

Original Research Article

Impact of conservation tillage on soil physical properties under sorghum-wheat cropping system in semi-arid tropics of Haryana

ABSTRACT

The study was conducted at ~~the~~ Research Farm of CCSHAU, Hisar. Three tillage (~~Zero tillage, conventional tillage, conventional~~, and minimum tillage) and four P treatments (0, 45, 60, and 75 kg ha⁻¹) were applied ~~in to~~ wheat. The mean weight diameter of soil aggregates in 0-5 cm soil depth was significantly higher under zero tillage ~~as compared to than~~ other tillage practices. Maximum aggregation was in 5-10 cm soil depth. Amongst ~~the~~ three tillage systems, bulk density increased with depth. The saturated hydraulic conductivity was significantly improved under zero tillage as compared to other practices. Moisture content was ~~significantly considerably~~ higher at field capacity under zero tillage as compared to other methods, while moisture content at permanent wilting point (PWP) was not affected significantly by tillage treatments. ~~Infiltration~~ ~~The infiltration~~ rate was almost identical under conventional tillage and minimum tillage practices, respectively which was significantly lower than the zero tillage.

Keywords: Soil physical properties, Tillage practices, Sorghum-wheat.

INTRODUCTION

The world's population is expanding day by day so the demand for food is also increasing, to meet the demand of ~~the~~ growing population there ~~is a~~ need to bring more lands under

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cultivation for crop production. The growing concern for ensuring food supply with the help of improved soil management practices requires for selection of better crop yield, sustainability, and ~~environmental~~environmentally friendly. As we know tillage practice is the mechanical manipulation of the soil with help of tools and implements to provide favorable conditions for seed germination and crop growth by affecting the soil characteristics like soil water conservation, soil temperature, infiltration and ~~evapo-transpiration~~evapotranspiration processes. Tillage practices have great impact on the soil properties and the soil environment which leads to increase in the yield of the field crops. Tillage practices affect physical properties of soil like bulk density, infiltration rate, hydraulic conductivity and moisture content etc. The wish for increasing yield to meet expanding demand should be done without soil degradation and the soil should be prepared in such a way to serve as a store rather than a source of atmospheric pollutants (Busari *et al.*, 2015).

Conservation tillage practice maintains at least 30% of the soil surface covered with crop residue after planting to reduce soil erosion. Lal (1990) described conservation tillage as the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as the key criteria. Conservation tillage along with crop residue cover on soil, rotation of crops and crop diversity could be a practically applicable method to safeguard sustainable crop production and perpetuate environmental quality. So it could be assumed that conservation tillage is a component of conservation agriculture (CA). Conservation tillage helps ~~in~~ ~~maintaining~~maintain soil health along with increased production and hence it is an ~~environment~~friendlyenvironment-friendly option.

Conservation tillage is an ecological approach to soil surface management and seedbed preparation. Shifting from conventional to conservation tillage, ~~in accordance with~~by the principle

of conservation agriculture, help in improving soil structure, ~~increase~~ increasing soil organic carbon, minimize soil erosion, conserve soil water, decrease fluctuations in soil temperature and enhance soil quality and environmental regulatory capacity of the soil. Crop residue is an important renewable resource which provides essential nutrients to the ~~soils~~ soil along with the conservation of soil. Developing techniques for effective utilization of this vast resource is a major challenge. Improper uses of crop residues (e.g. removal, burning or ~~ploughing~~ plowing under) can accelerate erosion, soil fertility depletion, and environmental pollution through burning. The principle of conservation tillage involves maintenance of surface soil cover through retention of crop residues achievable by practicing zero tillage and minimal mechanical soil disturbance. Retention of crop residues protects the soil from the direct impact of rain drops and sunlight while the minimal soil disturbance enhances soil biological activities as well as soil air and water movement. Soil compaction at the soil surface can be remediated by the usual soil tillage, root growth and biological activity. The soil is not inverted and mixed with the crop residues and this seems to profoundly impact on soil properties particularly in the upper soil layer under reduced tillage. So this study emphasized the need of conservation tillage for sustainable crop production and soil health.

MATERIALS AND METHODS

The study was conducted at research farm of CCS Haryana Agricultural University, Hisar. The experimental site at research farm of CCS Haryana Agricultural University, Hisar is situated in semi-arid, sub-tropics at latitude 29° 10' North, longitude of 75° 46' East and ~~at~~ an altitude of 215.2 m mean sea level in Haryana State of India.

The soil of the experimental field has been classified as Coarse loamy, calcareous, Typic Haplustepts by Soil Taxonomy, and the relevant physico-chemical properties of the soil are given in [Table 1](#) below.

