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The Effects of Tillage Systems on Some Soil Physical Properties and Grain Yield of Bread Wheat Under Tropical Conditions

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Abstract

This study was conduct during (2012/13 - 2013/14) seasons at the Experimental Farm of the Faculty of Agriculture, Nile Valley University, Darmali, Sudan to evaluate the effects of conventional tillage, minimum tillage and Zero tillage on soil bulk density, infiltration rate, soil moisture content, and crop yields under tropical condition Northern Sudan. The experimental design was randomized complete block with three replications. The treatments consisted of conventional tillage treatments disc plow followed by land leveller (DPL), conservation tillage disc harrow followed by land leveller (DHL) and zero tillage (ZT). The results revealed that soil bulk density in both seasons of the two layers (0-15 and 15-30 cm) decreased from before to after tillage by 33, 36 and 31%, for DPL, DHL and ZT systems, respectively. There were no detectable differences in soil bulk density on the third layer (depth 30-45 cm). The soil infiltration rate increased from before to after tillage in DPL, DHL and ZT by 98, 93 and 84% in the first season and by 82, 140 and 4% in the second season, respectively. However, the DHL and ZT systems displayed similar performance for the infiltration rate after the 50 mins. Soil moisture content increases with depth and then decreases at specific depths throughout the treatments. The maximum leaf area index was attained at conventional tillage systems (DPL) followed by conservation tillage (DHL) and ZT systems. The higher grain yield recorded in the first season by DH conservation tillage system (2295 kg ha^{-1}) followed by DPL tillage system (1470 kg ha^{-1}) and (810 kg ha^{-1}) for the ZT system. However, during the second season the significant difference was recorded between the ZT system and the two tillage systems DPL and DHL. The grain yield in the ZT system was the highest with 1383 kg ha -1, followed by DPL system 1033 kg ha^{-1}, while, DHL system yielded the lowest (607 kg ha^{-1}). Compared to the DPL and DHL systems, ZT system increased yield by 350 and 676 kg ha^{-1}, respectively.

Keywords

Tillage, Wheat, Soil Properties, Infiltration Rate

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1. Introduction

The total area of Sudan is about 188 million hectares of which 84 million hectares could easily be cultivable. Production in Sudan are impeded by various challenges such as absence of mechanization and modern technologies, The actual agricultural challenges today's are decreasing productivity, limited resources with decreasing human resources and their rising costs as an implications of socioeconomic changes [1, 2].

Maintaining optimum crop yield with economic and environmental returns required applying desirable agronomic

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practices such as tillage. Conservation tillage has been recommended by so many researchers [3, 4], to improve soil physical properties such as soil moisture, bulk density, soil strength and water availability for crops.

Tillage defined as the mechanical management of the soil to optimize conditions for germination, seedling establishment and crop growth. Tillage operation affecting significantly the soil characteristics such as soil temperature, evapotranspiration processes, infiltration and soil water conservation [5]. In field crop cultivation, soil tillage is usually considered as one of the largest consumers of energy and labor.

Frequent use of conventional tillage operations can produce hardpans in the subsoil, which can be negative effect to root development and water infiltration, resulting in constrained crop yield [6, 7 and 8].

A current trend in modern arable farming is the elimination of excessive cultivation by reducing tillage practices. In general, reduced tillage treatments need lower operation costs and gave economic returns compared with conventional tillage. The conservation tillage systems showed positive performances, in terms of reduced demand of fuel consumption and labour, best soil surface levelling and lower energy requirements [9].

The conservation agriculture, experienced over 96 million hectare area worldwide have proved to be energy and input efficient, it can contribute to improve production and income, and addressing the environment and soil health problems [10, 11]. The resource conservation technologies include zero or minimum tillage with direct seeding using seed drill and bed planting innovations in residue management to avoid straw burning, and crop diversification [12, 13].

Reducing tillage improves soil properties (physical, chemical and biological) and crop yields [14, 15]. However, wheat productivity was lower under reduced tillage and no-tillage than under conventional tillage [16]. On the other hand, comparable wheat yields between conventional and conservation tillage systems may be obtained under dry climates [17].

Studies on wheat, under minimum and zero tillage systems, are scarce and the results are not consistent because of different experimental conditions. Therefore, the objective of this study was to evaluate the effects of tillage systems on soil bulk density, infiltration, soil moisture content and grain yield of bread wheat in tropical conditions of Northern Sudan.

