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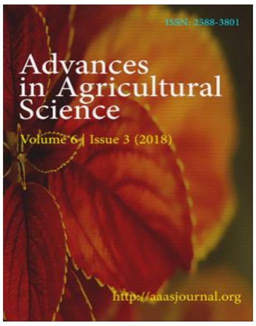

Research Article Open Access

Effects of Different Tillage and Straw Management Systems on Soil Aggregation and Crop Yield in Rainfed Loess Plateau

Stephen Yeboah [1,2,3*], Shirley Lamptey [1,4,5] and Renzhi Zhang [1,3]

[1] Gansu Provincial Key Lab of Arid Land Crop Science, Lanzhou 730070, China.

[2] CSIR–Crops Research Institute, P.O. Box 3785, Kumasi, Ghana.

[3] College of Resources and Environmental Sciences, Gansu Agricultural University, Lanzhou 730070, China.

[4] College of Agronomy, Gansu Agricultural University, Lanzhou 730070, China.

[5] University for Development Studies, P.O. Box TL 1882, Tamale–Ghana.

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* Corresponding Author;
E. Mail: proyeboah@yahoo.co.uk

ABSTRACT

Soil aggregation may be affected by soil tillage and crop rotation in dryland areas. The objective of this study was to determine the effects of different combinations of tillage and straw application on soil aggregation in the soil aggregate fractions after fifteen years of spring wheat–field pea rotation. Experimental work included the following treatments: conventional tillage with straw removed (T), no–till with straw removed (NT), no−till with straw retention on the soil surface (NTS) and conventional tillage with straw incorporated (TS). Soil samples were collected to depths of 0–5 cm, 5–10 cm and 10–30 cm from five points in each plot after harvest of the crop in 2015. Wet–sieving method was used to separate four classes of aggregates, named as large macroaggregate (>2000 μm), small macroaggregate (250–2000 μm), microaggregate (53–250μm) and silt and clay (<53 μm). The results showed that compare with T treatment, all conservation tillage methods significantly reduced soil bulk density and increased total porosity. NTS improved soil saturated hydraulic conductivity significantly at 0-30cm. In surface soil (0–10 cm) NTS and TS treatments increased mean weight diameter (MWD) by 19.23% and 12.52% compared with T treatment, respectively. The aggregate content (≥0.25 mm), Mean weight diameter (MWD), Geometric mean diameter (GMD) of the mechanical stable aggregates had significant positive correlation with crop yields. The result of this study suggests that NTS in Lossiah soils may be a better way to enhance soil productivity and improve soil C sequestration potential.

1. Introduction

Soil plays a crucial role in agricultural production; it is the main supplier of plant's water, fertilizer, gas and heat. However, soil fertility decline is a major problem confronting crop production. This is caused by crop nutrient removal and losses through soil erosion. As a result, most of the soils are poor in the essential plant nutrients required for optimum crop growth leading to low crop yields. The low yield by virtue of the decline thus renders many cropping systems unproductive. Cultivation measures can change the soil physical properties directly and effectively (Page and Dalal 2013; Chan and Heenan, 1996). Studies by many researchers have shown that, reasonable cultivation measures can improve soil structure, reduce soil erosion with unreasonable cultivation measures leading to soil fertility decline, soil and water loss (Chan and Heenan 1996; Zhang *et al.*, 2013). Maintaining innate soil fertility is therefore an urgent priority in any cropping system (Arihara, 2000). According to Grant et al. (2004), effective nutrient management is a critical part of crop production not only to improve financial returns, but also to maintain soil quality (Zanella *et al*., 2018) and reduce the likelihood of damage to the environment. Howarth (2005) stated that management of nutrients to maintain productivity and quality of cropping systems is a challenge that must be met through a combination of organic amendments and management practices. Tillage influences soil processes, predominantly by modifying the physical, chemical and biological properties of soil (Bernal *et al*., 2016). Bulk density is a major soil physical property affected by tillage system (Badalı´kova´ and Knˇa´kal 2000). Some researchers observed a decrease in bulk density under mulch (Khurshid, 2006; Glab and Kulig, 2008; Blanco-Canqui and Lal, 2007) while few reported an increase in the bulk density (Bottenberg *et al.*, 1999). Yet others observed no s ignificant effect of mulching on bulk density (Obalum, 2010). Soil tillage systems also considerably affect soil permeability. Soil infiltration is directly proportional to the stability of soil structure (Tisdall and Adem 1986), pore size, volume and structure (Ankeny *et al.*, 1990; Badalı´kova´ and Hruby´ 2006). Long-term zero-tillage or conventional tillage can change the volume of pores, aggregate stability and organic matter content and consequently the entire soil structure (Singh *et al.*, 1994; Diaz-Zorita *et al.*, 2004). This may also bring about changes to soil properties by influencing infiltration rate of soil and soil water movement. The typical traditional cultivation methods involving excessive turning of arable soil layer causes damage to soil structure. But during fallow periods, soil surface exposure increases evaporation and reduces water use efficiency. A reduction in crop straw leads to low soil organic matter resulting in worst cultivated land quality (Cai *et al.*, 2008). At present, many researchers have reported on different results for soil moisture and infiltration properties, physical properties such as bulk density and crumb structure (Chan and Heenen 1996; Cai *et al.*, 2008; Yeboah *et al*., 2016). These are likely to be influenced by the study area, selected crops, cultivation measures and the observation time length. Besides, results of impact of conservation tillage on soil physical properties are diverse (Xie *et al.*, 2007) and therefore, further study of the effects of conservation tillage on dryland farming requires attention.

