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Impact of Conservation Tillage on Soil Physical Properties under Sorghum-wheat Cropping System in Semi-arid Tropics of Haryana, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The study was conducted at Research Farm of CCSHAU, Hisar. Three tillage (Zero tillage, conventional tillage and minimum tillage) and four P treatments (0, 45, 60, and 75 kg ha-1) were applied in wheat. The mean weight diameter of soil aggregates in 0-5 cm soil depth was significantly higher under zero tillage as compared to other tillage practices. Maximum aggregation was in 5-10 cm soil depth. Amongst 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 higher at field capacity under zero tillage as compared

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to other methods, while moisture content at permanent wilting point (PWP) was not affected significantly by tillage treatments. 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.

1. INTRODUCTION

"The world'spopulationis expanding day by day so the demand for food is also increasing, to meet the demand of growing population there is need to bring more lands under 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 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 processes. Tillage practices have great impact on the soil properties and the soil environmentwhich leads to increase in the yield of the field crops. conventional tillage is also reported to have a huge impact on soil physical, chemical and biological properties which further are closely related to crop yield" [1,2,3]. "The use of conventional tillage techniques has resulted in edaphic issues such as soil erosion, degradation, and loss of fertility [4]. 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 de gradation and the soil should be prepared in such a way to serve as a store rather than a source of atmospheric pollutants" [5].

"Conservation tillage practice maintains at least 30% of the soil surface covered with crop residue after planting to reduce soil erosion Conservation tillage maintains the soil's stability and proper pore distribution, in contrast to conventional tillage techniques that break down soil aggregates and produce a hard pan" [6]. Lal [7] 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 withcrop 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 soil health along with increased production and hence it is an environment friendly option".

Conservation tillage is an ecological approach to soil surface management and seedbed preparation. Shifting from conventional to conservation tillage,in accordance with the principle of conservation agriculture, help in improving soil structure, increase 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 along with 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 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 cropresidues achievable by practicing zero tillage and minimal mechanical soil disturbance. Retention of crop residues protectsthe soil from direct impact of raindrop sand sunlight while the minimal soil disturbance enhancess oil biological activities as well assoilair 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 till age. So this study emphasized the need of conservation tillage for sustainable crop production and soil health.

2. 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^{o} 10' North, longitude of 75^{o} 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.

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 depth (0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 cm) using 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 of different treatments used in experiment is given in Table 2.

2.1 Soil Analysis

Soil samples were analyzed forbulk 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 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 infiltration rate was determined by using close top double ring infiltrometer [8].

Saturated hydraulic conductivity of each soil core was determined by constant head permeameter [9] and calculated using Darcy's equation. Moisture content at field capacity and permanent wilting point was determined using pressure plate apparatus at 0.33 and 15 bar suction, respectively [9]. Wet aggregate analysis was done by Yodder's apparatus [10].

2.2 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).

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

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_2O_5 ha^{-1} P_{45}: 45 kg P_2O_5 ha^{-1} P_{60}: 60 kg P_2O_5 ha^{-1} P_{75}: 75 kg P_2O_5 ha^{-1}

3. RESULTS AND DISCUSSION

3.1 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.

The maximum aggregation was foundin 5-10 cm soil depth and decreased upto 20 cm depth. It was also observed that there was no difference in mean weight diameter of soil aggregates throughout the depths under conventional tillage(CT) and minimum tillage (MT).The results are in conformity with those of Liebig et al*.,* [11] who reported that "within surface 7.5 cm, no-till system possessed greater soil aggregate stability (33.4%) relative to the CT system" while Six et al., [12] reported that "the rate of macro aggregate formation and degradation is reduced under no-till system compared to CT leading to formation of stable micro aggregates". ZT practices lead to better soil aggregation, resulting in the formation of macro aggregates in tropics and subtropics [13]. "Aggregate size and stability and soil structure were analyzed, these properties improved more under NT systems than CT systems. Increase in SOC storage is found significant under conservation than conventional tillage in surface soil. It may be due to change in the soil porosity, water content and reduction in soil aggregation" [14]. 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*.,* [15] 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*.,* [16] conducted "a 15-years 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).

Highest BD (1.65 Mg m^{-3}) was observed in20-25 and 25-30 cm soil depth. The lowest and significantly lower BD was observed in the 0-5 cm soil depth under ZT (1.55 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 [17,18,19,20,21,22,23,24].

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

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

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

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

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

Depth (cm)	ZT	MT	CT
0-5	0.84 ± 0.053	0.72 ± 0.053	0.68 ± 0.068
5-10	0.69 ± 0.050	0.68 ± 0.074	0.65 ± 0.030
10-15	0.66 ± 0.060	0.65 ± 0.032	0.65 ± 0.084
15-20	0.60 ± 0.059	0.62 ± 0.026	0.60 ± 0.066
20-25	0.59 ± 0.019	0.60 ± 0.053	0.59 ± 0.044
25-30	0.57 ± 0.078	0.60 ± 0.022	0.61± 0.055

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

Depth (cm)	ZT	MT	CT
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

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. Kswas highest in 0-5 cm soil depth and significantly decreased inlower soil depth under theall tillage treatments (Table 5).

"The Ks was significantly increased in the 0-5 cm soil depth under ZT as compared to other tillage practices and statistically at par inlower 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 pores responsible for higher water transmission in surface layer as compared to MT and CT practices. Numerous studies have indicated that ZT practices can significantly enhance both saturated and unsaturated hydraulic.

Conductivity" [25,26,27]. "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" [28]. "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" [29]. "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" [30].

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

"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" [31,32,33]. "The volume of soil water held at field capacity level increased at a much higher rate than that of water held at 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" [34].

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 mean of the observed values)

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

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)

Tillage practice	Infiltration rate (cm hr^{-1})
ZT	3.83 ± 0.096
MT	3.75 ± 0.095
CT	2.72 ± 0.056

It is possibly due to higher clay content in lower soil depths and PWP is a function of textural pores rather than structural pores [35].

Infiltration rate: Infiltration ratewas significantlyhigher underZT (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 per cent in ZT practice over CT practice under sorghum-wheat cropping system. The water intake rate of soil increased in ZT as compared to MT and CT (Table 8).

"ZT exhibited superior infiltration parameters compared to conventional tillage on as sandy Alfisol" [36]. As water infiltration into the soil is controlled by the number and connectivity of surface vented macrospores [37], therefore, the practice of ZT may have promoted macro-pores net working resulting in higher water infiltration into the soil as compared to soil which were disturbed under CT and MT practices [38,35]. Similar results were also reported for loam [39] and sandy clay loam [40] soils. "Infiltration, penetration resistance, and crusting/sealing improved under conservation tillage practices as compared to CT systems" [24,41-43].

4. 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

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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