2. Materials and Methods

Field experiments were conducted during 2012/2013 and 2013/2014 seasons at the Experimental Farm of the Faculty of Agriculture, Nile Valley University, Darmali, Sudan (17°48' N; 34°00' E; altitude 346.5 meters). Treatments of the three tillage systems: disc plow followed by land leveller (DPL), disc harrow followed by land leveller (DHL) and zero tillage were arranged in completely randomized block design with three replications. The depth of plowing was mostly within the range of 20-25 cm and the harrowing within the range of 8-10 cm. The wheat cultivar Imam was sown at plot size of 1.5 ×10 m^2, on 21th November 2012 and 25th November 2013, at a seed rate of 100 kg ha^{-1}. Sowing was carried by a seed driller 2 m width lifted on tractor. Irrigation intervals was 7-10 days, total number of irrigations were ten. Phosphorous (48% P_2O_5) was applied before sowing and urea (46% N) was applied in split dose as a source of nitrogen, half-dose applied at sowing and the rest four weeks after sowing

Soil physical and chemical properties for the experimental site was analyzed in Hudeiba Research Station Laboratory and were presented in Table 1.

Soil bulk density measured by soil samples taken from plots at random locations, from the depths 0-15 cm, 15-30 cm and 30-45 cm. The samples were collected by cylindrical tubes hammered to the appropriate depth. The samples, were transferred to the laboratory, where they were dried in an oven. The bulk density was calculated as follows:

$$\text{Bulk density } (g\ cm^3) = \frac{\text{Dry wt. of the sample (g)}}{\text{Volume of the cylinder } (cm^3)}$$

Volume of cylinder $= \pi \times r^2 \times h$, where r = radius of the tube (cm), h = height of the tube (cm) and π = 3.14

Table 1. Soil physical and chemical properties of the experimental site.

Soil properties	Value
Calcium carbonate (%)	15
Organic matter (%)	0.042
Nitrogen (ppm)	140
Phosphorus (ppm)	1.1
Exch. sodium percentage	1.2%
Electric conductivity (ds/m)	0.85
Soil texture	
Sand (%)	35
Clay (%)	63
Silt (%)	02
P^H	7.4

Infiltration rate was measured at before and after tillage systems by fixing three sets of double rings infiltrometer randomly fixed per plot. The elapsed time was recorded against depth of infiltrated water into the soil. Using the elapsed time in minutes and the depth in cm, the infiltration rate can be calculated as follows:

$$\text{The infiltration rate } (\text{cm hr}^{-1}) = \frac{\text{Depth in cm}}{\text{time in minutes}} \times 60$$

For soil moisture content determination soil samples were randomly selected within plots and samples were taken by auger from three soil depths 0-15, 15-30 and 30-45 cm. The samples were transferred to the laboratory using polyethylene bags. Samples were weighed wet and then dried with oven. The soil moisture content on dry basis calculated as follows:

$$M\% = \frac{W_1 - W_2}{W_2 - W_3}$$

Where:

W_1= weight of bag with wet sample, W_2= weight of bag with dry sample, W_3 = weight of empty bag and M = moisture content%.

Leaf area index was calculated by the following formula suggested by Voldeng and Simpson [18]:

Leaf area per plant (cm^2) = length × maximum width × 0.79

$$\text{Leaf area index} = \frac{\text{leaf area per plant (cm}^2)}{\text{ground area per plant (cm}^2)}$$

Grain yield per unit area was obtained from the three center rows of each plot. To avoid border effect 0.5 m of every side in each plot was not considered when harvesting, then grain yield was determined in kg ha^{-1}.

The data were statistically analyzed using analysis of variance to test the significance of treatment effects using the SPSS statistical program.