Table 1. Physico-chemical properties of soil of the experimental site at initiation

Soil properties	Soil depth (cm)	
	0-15	15-30
Sand (%)	69.8	71.6
Silt (%)	16.4	12.8
Clay (%)	13.8	15.6
Textural class	Sandy loam	Sandy loam
pH _(1:2)	8.20	8.12
EC _(1:2) dS m ⁻¹	0.52	0.54
Organic carbon (%)	0.48	0.34
Available N (kg ha ⁻¹)	140	126
Available P (kg ha ⁻¹)	14.6	11.7
Available K (kg ha ⁻¹)	450	478

The soil was sandy loam in texture, alkaline in reaction, nonsaline, medium in organic carbon content, low in available N, medium in available P and high in available K.

Soil samples were collected from different soil [depths](#) (0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 cm) using a core sampler for the determination of bulk density, hydraulic conductivity; moisture content at the field capacity level and permanent wilting point. Soil samples were also taken from each treatment without disturbing the natural aggregates from different soil depths for wet aggregate analysis. The big sized clods of soil samples were gently broken by free fall from

about 60-70 cm height on a vegetative surface ~~so as to~~ break the clods at natural cleavage planes. ~~Description~~ A description of different treatments used in ~~the~~ experiment is given in ~~table~~ Table 2 below.

Table 2. Description of treatments used for the experiment and their plot allocations

Treatment	Plot allocation	Description
Type of tillage (T)	Main plot	ZT: Zero tillage
		MT: Minimum tillage
		CT: Conventional tillage
Levels of phosphorus (P)	Sub-plot	P ₀ : 0 kg P ₂ O ₅ ha ⁻¹
		P ₄₅ : 45 kg P ₂ O ₅ ha ⁻¹
		P ₆₀ : 60 kg P ₂ O ₅ ha ⁻¹
		P ₇₅ : 75 kg P ₂ O ₅ ha ⁻¹

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Soil analysis

Soil samples were analyzed for bulk density, moisture content at field capacity and permanent wilting point, wet aggregate analysis, saturated hydraulic conductivity, and infiltration rate. The bulk density was determined using a core sampler (5 cm inner diameter and 5 cm in height) from different soil depths (0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm) after oven drying at 105°C for 24 hours. ~~Soil~~ The soil infiltration rate was determined by using a close top double ring infiltrometer (Malik *et al.*, 1985).

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~~Saturated~~ The saturated hydraulic conductivity of each soil core was determined by a constant head permeameter (Richards, 1954) and calculated using Darcy's equation. ~~Moisture~~ The moisture content at field capacity and permanent wilting point was determined using pressure

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plate apparatus at 0.33 and 15 bar suction, respectively (Richards, 1954). Wet aggregate analysis was done by Yodder's apparatus (Yodder, 1936).

Statistical analysis

Statistical analysis was carried out for data calculation using Microsoft Excel (Microsoft Corporation, USA) and SPSS 16 (Statistical Package for the Social Science, SPSS, Inc., Chicago, USA, window version 16.0).

RESULTS AND DISCUSSION

Impact of tillage practices on soil physical properties

Wet aggregates: Mean weight diameter of soil aggregates (Table 3) was significantly higher under Zero tillage (ZT) as compared to other tillage practices.

Table 3. Mean weight diameter (mm) at various soil depths under zero (ZT), minimum (MT) and conventional (CT) tillage (\pm indicates standard error of the mean of the observed values)

Depth (cm)	ZT	MT	CT
0-5	0.28 \pm 0.012	0.25 \pm 0.016	0.23 \pm 0.014
5-10	0.29 \pm 0.015	0.26 \pm 0.015	0.24 \pm 0.012
10-15	0.26 \pm 0.013	0.24 \pm 0.016	0.24 \pm 0.012
15-20	0.23 \pm 0.010	0.23 \pm 0.009	0.22 \pm 0.009
20-25	0.23 \pm 0.008	0.22 \pm 0.006	0.21 \pm 0.005
25-30	0.24 \pm 0.009	0.23 \pm 0.006	0.22 \pm 0.006