2. Materials and methods

2.1 Description of the study area

The research was a layout of long-term conservation tillage experiments from 2001. The study was conducted in 2012/2013 at the Loess Plateau Gully and Hill Region of Lijiabao town, Dingxi city at Gansu agricultural university experimental station. The site has a typical yellow spongy soil. Geographically, the area lies between latitudes 35^0 28' North and longitudes 104^0 44'East of the Greenwich meridian. The study area has a mean annual precipitation of about 390.9 mm with mean annual and accumulated temperatures of 6.4 ^oC and 2933.5 ^oC. Mean annual average sunshine hours of 247.6 h with wilting moisture content of 7.3%. The site has an average altitude of 2000 m. The area has an annual evaporation drying of 2.53^{o}c and annual solar radiation of 594.7 KJ/m^2 with 140 frost-free days.

2.2 Experimental design and treatment description

The experiment **w**as laid out as 2x3 factorial arranged in Randomized Complete Block Design (RCBD) with four replications. The study consisted of 2 phases of spring wheat (cv. Dingxi 38) and field pea (cv. Yannong) double sequence rotation with both phases present in each year. The wheat-field pea double sequence rotation was laid out as wheat

– field pea - wheat (herein referred to as W - P - W) sequence, field pea-wheat-field pea (herein referred to as the P - W - P) sequence. There were 48 plots with a plot size of 20 m x 4 m = 80 m^2. The detail and specific treatments are shown below.

2.2.1 Conventional tillage with stubble removed (T)

The field was ploughed 3 times and harrowed twice after harvesting. The first plough was conducted in August immediately after harvesting; the second and third ploughs were in late August and September respectively. The plough depths were 20 cm, 10 cm and 5 cm, respectively. The field was harrowed after last cultivation in September and re-harrowed in October before the ground is frozen. This is the typical conventional tillage practice in Dingxi Region.

2.2.2 No- till with no stubble (NT)

No-till was conducted throughout the experimental period. Seed sowing and fertilization was performed with seeding-machine at the same time.

2.2.3 Conventional tillage with stubble incorporating (TS)

The field was ploughed and harrowed exactly as that of T treatment (3 ploughs and 2 harrows), but with straw incorporated at the first plough. All the straw from the previous crop was sent back to the original plot immediately after threshing and then incorporated into soil.

2.2.4 Conventional tillage with plastic mulching (TP)

The field was ploughed and harrowed exactly the same as that for T treatment (3 ploughs and 2 harrows), but covered with plastic after the last harrow in October. Plastic film was laid out between crop rows with a covering belt width of 40 cm. Row spaces between crops were 40 cm and 10 cm alternatively, with an average of 25 cm.

2.2.5 No till with plastic mulching (NTP)

No-till was throughout the experimental period. The plastic film was laid in October. To avoid the damage of plastic film, the crop residue was mowed or/and harrowed after harvesting.

2.3 Data measurement

2.3.1 Determination of soil bulk density (ℓ_b)

This was determined using the beveled stainless steel ring method, 100 cm^3 with 5.05 cm diameter and 5.00 cm height (Carter, 1993). The core sampler was driven into the soil with the aid of a mallet to a depth of 0-5 cm, 5-10 cm and 10-30 cm. Soil at both ends of the tubes was trimmed and the end flushed with a straight-edged knife. The core sampler with its content was oven-dried at 105^0C to a constant weight, removed, allowed to cool and its weight taken to determine bulk density.

