 x C_3). The maximum impact of improvement of soil parameters were observed under the treatments of T_3 (MB) and C_6 (GM + rice husk) and their interactions (T_3 x C_6).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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