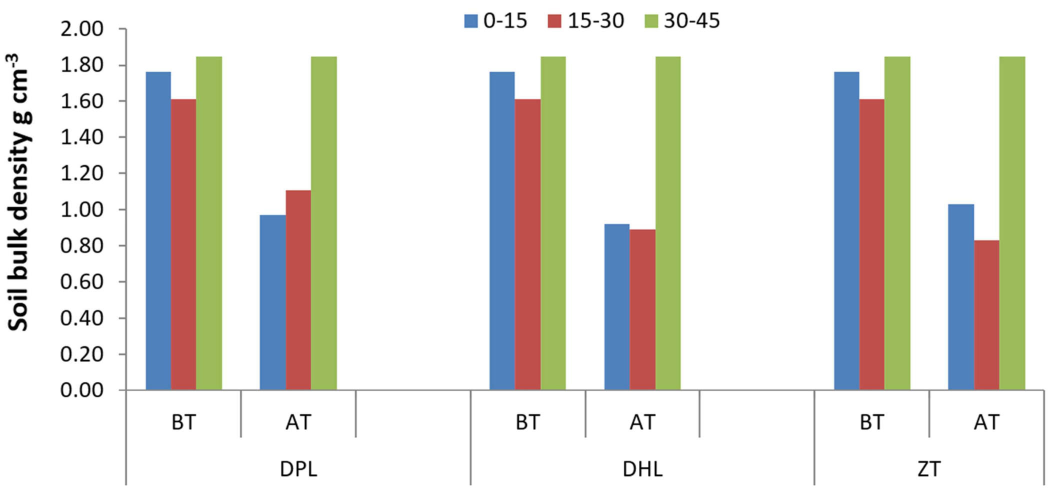
3. Results and Discussion

3.1. Soil Bulk Density (SBD) (g cm^{-3})

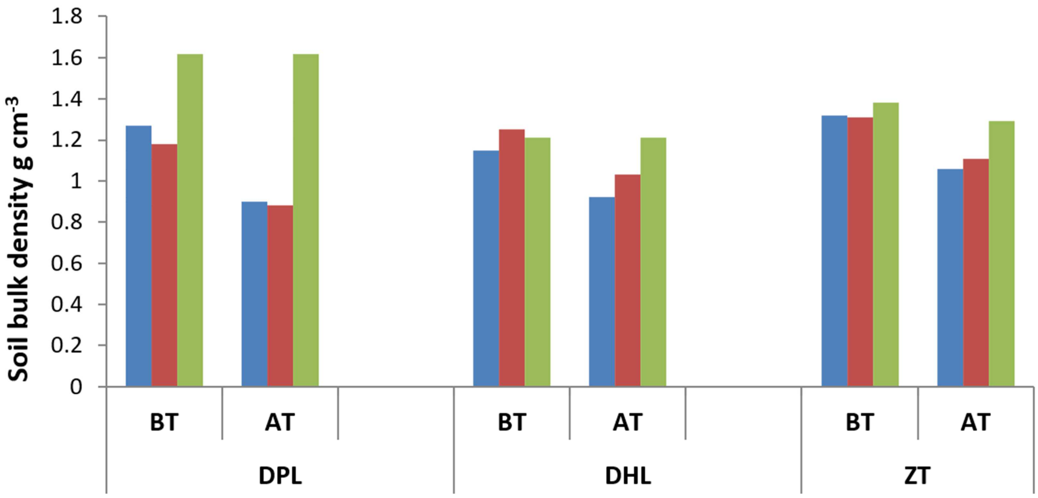
Figure 1 (a and b) showed progressive variation of SBD of three layers 0-15, 15-30 and 30-45 cm under three tillage systems; disc plow - land leveller (DPL), disc harrow - land leveller (DHL) and zero tillage (ZT). The results obtained for the first season (2012/2013) SBD of the first layer 0-15 cm decreased from before to after tillage by 45, 48 and 42%, for DPL, DHL and ZT systems, respectively. Where as in the second season (2013/2014) for the first layer 0-15 cm depth, the SBD decreased from before to after tillage by 29, 25 and 20% for DPL, DHL and ZT systems, respectively.

For the second layer (depth 15-30 cm) season 2012/2013, SBD decreased from before to after tillage by 31, 45 and 48%, respectively. However, for second layer (15-30 cm) season 2013/2014, SBD decreased from before to after tillage by 25, 25 and 15%, respectively. Whereas on the third layer (depth 30-45 cm) for the two seasons there were no detectable differences in soil bulk density. Nevertheless, numerous literature studies reported contradictory results of ZT conservation system effects on SBD. In some cases, the ZT system has been found to decrease the SBD (decrease compaction) [19, 20], in other studies it increases the SBD [21, 22] while in some trials no differences were detected [13]. These results indicated that the effect of ploughing and harrowing in land preparation for the two consecutive seasons in reducing soil compaction was limited to a depth of 30 cm. On ZT conservation system the surface soil (0-15 cm), SBD affected by seed drill (decreased by 42%) and this is necessary for seed bed preparation. These results revealed that replication of land preparation procedure using disc plow, disc harrow followed by land leveller for consecutive seasons may not add positive outcome. On the other hand, using ZT system may decrease the cost of land preparation.