2.3.2 Porosity (ƒ)

This was computed from the relation:

$$\text{Porosity } (f) = 1 - \frac{\ell_b}{\ell_s} \quad (1)$$

where:

ℓ_b = dry bulk density

ℓ_s = particle density, with a value of 2.65 g cm^{-3}

2.3.3 Soil aggregate

The soil aggregate was determined by using dry sieve and Savinov's methods (CAS, 1978). Wet sieve method (CAS, 1978) was used to determine mechanical stability aggregates and water stable aggregate content. Van Bavel (Van, 1949) and Mazurak *et al*. (1950) methods were used for the mean weight diameter [MWD, mm and geometric mean diameter [GMD (mm)] for the characterization of aggregate stability.

$$MWD = \frac{\sum_{i=1}^{n}(\overline{R_i} w_i)}{\sum_{i=1}^{n} w_i} \quad (2)$$

$$GMD = Exp\left[\frac{\sum_{i=1}^{n}(w_i \ln \overline{R_i})}{\sum_{i=1}^{n} w_i}\right] \quad (3)$$

Where R_i is a certain level of aggregate average diameter, w_i is the level of aggregate dry weight.

2.4 Data analysis

The data were statistically analysed using SPSS 10.0 software package (SPSS, Chicago, IL, USA) and thereafter pairs of mean values were compared by the least significant difference (LSD) at 5% significance level.

3. Results

3.1 Soil bulk density and total soil porosity

The soil bulk density was significantly lower (1.03 g/cm^3, 1.08 and 1.18 g/cm^3) with the Wheat-Pea-Wheat (W - P - W) sequence at 0 - 5 cm, 5-10 and 10-30 cm soil layers respectively (Table 1). NTS produced soil bulk density that was significantly lower than TP, NT, T and TS treatments at 0-5 cm, 5-10 cm and 10-30 cm depths. The result shows that T produced the highest bulk density (1.22, 1.27 1nd 1.33 g/cm^3) at all the soil layers respectively. NTS consistently recorded significantly the lowest soil bulk density at all the soil layers of the experiment. NTS produced the highest total soil porosity (61.12, 59.11 and 55.34 g/cm^3) with Wheat-Pea-Wheat (W - P - W) sequence at 0-5 cm, 5-10 cm and 10-30 cm respectively. NTS was significantly higher ($p<0.05$) than TP, TS, NT and T in the 0-5 cm, 5-10 cm and 10-30 cm. NTP treatment was significantly higher ($p<0.05$) than that of TP, NT, T and TS. T consistently produced the lowest total soil bulk density at all the soil layers.

T produced the highest soil bulk density at all the soil depths sampled for P – W - P with NTS producing the lowest bulk density at both depths. With Pea-Wheat-Pea (P - W – P), in all the soil layers, T recorded significantly low ($p>0.05$) total soil porosity compared to the other treatments. NTS produced consistently the highest total soil porosity at all the depths compared to TP, TS, NT and T.

3.2 Soil aggregate stability

3.2.1 Soil aggregate quantity

Wheat-Pea-Wheat (W - P - W) sequence under wet-sieving method at the depth of 0 -- 5 cm of 0.25 mm aggregate content of water stability, increased in the order NTS>NTP>TS>TP>NT>T (Table 2). NTS obtained the highest soil aggregate stability under both wet and dry sieving methods. The treatments NT, TS, NTS, TP and NTP for 0-5 cm increased by 1.84%, 19.29%, 36.74%, 17.91%, 23.08% respectively.

In the 5-10 and 10-30 cm soil layers under 0.25 mm, NTS consistently produced the highest soil aggregate stability for both wet and dry sieve methods. The ≥ 0.25 mm or greater aggregate content of water stability, increased in the order NTS>NTP>NT>TS>TP>T for both wet and dry sieve methods for all the depths. The treatment T produced the lowest soil aggregate stability for all the soil depths sampled for both wet and dry sieve methods. NT, TS, NTS, TP, NTP treatment for 0.25 mm soil aggregate content increased by 1.36%, 33.18%, 55.76%, 6.82%, 37.42% respectively for 5-10 cm. With 10-30 cm soil aggregate content increased by 24.44%, 46.13%, 74.53%, 28.23% and 40.62% respectively. Under the P - W - P sequence, similar results were obtained for the soil aggregate content.

