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Full Length Article

Long term Reduced Tillage Improved Soil Physical Characteristics and Crop Productivity in Subtropical Dryland of Pakistan

Sana ur Rehman[1], Shahzada Sohail Ijaz[1*], Khalid Saifullah Khan[1] and Muhammad Ansar[2]
[1]*Institute of Soil Science, PMAS-Arid Agriculture University, Rawalpindi, Pakistan*
[2]*Department of Agronomy, PMAS-Arid Agriculture University, Rawalpindi, Pakistan*
[*]For correspondence: shahzadasohail@uaar.edu.pk; sana07139@gmail.com
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Abstract

Recently there is a worldwide emphasis to shift intensive tillage to conservation tillage to control soil degradation. The objectives of this study were to evaluate long-term effects of conservation tillage on soil characteristics and prospects of cropping intensification in a subtropical dryland. This two-year field study was carried out in the plots of an established long-term field experiment (initiated in 2011) where four tillage systems were compared *viz.*, conventional tillage (CT, moldboard), minimum tillage (MT), reduced tillage (RT) and zero tillage (ZT). Each tillage plot was split into three subplots for crop sequences *viz.*, fallow-wheat (*Triticum aestivum*) (F-W), mung bean (*Vigna radiata*) green manure-wheat (M-W) and sorghum (*Sorghum bicolor*) fodder-wheat (S-W). Under all crop sequences soil profile water content (0–90 cm) was the highest in RT tillage plots (19%) and the lowest in ZT plots (13%). Both RT and ZT significantly increased water stable aggregates in soil (35%) compared with CT (22%). However, ZT had the highest bulk density that was on average 1.53 Mg ha^{-1} compared to 1.45 Mg ha^{-1} under CT. In summer, RT tillage produced higher biomass yield of sorghum and mung bean than other tillage systems. In winter, RT produced the highest wheat grain yield, which was 2.89 and 2.84 t ha^{-1} in 2016, and 2.63 and 2.61 t ha^{-1} in 2017 especially in F-W and M-W systems, respectively. Moreover, DSSAT model also confirmed increase in biomass and grain yields of wheat with long-term application of RT practices. In conclusion, reduced tillage strategy should be implemented to avoid soil deterioration and enhance crop productivity in subtropical drylands. © 2020 Friends Science Publishers

Keywords: Tillage; Stable aggregates; Soil profile; Bulk density; Soil structure

Introduction

The shortage of water worldwide is one of the major limiting factors of agricultural sustainability, which severely threats the global food security (Guan *et al.* 2015). Due to the strong correlation of soil moisture with crop yield, management practices are pivotal to increase soil water storage potential in arid and semi-arid regions. Tillage is one of the valuable agricultural practices, consists mainly of mixing the soil with organic residues and fertilizers, losing the topsoil, controlling weeds and creating a suitable seedbed for plant growth (Rasmussen 1999) that also greatly influences soil physical, chemical and biological characteristics (Wasaya *et al.* 2011; Hassan *et al.* 2016). Tillage practices cause change in soil moisture by modifying soil bulk density and structural stability (Singh *et al.* 2014; Hassan *et al.* 2016; Shahzad *et al.* 2016a). In addition, repeated disturbance by intensive tillage gives birth to a finer and loose-setting soil structure (Rashidi and Keshavarzpour 2007).

In recent scenario there is an emphasis on the shift from intensive tillage to conservation tillage methods to control soil degradation (Iqbal *et al.* 2005). Dryland populations are highly vulnerable to desertification and climate change, because their livelihoods are predominantly dependent on agriculture; one of the sectors most susceptible to climate change (Parry 2019). There is more potential in conservation tillage to improve soil quality by increasing organic matter, structural stability, and moisture conservation in arid and semi-arid regions of the world (Ozpinar and Cay 2006; Shahzad *et al.* 2016a).

The dryland region of Pothwar, Pakistan is known for its erratic rainfall and undulating topography. The local farmers perform intensive tillage with the combination of moldboard plow and repeated tine cultivators to conserve moisture in summer fallow period for winter wheat (*Triticum aestivum* L.). Under climate change situation a rise of 18–32% in the summer rainfall have been observed during the last century in monsoon region of Pakistan. Furthermore, winter wheat yield is predicted to decline in

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future (ADB 2017). Therefore, current study compared different conservation tillage options as an alternative to current intensive tillage practices for improving soil health and crop intensification in the subtropical dryland region of Pothwar, Pakistan.