The maximum aggregation was found in 5-10 cm soil depth and decreased ~~upto~~ up to 20 cm depth. It was also observed that there was no difference in the mean weight diameter of soil aggregates throughout the depths under conventional tillage (CT) and minimum tillage (MT). The

results ~~are in conformity~~ conform with those of Liebig *et al.*, (2004) who reported that within a surface of 7.5 cm, ~~the~~ no-till system possessed greater soil aggregate stability (33.4%) relative to the CT system while Six *et al.*, (2000) reported that the rate of macroaggregate formation and degradation is reduced under no-till system compared to CT leading to ~~the~~ formation of stable microaggregates. Aggregate size ~~and~~ stability and soil structure were analyzed, these properties improved more under NT systems than ~~in~~ CT systems. ~~Increase~~ An increase in SOC storage is found significant under conservation than conventional tillage in surface soil. It may be due to ~~change~~ changes in the soil porosity, water content and reduction in soil aggregation (Srivastava *et al.*, 2016). Water-stable aggregates cannot be sustained with CT since the residue cover is not sufficient to protect against surface crusting. Aggregate stability and size are very important in maintaining soil structure and minimizing erosion. Karlen *et al.*, (1994) demonstrated that there was a significant increase in aggregate size after 10 years of growing corn under a NT system on highly erodible silt loam with slopes of 10 to 13 percent, near Lancaster, Wisconsin. Rhoton *et al.*, (1993) conducted a ~~45 years~~ 15-year study on four soils with different textures in four different southeastern States. Aggregate stability was higher under NT than CT in all soils. These studies indicate that physical soil properties are improved with NT, regardless of the temperature and moisture region.

Soil bulk density: Bulk density (BD) of a soil is an indication of the soil's compaction and thus resistance to tillage implements or plants as they penetrate the soil. The BD was increased with soil depth amongst all the tillage systems (Table 4).

Table 4. Soil bulk density (Mg m^{-3}) at various soil depths under zero (ZT), minimum (MT) and conventional (CT) tillage (\pm indicates standard error of the mean of the observed values)

Depth (cm)	ZT	MT	CT
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0-5	1.53 ± 0.015	1.57 ± 0.008	1.58 ± 0.009	Formatted: English (United States)
5-10	1.56 ± 0.028	1.59 ± 0.008	1.58 ± 0.005	Formatted: English (United States)
10-15	1.60 ± 0.017	1.60 ± 0.005	1.61 ± 0.010	Formatted: English (United States)
15-20	1.64 ± 0.006	1.63 ± 0.008	1.63 ± 0.000	Formatted: English (United States)
20-25	1.64 ± 0.005	1.65 ± 0.006	1.65 ± 0.006	Formatted: English (United States)
25-30	1.65 ± 0.006	1.65 ± 0.005	1.65 ± 0.006	Formatted: English (United States)

Highest The highest BD (1.65 Mg m^{-3}) was observed in 20-25 and 25-30 cm soil depth. The lowest and significantly lower BD was observed in the 0-5 cm soil depth under ZT (1.53 Mg m^{-3}) than MT (1.57 Mg m^{-3}) and CT (1.58 Mg m^{-3}) respectively. Similar results were also observed by other workers (Daraghme *et al.*, 2009; Osunbitan *et al.*, 2005; Logsdon *et al.*, 1999; López-Fando and Pardo, 2009; Tripathi *et al.*, 2005; Kahlon *et al.*, 2013; Franzluebbbers and Stuedemann, 2008 and Villamil *et al.*, 2006).

Saturated Hydraulic conductivity: Saturated hydraulic conductivity (Ks) is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement. Ks was highest in 0-5 cm soil depth and significantly decreased in lower soil depth under the all tillage treatments (Table 5).

Table 5. Saturated hydraulic conductivity (cm hr^{-1}) for various depths under zero (ZT), minimum (MT) and conventional (CT) tillage (\pm indicates standard error of the mean of the observed values)

Depth (cm)	ZT	MT	CT	Formatted: English (United States)
0-5	0.84 ± 0.053	0.72 ± 0.053	0.68 ± 0.068	Formatted: English (United States)
5-10	0.69 ± 0.050	0.68 ± 0.074	0.65 ± 0.030	Formatted: English (United States)

10-15	0.66 ± 0.060	0.65 ± 0.032	0.65 ± 0.084	Formatted: English (United States)
15-20	0.60 ± 0.059	0.62 ± 0.026	0.60 ± 0.066	Formatted: English (United States)
20-25	0.59 ± 0.019	0.60 ± 0.053	0.59 ± 0.044	Formatted: English (United States)
25-30	0.57 ± 0.078	0.60 ± 0.022	0.61 ± 0.055	Formatted: English (United States)

The Ks ~~was~~ were significantly increased in the 0-5 cm soil depth under ZT as compared to other tillage practices and statistically at par in lower soil depths. Since Ks is a function of the size and continuity of pores, therefore, higher accumulation of soil organic carbon and less soil disturbance in ZT may have promoted the formation of ~~larger sized~~ larger-sized pores responsible for higher water transmission in the surface layer as compared to MT and CT practices. Ks is reported to be higher under ZT than MT and CT in different textured soils with a variable magnitude of difference between the two treatments (Naresh *et al.*, 2016). The hydraulic conductivity and infiltration rate were increased under zero tillage as compared to conventional tillage in ~~an~~ alluvial soil of the semi-arid subtropics (McGarry *et al.*, 2000). The tillage practices were implemented for 6 and 8 years which showed that the soils under conservation tillage had better pore connectivity and higher saturated hydraulic conductivity than conventional tillage (Vogeler *et al.*, 2009).

