RESEARCH ARTICLE

EFFECT OF CONSERVATION TILLAGE SYSTEMS AND WATER SAVING ON THE PRODUCTIVITY OF WHEAT AND BARLEY CROPS UNDER SEMI-ARID CONDITIONS OF SUDAN

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ABSTRACT

The objective of this study was to investigate the effect of conservation tillage systems and water saving on the productivity of wheat and barley crops. The experimental work was conducted at Tamboul Testing and Training Centre, Sudan located at 150km south east of Khartoum during two different seasons (1995 -1996) in a heavy clay soil with an area of 2.4ha. The treatments were deferent tillage systems (zero tillage, ridging, shallow harrowing, heavy harrowing, disc ploughing, discing+harrowing, split ridging and ridging thrice). These treatments were arranged in randomized complete block design (RCBD) with four replications. A computer program (SAS statistical package) was used to analyze the data while the variations among the means were checked by the least significant difference (LSD).The parameters tested were soil physical properties, crop water requirements (mm/day) and crop productivity (kg/ha). The results showed that, conservation tillage systems significantly ($P \leq 0.05$) affected clearly soil physical properties. Discing+harrowing decreased the bulk density (1.3g/cm3) as compared to zero tillage system (1.5g/cm3). The highest moisture content was recorded under zero tillage (28 cm/m). The use of crop water requirement technique resulted on saving the amount of water applied at the winter season by 13.2% compared with the summer season. The amount of water increased as irrigation decreased up to the 5th irrigation then decreased in final stages of the crop development. Crop productivity significantly affected by the water saving and conservation tillage systems. Discing+harrowing gave the highest mean values crop productivity of wheat (1305kg/ha) and barley (1011kg/ha) as compared to zero tillage which ranked the least (680.7kg/ha). It is concluded that for increasing the productivity, water saving and soil conserving should be followed and adopted as one of the most important technical packages.

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INTRODUCTION

The shortage of water resources worldwide is one of the major limiting factors of agricultural development, which significantly affected the global food security. Agricultural practices conserving soil and water are vitally needed to sustain agricultural production under changing climate (Mert, *et al.*, 2017). Conservation tillage systems are important for crop production because of increasing soil water by reducing evaporation and increasing water infiltration due to crop residues remained on soil surface (Jalota *et al.*, 2006).

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Zero tillage stored more water at sowing depth and at the end improved grain yield compared to conventional tillage as reported by Fernandez-Garcia *et al.* (2013). Copec *et al.* (2015) mentioned that the highest average soil water content was measured under zero tillage compared to conventional system which reduces water infiltration by weakening soil aggregate stability and decreasing macro-porosity and increasing surface crusting. Due to the strong influence of soil moisture on crop yield, management practices caused to increase soil water storage potential are important to be adopted for sustaining crop production in arid and semi-arid regions of the world. Tillage systems were affected clearly on soil physical properties; namely bulk density and moisture content and it is necessary to modify environment to create optimum conditions

for increasing crop production as mentioned by Mohamed *et al.* (2017). Wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare*) are the most important arable crops in Sudan and the major challenge to production is the enhancing of its productivity and profitability. Different tillage operations and irrigation quantities significantly affected the yield as mentioned by Sessiz *et al.* (2008).

The production is highly influenced by water availability during the growing season and it is very important to apply a tillage system that helps maintain a favorable soil water regime for optimal crop growth and development. It needs about 10000 m^3/ha to produce optimum wheat yield as mentioned by Farah (1995). But, however, saving of water without harming yield and quality can be achieved, and that varietal response differences to irrigation regimes exist to fill yield gaps. Moreover, to increase productivity, farmers should be aware of the effects of over-irrigation and that; energy is more expensive, particularly in tillage operations and should be efficiently allocated (Farah, 1995). In Sudan, there were no standard practices as far as irrigation amounts and tillage systems are concerned which resulted on low crop productivity and it represents as one of the major problems that are facing agricultural production. Low crop productivity in addition to high production costs, low prices and high taxes had all resulted in a general deterioration of the agricultural sector. This has contributed in converting agriculture from an attractive business to a repellent activity and caused many farmers to abandon agriculture and migrate to cities (Ministry of Finance and National Economy, 1996). It is evident that, the optimum and economical package of tillage and irrigation quantities for wheat production need to be identified and related factors to be quantified accordingly and processed. Therefore, the objective of this study was to investigate the effect of conservation tillage systems and water saving on crop productivity of wheat and barley crops under semi-arid conditions of Sudan.