Generally, the soil bulk density increases with depth for all treatments. There were odd results and this was mostly due to the presence of hard pans on the top layer of the soil. The lowest bulk density results were recorded after tillage treatments than before tillage and that was because when the soil being disturbed the interspaces between the clods increased and this lead to bigger volume for the same weight. The mean value of soil bulk density for the two seasons showed the lowest values when the lands was being treated with disc plow and this agree with the findings of Nayel et al. [23].



(a)



(b)

Figure 1. Soil bulk density for the three soil layers under the three tillage systems DPL: Disc plow followed by land leveler DHL: Disc harrow followed by land leveler, ZT: Zero tillage, BT: Before tillage, AT: After tillage during (a) 2012/2013 and (b) 2013/2014.

3.2. Infiltration Rate (cm hr^{-1})

The infiltration rate increased from before to after tillage in DPL, DHL and ZT by 98, 93 and 84% in the first season and by 82, 140 and 4% in the second season, respectively (Figure 2). The results observed that the infiltration rate on ZT system at the beginning of the second season (before drilling) increased with 23% as compared with 55 and 60% for DPL and DHL, respectively. This can be justified by soil compaction excused by the machines movement. The infiltration rate at the second season for the ZT system increased by just 4%, these results in the same line with those of Ruiz et al. [24].

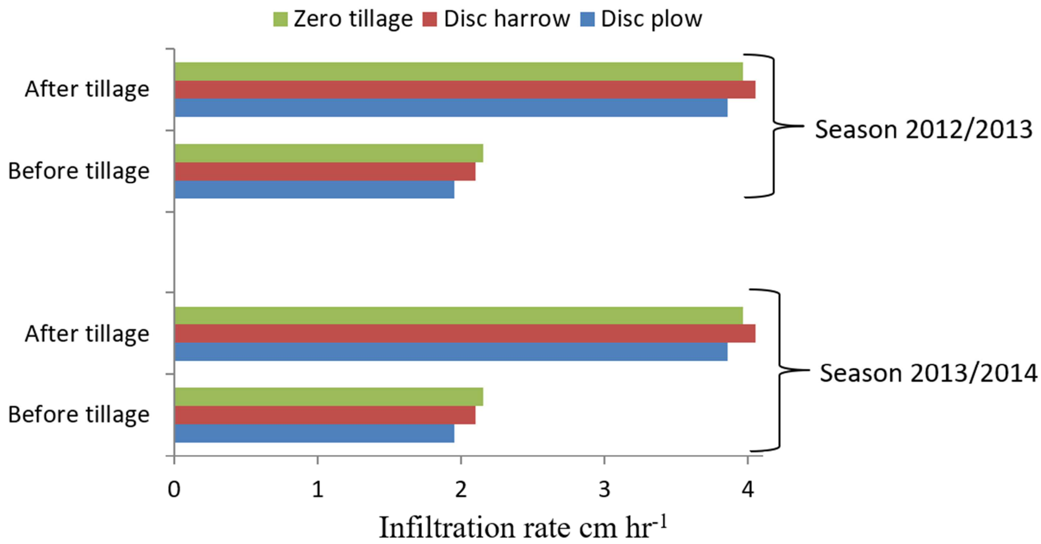


Figure 2. Soil infiltration rate for the three tillage systems before and after tillage for the two seasons.

As shown in Figure 2, soil infiltration rate under three tillage systems (DPL, DHL and ZT) decreased with time. During the first ten minutes, no differences occurred on accumulated infiltrated water depth between the three tillage systems (for the two seasons). These negligible differences probably due to the similarity of soil physical properties in the upper layer. In the second season, the DPL (conventional tillage system) showed different behaviour (not significant difference) for the infiltrated rate after the 50 minutes. Whereas, the conservation tillage systems (DHL and ZT) displayed similar performance for the infiltration rate after the 50 min.