Moisture ~~The moisture~~ content at field capacity: The moisture content was significantly higher at field capacity level in 0-5 cm soil depth under ZT (16.56%), MT (16.06%), and CT (16.0%) respectively (Table 6).

Table 6. ~~Moisture~~ The moisture content at field capacity (%) at various depths under zero (ZT), minimum (MT) and conventional (CT) tillage (± indicates standard error of the mean of the observed values)

Depth (cm)	ZT	MT	CT
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0-5	16.56 ± 0.170	16.06 ± 0.210	16.00 ± 0.190
5-10	16.42 ± 0.190	16.17 ± 0.160	16.22 ± 0.230
10-15	16.57 ± 0.210	16.42 ± 0.223	16.34 ± 0.190
15-20	17.10 ± 0.177	17.07 ± 0.128	17.01 ± 0.190
20-25	17.24 ± 0.162	17.34 ± 0.115	17.56 ± 0.178
25-30	17.74 ± 0.178	17.89 ± 0.156	17.56 ± 0.155

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The moisture content was increased with depth under different tillage practices. The ZT treatment was found effective over MT and CT in increasing water retention in soil as the moisture content at field capacity level and observed to be higher in 0-5, 5-10, and 10-15 cm soil depth respectively (Ghuman and Sur, 2001; Schwen *et al.*, 2011; Castellini and Ventrella, 2012). The volume of soil water held at the field capacity level increased at a much higher rate than that of water held at the permanent wilting point. NT systems along with using high-residue crops in the crop rotation, using cover crops that provide high levels of biomass, maintaining crop residue with a high content of carbon, and avoiding excessive removal of residue, as well as climate, are key to increasing the content of SOM (Ernest *et al.*, 2015).

Moisture-The moisture content at permanent wilting point: The moisture content was not affected by tillage treatment at permanent wilting point (PWP). However, the lowest moisture content at PWP was observed in the 0-5 cm soil depth which was gradually increased in 5-10, 10-15, and 15-20 cm and then remained identical at lower soil depths (Table 7).

Table 7: Moisture content at permanent wilting point (%) at various depths under zero (ZT), minimum (MT) and conventional (CT) tillage (± indicates standard error of the mean of the observed values)

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Depth (cm)	ZT	MT	CT
0-5	7.42 ± 0.079	7.40 ± 0.072	7.45 ± 0.081

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5-10	7.60 ± 0.089	7.61 ± 0.086	7.55 ± 0.079
10-15	7.82 ± 0.068	7.78 ± 0.083	7.74 ± 0.081
15-20	7.98 ± 0.063	7.95 ± 0.062	7.91 ± 0.071
20-25	8.05 ± 0.054	8.01 ± 0.046	8.00 ± 0.042
25-30	8.06 ± 0.045	8.03 ± 0.051	8.04 ± 0.046

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It is possibly due to higher clay content in lower soil depths and PWP is a function of textural pores rather than structural pores (Govaertset *al.*, 2007).

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Infiltration rate: Infiltration rate was significantly higher under ZT (3.83 cm hr⁻¹) as compared to CT (3.73 cm hr⁻¹) and MT (3.75 cm hr⁻¹) practices. The infiltration rate was increased by 3 percent in ZT practice over CT practice under the sorghum-wheat cropping system. The water intake rate of soil increased in ZT as compared to MT and CT (Table 8).

Table 8. Infiltration rate (cm hr⁻¹) of soil under zero (ZT), minimum (MT) and conventional (CT) tillage (± indicates standard error of mean of the observed values)

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Tillage practice	Infiltration rate (cm hr ⁻¹)
ZT	3.83 ± 0.096
MT	3.75 ± 0.095
CT	2.72 ± 0.056

As water infiltration into the soil is controlled by the number and connectivity of surface vented macrospores (Ehlers, 1975), therefore, the practice of ZT may have promoted macro-pores ~~net~~ working networking resulting in higher water infiltration into the soil as compared to the soil which were disturbed under CT and MT practices (Horn and Baumgartl, 2000; Govaertset *al.*, 2007). Similar results were also reported for loam (Ferreraset *al.*, 2000) and sandy clay loam (Pelegrin and Moreno, 1993) soils. Infiltration, penetration resistance, and crusting/sealing

improved under conservation tillage practices as compared to CT systems (Villamil *et al.*, 2006 and Franzluebbbers, 2002).