Table 1. Effect of different tillage treatments on Soil bulk density and Total soil porosity

Depth (cm)	Treatments	W→P→W		P→W→W	
		(g·cm^{-3})	(%)	(g·cm^{-3})	(%)
0-5 cm	T	1.22a	54.03d	1.25a	52.71c
	NT	1.17ab	56.06cd	1.23a	53.80c
	TS	1.13bc	57.49bc	1.19a	55.02c
	NTS	1.03d	61.12a	1.06c	60.10a
	TP	1.17ab	55.07cd	1.24a	53.31c
	NTP	1.06cd	59.92ab	1.13b	57.43b
5-10 cm	T	1.27a	51.99c	1.31a	50.68c
	NT	1.23ab	53.63bc	1.25ab	52.74bc
	TS	1.16bc	56.23bc	1.25ab	52.94bc
	NTS	1.08c	59.11a	1.11c	58.17a
	TP	1.19bc	55.83bc	1.26ab	52.50bc
	NTP	1.13bc	57.38ab	1.16bc	56.22ab
10-30 cm	T	1.33a	49.96b	1.34a	49.58b
	NT	1.31a	50.64b	1.30a	50.94b
	TS	1.28a	51.78b	1.24ab	53.13ab
	NTS	1.18b	55.34a	1.18b	55.33a
	TP	1.31a	50.75b	1.30ab	51.14ab
	NTP	1.26a	52.73b	1.24ab	53.06ab

Note: The lower case letter stand for significance at P <0.05

Table 2. Effect of different treatments on soil aggregates content (≥0.25 mm) by dry and wet sieving

Rotation	Treatment	Dry sieve (%)			Wet sieve (%)		
		0-5cm	5-10cm	10-30cm	0-5cm	5-10cm	10-30cm
W→P→W	T	57.98a	61.06a	74.36a	8.71a	6.60b	5.81b
	NT	59.87a	62.69a	77.21a	8.87a	6.69b	7.23ab
	TS	61.40a	71.67a	84.79a	10.39a	8.79ab	8.49ab
	NTS	70.99a	76.48a	88.41a	11.91a	10.28a	10.14a
	TP	61.14a	64.75a	80.85a	10.27a	7.05b	7.45ab
	NTP	65.41a	74.89a	84.85a	10.72a	9.07ab	8.17ab
P→W→P	T	53.76a	66.17a	65.99a	7.50a	6.27a	5.34a
	NT	59.98a	67.05a	72.10a	7.72a	6.44a	6.31a
	TS	62.54a	71.64a	76.29a	8.87a	7.39a	7.12a
	NTS	71.08a	78.73a	83.33a	11.22a	10.53a	9.21a
	TP	60.46a	71.54a	71.27a	8.33a	7.12a	6.72a
	NTP	63.80a	78.18a	80.51a	9.93a	8.31a	7.39a

Note: The lower case letter stand for significance at P <0.05

3.2.2 Soil aggregate size

Results of table 3 shows that under the two sequences, MWD and GMD the values for the dry sieving method were higher than wet sieving method. In the W - P - W sequence, NTS produced the highest MWD and GMD under both dry and wet sieving methods for all the depths sampled. The treatment T also resulted in the lowest MWD and GMD for all the depths sampled. In 10 to 30 cm soil layer under the dry sieve method, the MWD recorded significant difference (P<0.05) between the treatments. Under wet sieving method, in all the soil layers, both MWD and GMD did not record any significant difference (P>0.05) between the treatments.

Table 4 shows that in the P - W - P sequence, NTS produced the highest MWD and GMD values for all the soil layers sampled for both dry and wet sieving methods. The treatment T produced the lowest MWD and GMD values for all the soil layers sampled. In the 5-10 cm soil layer for dry sieve method, significant difference (P<0.05) were observed among the treatments for MWD. For the wet sieve method, significant differences were observed among treatments at the 5-10 cm soil layer.

3.3 crop yields

Results in table 5 under the W-P-W sequence shows that NTP produced the highest grain yield (1857 kg/hm^2) and this was closely followed by NTS (1723 kg/hm^2). NTP and NTS were significantly different (P>0.05) from the other treatments. The grain yield obtained increased in order NTP > NTS > > TS TP > NT > T.