MATERIALS AND METHODS

The experimental work was conducted at Tamboul Testing and Training Centre located at 150km south east of Khartoum during two different seasons (1995 -1996). The soil was classified as heavy clay soil with average bulk density of 1.5 – 1.9g/cm^3. The area falls in the tropical climate usually hot in summer and mild and dry in winter with a noted variation in temperature.

Experimental Design

Different tillage systems were adopted to assess the effect of some tillage systems on the crop yield in an area of 2.4 ha. These treatments were arranged in randomized complete block design (RCBD) with four replications. The treatments included:

- Zero tillage (control).
- Ridging.
- Shallow Disc harrowing.
- Heavy Disc harrowing.
- Disc Ploughing.
- Discing + harrowing.
- Split ridging.
- Ridging thrice.

Characteristics of tillage implements used

- Ridger: fully tractor mounted on three point linkage, lister type with four units, each unit have two wings and shear and spaced at 80 cm.
- Shallow disc harrowing.
- Heavy disc harrowing.
- Disc plough: fully tractor mounted on three point linkage, standard type with three discs each 66cm in diameter and 63 cm cutting width with 21.3 cm ploughing depth.
- Disc harrow: fully tractor mounted on three point linkage with 10 discs each 56 cm in diameter, 180 cm cutting width with 6.6 ploughing depth.
- Split ridging: fully tractor mounted on three point linkage.
- Ridging thrice fully tractor mounted on three point linkage
- Renault 751 (75hp) and Belarus MTZ 380 (80hp) tractors were used to perform all tillage operations where as a fully mounted scraper was used as leveler.

Crop water requirements

Irrigation water amounts were calculated according to crop water requirement (ETc). It is generally related to reference evapotranspiration (ETo) which is calculated from meteorological data using Penman Monteith equation as stated by Smith *et al.* (1998).

$$ET_o = \frac{0.408\Delta(Rn-G)+\gamma\left(\dfrac{900}{T}+273\right)U_2(es-ea)}{\Delta+\gamma(1+0.34U_2)} \quad \text{.............(1)}$$

Where:

ETo= Reference crop evapotranspiration (mm day^{-1})

R_n = Net radiation at crop surface (Mj$m^{-2}day^{-1}$)

T = Average temperature at 2m height (^{o}c).

e_s = Svp, kPa e_a = Actual vp (kPa)

$(e_s - e_a)$ = Saturation pressure deficit for measurement at 2m height (kPa).

U_2 = Wind speed at 2m height (ms^{-1}).

Δ = Slope of vapor pressure curve (k Pa ^{o}c).

γ = Psychometric constant (k Pa ^{o}c)

900 = Coefficient for reference crop (kj Kg day^{-1})

0.34 = Wind coefficient for the reference crop (sm^{-1})

G = Soil heat flux (Mj m^{-2} day^{-1})

Irrigation water amounts were measured using a V-notch 90° weir. The discharge over the weir was calculated using the following equation as stated by Michael (1978).

Q = 0.0138 $H^{5/2}$ …………………………………(2)

Where:

Q = discharge over the weir in l/s.

H = the head over the weir in cm.

Measurement of rainfall

Daily rainfall was measured using the standard ordinary rain gauge exposed 1 m above ground level away from buildings and trees. The diameter of the standard gauge is 5 inches (12.7 cm).

The space between outer and inner cylinders was filled immediately with water so as to act as a buffer area. A stop-watch was used to note the time taken for each applied liter of water to disappear in the soil as mentioned by Michael (1978).

Bulk density (g/cm^3): Bulk density was measured using the cylinder method (Johnson, 1945) as shown in the following equation:

$$\text{Bulk density} = \frac{\text{the mass of the clod}}{\text{the volume of the same clod}} \qquad \text{...................} \quad (4)$$

Table 1. Effect of different tillage systems on bulk density g/cm^3 and moisture content cm/m after three days from 1st and 7th irrigation for two seasons

Parameter	Season	ZT	Rid.	SH	HH	DP	DH	SR	RT	SE±
Bulk density	1995	1.5^a	1.46^a	1.4^a	1.3^b	1.3^b	1.35^b	1.4^a	1.43^a	0.03
Ød 1st moisture	"	13.4^a	12^{ab}	13.0^a	11.7^b	13^{ab}	12.2^{ab}	11.8^{ab}	12.3^{ab}	0.40
Ød7th moisture	"	21.6	18.8	21.1	18.4	19	18.7	18.5	18.7	ns
	1996									
Bulk density	"	1.4^a	1.30^b	1.33^a	1.3^c	1.3^b	1.32^b	1.30^b	1.30^b	0.01
Ød 1st moisture	"	28.2^a	25^{ab}	27.2^a	20^c	22.5^{bc}	21.6^{bc}	24.2^{ab}	24.6^{ab}	0.12
Ød7th moisture	"	28.0^a	18.6^b	26.7^a	21.2^{ab}	24^{ab}	25.1^{ab}	18.3^b	19.1^b	1.6