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This study presents crucial insights into how different tillage practices influence soil physical properties, such as soil aggregation, bulk density, hydraulic conductivity, and moisture content. Conducted in the semi-arid tropics of Haryana, this research has significant implications for sustainable agricultural practices and soil health management.

The findings highlight the benefits of no-till systems in enhancing soil structure and moisture retention, which are critical for maintaining soil fertility and productivity in arid and semi-arid regions. The improvement in saturated hydraulic conductivity and field capacity moisture content under no-till conditions suggests that conservation tillage can effectively reduce soil erosion and improve water use efficiency. These results are essential for developing sustainable agriculture strategies aimed at mitigating the adverse effects of conventional tillage, such as soil compaction and degradation.

In tropical agricultural territories of Latin America, agro-environmental variables, including climate (Olivares and Hernandez, 2019; Vilorio *et al.* 2023), soil type (Araya-Alman *et al.* 2020; Calero *et al.* 2022; Olivares *et al.* 2022 and Franco, 2015), crop systems (Paredes *et al.* 2021), and socio-economic factors (Montenegro *et al.* 2021), significantly influence the adoption and effectiveness of conservation tillage practices. The relevance of the Haryana study's findings can

be extrapolated to these regions, considering the similarities in climatic conditions and agricultural challenges.

Climate: Tropical regions often face high rainfall variability and intense periods of both wet and dry conditions (Olivares and Zingaretti, 2019; Olivares et al. 2018; Olivares and Zingaretti, 2018). Conservation tillage, especially no-till, can help maintain soil moisture and reduce runoff(Olivares et al. 2012; Olivares et al. 2017; Olivares, 2018), which is crucial for crop survival during dry spells and reducing soil erosion during heavy rains (Rodriguez et al. 2013; Rodriguez et al. 2016a; 2016b).

Soil Type: The benefits of improved soil structure and moisture retention observed in the Haryana study are particularly pertinent for the often fragile and nutrient-poor soils in tropical Latin America (Olivares et al. 2015; Olivares et al. 2016; Olivares, 2022). Enhanced soil aggregation and reduced bulk density under no-till practices can lead to better root growth and nutrient uptake in these soils (Lopez et al. 2019; Lopez and Olivares, 2019).

Crop Systems: The sorghum-wheat cropping system in Haryana is comparable to various crop rotations in tropical Latin America, such as maize-bean or rice-bean systems (Hernandez et al. 2018a; 2018b). The principles of conservation tillage can be adapted to these crop systems to improve soil health and yield stability (Hernandez et al. 2018c; Hernandez et al. 2020).

Socio-Economic Factors: Smallholder farmers dominate agriculture in tropical Latin America, similar to parts of Haryana (Lobo et al. 2017; Hernandez and Olivares, 2019). The lower labor and machinery costs associated with no-till practices can provide economic benefits to these farmers, making conservation tillage a viable and attractive option (Hernandez and Olivares, 2020).

Sustainable Agriculture Goals: The global push towards sustainable agriculture aligns with the benefits highlighted in the study (Cortez et al. 2018; Casana and Olivares, 2020). Conservation tillage supports goals like reducing greenhouse gas emissions, improving soil carbon sequestration, and enhancing biodiversity (Paredes et al. 2023), which are critical for the long-term sustainability of agricultural landscapes in tropical Latin America (Cortez et al. 2019; Campos, 2023).

In summary, the study's findings on the positive impacts of no-till systems on soil physical properties are highly relevant to tropical agricultural territories of Latin America. By considering agro-environmental variables such as climate, soil type, crop systems, and socio-economic factors, the adoption of conservation tillage can be optimized to enhance soil health, improve water use efficiency, and support sustainable agricultural practices in these regions.

CONCLUSIONS

The mean weight diameter (MWD) of soil aggregates was significantly higher under ZT as compared to MT or CT in 0-5 cm soil depth. The bulk density (BD) was increased with depth. There was no significant effect of tillage below 10 cm soil depth. Saturated hydraulic

conductivity (Ks) was highest in the 0-5 cm soil depth then decreased with depth under different tillage systems. The Ks was significantly increased in the 0-5 cm soil depth under ZT as compared to other tillage practices. Moisture content at field capacity was significantly higher under ZT as compared to MT/CT in 0-5 cm soil depth. The infiltration rate was increased by 3 per cent in ZT practice over CT practice under sorghum-wheat cropping system

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