Generally, the infiltration rate is higher after tillage treatments than before tillage application. The highest infiltration rate was observed with conventional tillage system treatment (disc plow). At the beginning of the infiltration process after tillage operations showed high rates of infiltration among treatments, but as time elapsed the infiltration rates appeared to be the same as shown in Figure 3.

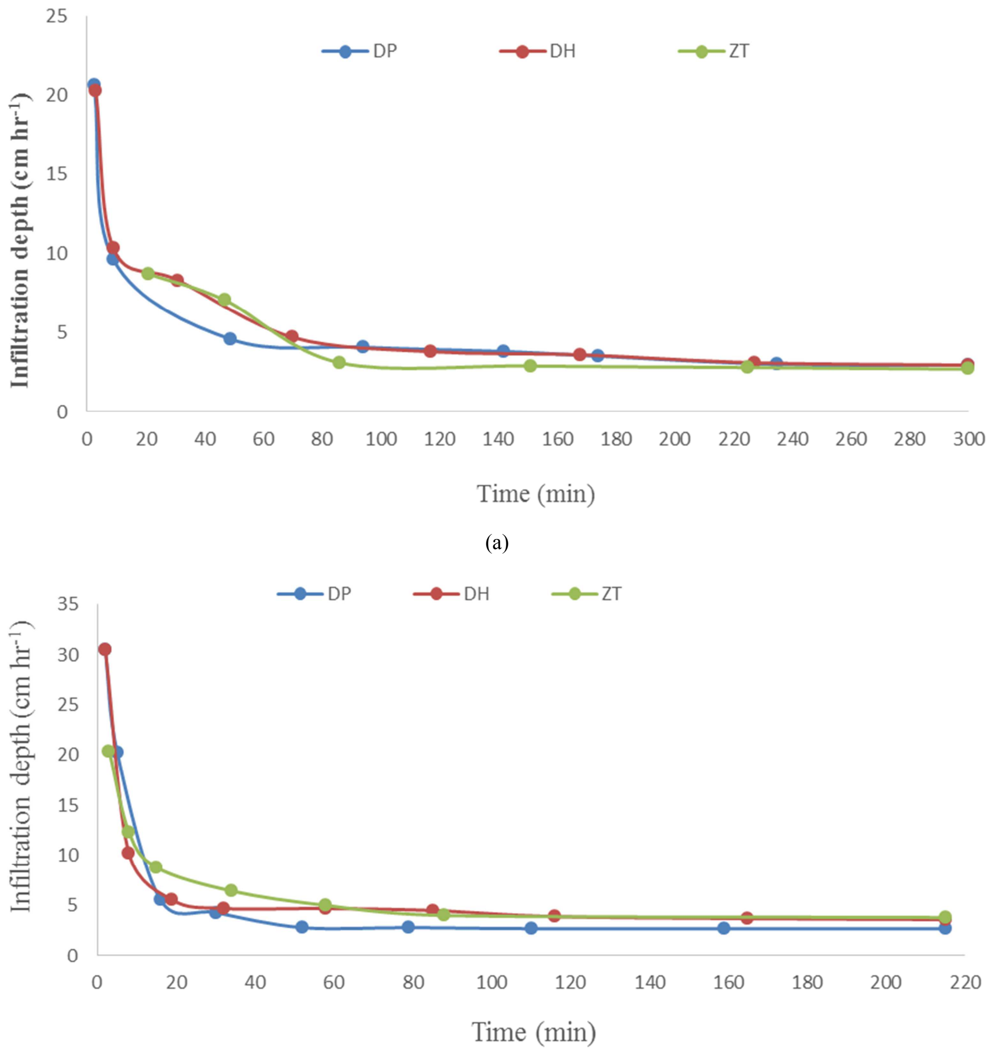


Figure 3. Changes in soil infiltration rate under tillage treatments disc plow (DP), disc harrow (DH) and zero tillage (ZT) during (a) 2012/2013 and (b) 2013/2014.