Means with the same letter (s) within a row are not significantly differences at (P ≤ 0.05) according to DMRT

Where:

ZT = Zero tillage

Rid. = Ridging

SH = Shallow harrowing

HH = Heavy harrowing

DP = Disc plough

DH = Discing + harrowing

SR = Split ridging

RT = Ridging thrice

There was a measuring Jar calibrated to read the rainfall in mm this Jar should only be used with 5in diameter rain gage. A recording rain gauge was used to give a continuous record of rainfall, this type of rain gauges is very important because it gives the intensity of rainfall (Adam, 2014).

Effective rainfall

Effective rainfall is defined as the fraction of rainfall that is effectively intercepted by the vegetation or stored in root zone and used by the plant-soil system for evapotranspiration. It can be estimated by the following equation mentioned by Adam (2014):

$$Pef = E * Ptot + A \qquad \text{.....................} \quad (3)$$

Where:

Pef = Effective rainfall over the growing season.

E = Ratio of consumptive use of water (cubic) to Ptot. 65.

Ptot = Total rainfall over the growing season.

A = Average irrigation application.

Infiltration rate (mm/h)

Double ring cylinder infiltrometers were used to calculate infiltration rates. The diameter of the inner cylinder from which the infiltration measurements were taken was 28cm and the outer cylinder was 60cm. the height of both cylinders was 25cm.The cylinders were installed at 10cm depth in the soil. Care was taken to keep the installation depth of the cylinders the same in all the experiments. A graduated measuring cylinder (one litre) was used for measuring the water added at each time. Water was poured gently into the inner cylinder during the first filling through a polythene sheet to minimize disturbing the soil. After pouring the water, the sheet was then removed gently.

Moisture content on mass basis was determined using the gravimetric method as stated by Michael (1978) as follows:

$$Ød = Øm\% * pb \qquad \text{...} \quad (5)$$

Where:

Ød = moisture content on depth basis cm/m.

Øm% = moisture content on mass basis.

Pb = bulk density g/cm^3.

Plant height

Ten plants were randomly selected to represent the experimental area. Plant height was measured after emergence using a metre stick then the average plant height was recorded.

Tillering

1m^2 was randomly selected at the central area of each experimental plot. The number of tillers was taken and recorded.

Final yield (kg/ha)

The harvesting started when signs of maturity were observed, the back of the head turned from green to yellow. Harvesting was done manually using sickles and the crop was arranged in heaps and left for one week, then fed to a stationary thresher for threshing. The grains from each plot were collected, weighed and final yield was expressed in kg/ha.

RESULTS AND DISCUSSION

As presented in Table 1 different tillage systems significantly (P ≤ 0.05) affected the soil physical properties. The lowest bulk density (g/cm^3) was given under disc ploughing + harrowing system as compared to zero tillage.

Table 2. Actual ETo using Penman Monteith equation as stated by Smith *et al.*(1998)

Month	Season	Estimated ETo mm/day	Actual ETo mm/day
October	1995	6.5	7.2
November		7.0	6.4
December		6.1	5.6
January		6.0	5.3
Mean		6.4	6.1
June	1996	7.6	7.7
July		8.0	8.5
August		7.0	7.8
September		7.8	8.3
Mean		7.6	8.0

Table 3. Effect of different tillage operations on wheat and barley yield

Treatment	Wheat			Barley		
	Plant height (cm)	No. of tillering/m^2	Yield (kg/ha)	Plant height (cm)	No. of tillering/m^2	Yield (kg/ha)
ZT	43.26[c]	202.3[c]	806.8[d]	83.19[c]	150.0[c]	680.7[d]
Rid.	43.33[c]	207.4[c]	950.3[c]	84.97[c]	155.6[c]	626.7[d]
SH	42.39[c]	225.3[b]	893.2[c]	85.90[c]	168.3[b]	626.0[d]
HH	52.57[b]	229.0[b]	1131[b]	88.46[b]	176.1[b]	780.6[c]
DP	64.21[a]	241.1[a]	1236[a]	94.77[b]	186.1[a]	922.5[b]
DH	65.83[a]	246.3[a]	1305[a]	100.9[a]	192.4[a]	952.2[a]
SR	62.74[a]	238.6[a]	1022[b]	97.24[a]	195.9[a]	1011[a]
RT	62.17[a]	238.6[a]	1091[b]	98.50[a]	193.1[a]	1010[a]
LSD	5.57	11.58	84.5	2.55	9.94	84.6