In the P - W - P sequence, NTS recorded the highest grain yield (1428 kg/hm^2). The grain yield obtained increased in the order NTS>NTP>TS>TP>NT>T. The treatment NTS was significantly (P>0.05) higher than TP, TS, NT and T. In both sequences, the treatment T produced the lowest grain yield.

3.4 Correlation Analysis

Table 6 shows the correlation between crop yield and soil physical indicators. The data for the various soil layers was analyzed to find out the relationship between the crop yield and the indicators of the soil physical characteristics. Saturated hydraulic conductivity (SHC) had no significant positive correlation with any of the measured index. Bulk density had negative significant correlation with crop yield. MWD [dry sieve (ds)] and GMD [dry sieve (ds)] had significant positive correlation with total porosity (TP), 0.908** [dry sieve (ds)] and 0.908** [wet sieve (ws)]. MWD [wet sieve (ws)] and GMD [wet sieve (ws)] had high significant positive correlation with crop yield. The significant positive correlation between TP, MWDS [wet sieve (ws)], MWD [dry sieve (ds)] and GMD [dry sieve (ds)] and GMD [wet sieve (ws)] could significantly boost crop yields, indicating a good soil structure has a positive effect on crop yield (CY).

4. Discussion

Soil bulk density increased along with the increasing soil depth whiles soil total porosity on the other hand decreases with increasing depth. This result is consistent with the findings by (Cai *et al.*, 2012). Zhang *et al*. (2011) who noted that conservation tillage treatments can reduce soil bulk density and increase total soil porosity. NTS treatment significantly reduced soil bulk density and increased the total porosity at 0-30 cm, while NTP treatment in soil layer of 0 -10 cm reduced the soil bulk density and increased soil total porosity significantly. This is mainly due to the The real biological activity of the soil, which is improved by no tillage and addition of straw (Stellin *et al.*, 2017) Straw mulching reduces the exposure of the soil surface and alleviate the impact of the external forces on the soil structure causing a reduction in soil "skinning" and "harden" phenomenon in addition to biological force” that makes and enlarge the soil aggregates.

The mechanical stability of aggregate content (≥0.25 mm) of MWD and GMD increased along with

Table 3. Effect of different treatments on MWD and GMD of dry and wet sieving under wheat→ pea→ wheat rotation

Index	Treatment	Dry			Wet		
		0-5cm	5-10cm	10-30cm	0-5cm	5-10cm	10-30cm
MWD (mm)	T	1.69a	1.82a	2.21b	0.31a	0.30a	0.28a
	NT	1.76a	2.01a	2.39ab	0.34a	0.31a	0.29a
	TS	1.81a	2.28a	2.51ab	0.36a	0.32a	0.30a
	NTS	2.07a	2.58a	2.71a	0.39a	0.35a	0.32a
	TP	1.84a	2.08a	2.47ab	0.35a	0.31a	0.29a
	NTP	1.90a	2.35a	2.63ab	0.37a	0.33a	0.31a
GMD (mm)	T	0.99a	1.11a	1.28b	0.28a	0.27a	0.26a
	NT	1.05a	1.23a	1.36ab	0.31a	0.27a	0.27a
	TS	1.09a	1.35a	1.44ab	0.32a	0.29a	0.28a
	NTS	1.25a	1.49a	1.61a	0.34a	0.32a	0.29a
	TP	1.15a	1.33a	1.40ab	0.31a	0.28a	0.27a
	NTP	1.18a	1.40a	1.52ab	0.33a	0.29a	0.28a

Note: The lower case letter stand for significance at $P < 0.05$

increasing soil depth and the water stability of aggregate and vice versa. This results is consistent with Li *et al.* (2012) who compared conventional and conservation tillage practices and concluded that NTS can improve both the mechanical stability of soil aggregate in the rotation sequence and aggregate content of water stability (≥0.25 mm). Studies have also shown that conservation tillage can improve the mechanical stability of aggregate content and soil particle size (Cai *et al.*, 2012) as compared with conventional tillage and it can also increase the soil aggregate water stability at all levels (Blevins *et al.,* 1983). This is mainly due to the reduction of soil disturbance by conservation tillage. Conservational tillage can also improve the content of soil microbial biomass (Cai *et al,* 2009; Yeboah *et al*., 2016) and organic matter content (Lu and Li 2002; Bernal et al., 2016).