3.3. Soil Moisture Content (%)

The soil moisture content was shown in table 2. In general, for all treatments during both seasons, soil moisture content increases with depth and then decreases at specific depths. Through all treatments the highest soil moisture content was recorded within depths 15-30 cm and this could be explained by the tillage treatment for the soil. The totals appear to be nearly equal and this shows that the soil texture (more sand) has the greater effect on soil moisture content than the tillage treatments. The results agreed with results of Nayel et al. [23] and could be explained by the changes impeded in soil structure which resulted in more voids and spaces for water to percolate into the soil.

3.4. Leaf Area Index (LAI)

Leaf area index followed a similar trend as the grain yield (Figure 4). In all tillage systems leaf area index increased steadily till 60 days after sowing and declined thereafter due to leaf senescence. The maximum leaf area index was attained at DPL (conventional tillage systems) followed by DHL and ZT (conservation tillage system). Several studies indicated that total resistance in the soil-plant system increases with decreasing soil-water potential, which leads to reduce the photosynthesis activity and growth [25, 26].

Table 2. Soil moisture content as affected by tillage systems.

Season	2012/2013			2013/2014		
Tillage system	DP	DH	ZT	DP	DH	ZT
Depth						
0-15	16.0	16.0	14.6	19.2	22.0	19.5
15-30	17.0	17.5	20.0	21.0	22.4	21.2
30-45	16.1	17.3	16.5	20.8	21.2	20.3

3.5. Grain Yields (kg ha^{-1})

In the first season, tillage systems DH and DP significantly improved grain yield as compared to ZT (Table 3). The higher grain yield recorded by DH conservation tillage system (2295 kg ha^{-1}) followed by DP system (1470 kg ha^{-1}) and (810 kg ha^{-1}) for the ZT system.

However, during the second season the significant difference was observed between the ZT system and the two tillage systems DP and DH. Among the three tillage systems, the grain yield in the ZT system was the highest grain yield with 1383 kg ha $^{-1}$, followed by DP system 1033 kg ha^{-1}, while, DH system yielded the lowest (607 kg ha^{-1}). Compared to the DP and DH systems, ZT system increased yield by 350 and 676 kg ha^{-1}, respectively. This different yield may be attributed to soil properties improvements as a result of increases in soil fertility. It may be due to greater inorganic N and N uptake. These results agreed with those obtained by [27, 28].

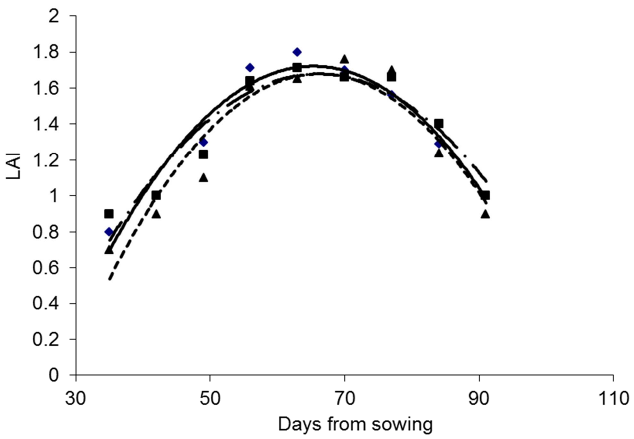


Figure 4. Leaf area index as affected by tillage methods (disc plow, disc harrow and zero tillage) during 2012/2013 season.

Table 3. Mean grain yield as affected by tillage systems.

Season	**Grain yield (kg ha^{-1})**	
	2012/2013	**2013/2014**
Tillage Systems		
Disc Plow	1470b	1033b
Disc Harrow	2295a	607b
Zero Tillage	810c	1383a
C.V.%	14.3	11.3

Means followed by different letters in a column are significantly different. According to LSD (P≤0.05)

4. Conclusion

In this study the soil bulk density decreased from before to after tillage by 33, 36 and 31%, for DPL, DHL and ZT tillage systems, respectively. The infiltration rate increased from before to after tillage in the three tillage systems. The maximum leaf area index was attained at conventional tillage systems (DPL) followed by conservation tillage system (DHL and ZT). In the first season, tillage systems DHL and DPL significantly improved grain yield as compared to ZT system. However, the grain yield in the second season for the ZT system was the highest. Compared to the first season higher grain yield in ZT system may be due to improvements in soil properties. So, conservation tillage systems (DH and ZT) can be recommended for wheat production in tropical conditions of Northern Sudan.

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