Means with the same letter (s) in the same column are not significantly difference at $P \leq 0.05$.
Where:
ZT = Zero tillage
Rid. = Ridging
SH = Shallow harrowing
HH = Heavy harrowing
DP = Disc plough
DH = Discing + harrowing
SR = Split ridging
RT = Ridging thrice
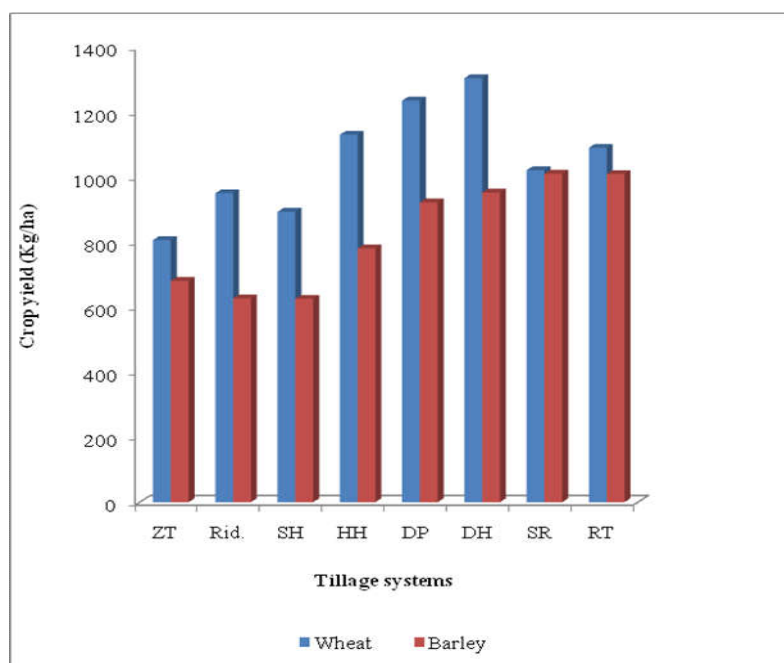
Where:
ZT = Zero tillage
Rid. = Ridging
SH = Shallow harrowing
HH = Heavy harrowing
DP = Disc plough
DH = Discing + harrowing
SR = Split ridging
RT = Ridging thrice

Fig. 1. Effect of soil and water conservations on the productivity of wheat and barley

These may be due to the mixing of the different particles size which resulted in greater pore space and hence decreased the bulk density as presented in disc ploughing + harrowing system. The results also indicated that zero tillage system recorded the highest moisture content (cm/m) as compared to other treatments. The higher moisture content under zero tillage system might be attributed to the dominance of micropores and the uncovered fissures in the zero tillage soil profile as mentioned by Copec et al. (2015). The highest initial infiltration rates were recorded under disc ploughing + harrowing followed by ridging thrice compared to heavy harrowing. These results agreed with the result obtained by Mohamed et al. (2017) who mentioned that, different tillage systems had different effects on soil physical properties. As shown in Table 2 the use of crop water requirement technique resulted on saving the amount of water applied at the winter season by 13.2% compared with the summer season. The variation between the estimated and actual ETo within the two seasons was found 5% on the winter season and 7% on the summer season. These variations may be attributed to the changes in at the recent years. While the variations on crop water requirements between summer and winter seasons are due to the differences on seasonal climatic conditions e.g. mean temperature, relative humidity, sunshine,...etc. The results agreed with the result obtained by Adam (2014) who reported that water shortage and water productivity significantly affected by the climate change especially in arid and semi-arid regions. The amount of water increased as irrigation decreased up to the 5th irrigation then decreased in final stages of the crop development. These may be due to the changes in the crop factor (kc) which increased during the development stage and decreased at the initial and maturity stages. The results were in line with result obtained by Mohamed et al. (2017) who reported that tillage systems and irrigation water amount are necessary to create optimum conditions for increasing crop production. The productivity of wheat and barley crops significantly (P ≤ 0.05) affected by the conservation tillage system and water saving. Discing + harrowing gave the highest crop productivity as compared to zero tillage which ranked the least. The superiority of discing+harrowing over zero tillage may be attributed to the good uniformity of water distribution in that plot and improvement of soil aeration conditions and moisture status and good control of weeds which led to good crop stand as stated by Guirgius et al. (2015).

Conclusion

Conservation tillage systems and water saving techniques significantly (P ≤ 0.05) increased the crop productivity and the farmers should be followed and adopted as one of the most important technical packages.

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