Compared with conventional tillage treatments, conservation tillage treatments significantly boosted crop yields with NTS and NTP recording higher crop yield than the other treatments. The results obtained are consistent with the findings of Chan and Heenan 1996 unlike previous findings of Huang *et al.*, 2006. Soil structure improves after long-term implementation of conservation tillage. Highly significant positive correlation were observed between R0.25(ds), R0.25(ws),MWD (ds), GMD (ds), MWD (ws) and GMD (ws) and crop yield. This indicates the expected influence of these indicators on crop yield.

Table 4. Effect of different treatments on MWD and GMD of dry and wet sieving under pea→ wheat →pea rotation

Index	Treatment	Dry			Wet		
		0-5cm	5-10cm	10-30cm	0-5cm	5-10cm	10-30cm
MWD(mm)	T	1.72a	1.83d	2.22a	0.31a	0.29a	0.27a
	NT	1.83a	1.92cd	2.39a	0.32a	0.30a	0.28a
	TS	1.94a	2.34ab	2.58a	0.34a	0.31a	0.30a
	NTS	2.16a	2.56a	2.72a	0.38a	0.35a	0.33a
	TP	1.88a	2.18bc	2.45a	0.32a	0.30a	0.28a
	NTP	2.04a	2.30ab	2.55a	0.35a	0.32a	0.30a
GMD(mm)	T	0.96a	1.07a	1.19a	0.28a	0.27b	0.26a
	NT	1.11a	1.22a	1.32a	0.29a	0.28b	0.26a
	TS	1.19a	1.31a	1.44a	0.31a	0.29ab	0.28a
	NTS	1.27a	1.49a	1.61a	0.34a	0.32a	0.29a
	TP	1.20a	1.29a	1.40a	0.29a	0.29ab	0.27a
	NTP	1.25a	1.39a	1.52a	0.31a	0.30ab	0.27a

Note: The lower case letter stand for significance at P <0.05

Table 5. Effects on Grain yields under different treatments

Treatment	W→P→W		P→W→P	
	(kg·hm^{-2})	(%)	(kg·hm^{-2})	(%)
T	1229c	—	839c	—
NT	1419b	15.46	1051b	25.22
TS	1526b	24.17	1152b	37.25
NTS	1723a	40.2	1428a	70.17
TP	1468b	19.45	1106b	31.77
NTP	1857a	51.1	1241ab	47.82

Note: The lower case letter stand for significance at P <0.05.

Table 6. Relationship between Soil Physical Properties and Grain yield

	TP	SHC	$R_{0.25(ds)}$	$R_{0.25(ws)}$	$MWD_{(ds)}$	$GMD_{(ds)}$	$MWD_{(ws)}$	$GMD_{(ws)}$	CY
BD	0.973**	0.145	0.766**	0.801**	-0.898**	-0.900**	-0.978**	-0.960**	0.801**
TP		0.159	0.761**	0.799**	0.908**	0.908**	0.977**	0.960**	0.796**
SHC			-0.351	-0.128	0.242	0.107	0.134	0.200	0.107
$R_{0.25(ds)}$				0.534	0.806**	0.778**	0.385	0.318	0.783**
$R_{0.25(ws)}$					0.626*	0.675*	0.832**	0.678*	0.872**
$MWD_{(ds)}$						0.973**	0.894**	0.915**	0.577*
$GMD_{(ds)}$							0.879**	0.892**	0.639*
$MWD_{(ws)}$								0.966**	0.825**
$GMD_{(ws)}$									0.753**

* Correlation is significant at P < 0.05 ** Correlation is significant at P < 0.01

Conclusions

The results of this study showed that conservation tillage can reduce soil bulk density and increase the soil total porosity. NTS treatment significantly reduced the 0 to 30 cm soil layer bulk density and significantly improved 0-30 cm soil total porosity and saturated hydraulic conductivity. Conservation tillage increases 0 to 30 cm depth soil mechanical stability and water stability of aggregate content (≥0.25 mm) , MWD and GMD. Bulk density had significant negative correlation with crop yield with total porosity recording significant positive correlation with crop yield. Mechanical stability of the aggregate content, MWD and GMD had significant and positive correlation with crop yield. Long-term implementation of conservation tillage by practicing No tillage with straw incorporated (NTS) could significantly improve soil structure, quality and stability resulting in crop yield increases.

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