Materials and Methods

Site and soil

This two-year (2015–16 and 2016–17) field trial was conducted at Pir Mehr Ali Shah-Arid Agriculture University Rawalpindi, Pakistan (University Research Farm, Koont) (32° 10′ N and 73° 55′ E), under different tillage practices. The soil of site was sandy clay loam and belonged to calcisole of world reference base soil group. Physico-chemical properties of experimental soil were pH 7.87, EC 0.53 dS m^{-1}, total organic carbon 5.06 g kg^{-1}, nitrate nitrogen 3.90 mg kg^{-1}, available phosphorus 3.12 mg kg^{-1} and 126 mg kg^{-1} available potash (Table 1). Before conducting this experiment, fallow-wheat cropping system was being practiced on experimental site for the last four years under different tillage systems. Weather data of experimental site is given in Fig. 1.

Table 1: Physico-chemical properties of experimental soil

Characteristics	Values
Texture	Sandy clay loam
Sand	56%
Silt	23%
Clay	21%
Bulk density	1.53 Mg m^{-3}
ECe (1:1)	0.53 dS m^{-1}
pH (1:1)	7.87
Total organic carbon	5.06 g kg^{-1}
Nitrate-nitrogen	3.90 mg kg^{-1}
Available phosphorus	3.12 mg kg^{-1}
Extractable potassium	126 mg kg^{-1}

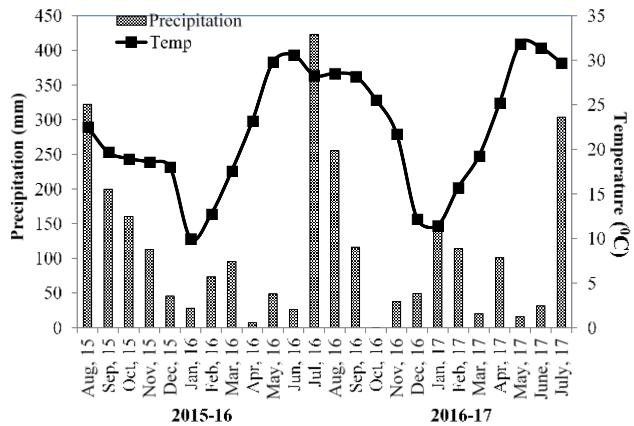

Fig. 1: Mean monthly temperature and precipitation during the experimental period (2015–17)

Experimental details

Four tillage systems *viz*., conventional tillage (CT), minimum tillage (MT; chiseling at 35 cm depth), reduced tillage (RT; chiseling at 45 cm depth) and zero tillage (ZT) were evaluated under crops sequences *viz*., fallow-wheat, mung bean-wheat and sorghum-wheat. In CT, the field was cultivated many times with a tractor-mounted cultivator, moldboard plow and by harrowing up to a depth of 20 cm followed by leveling before seeding. For MT, the field was ploughed twice with common cultivator and also up to a depth of 35 cm, with a tractor-mounted chisel plough followed by two cultivations with cultivator up to a depth of 20 cm. In case of RT, the plots were ploughed up to a depth of 45 cm, with a tractor-mounted chisel plough and weeds were controlled with chemicals and wheat was sown through direct drilling with zero tillage drill. In ZT treatment, seeds were drilled into the soil with zero drill directly without any tillage and stubbles and weeds were controlled with chemicals. The experiment was laid out in a split plot arrangement under randomized complete block design (RCBD) with three replicates keeping the tillage practices in the main and crops sequences in sub-plots. In mung bean-wheat and sorghum-wheat sequences, both crops were sown in summer at seed rate of 20 kg ha^{-1} with fertilizer P at 50 kg ha^{-1} as di-ammonium phosphate (DAP) for mung bean and at seed rate of 10 kg ha^{-1} with fertilization of NP at 100 and 50 kg ha^{-1} as urea and DAP for sorghum. Later, the mung bean crop was plowed into the soil with disc harrow as green manure at flowering stage. Sorghum was harvested as green fodder. Wheat was sown using seed rate of 100 kg ha^{-1} along with NP at 100 and 50 kg ha^{-1} as urea and DAP during winter. The wheat crop was harvested in May with return of residue in conservation tillage plots. The plot size of main and sub-plots were 12 m × 58 m and 12 m × 19.4 m, respectively.

Soil samples were collected from each of the replicate treatment at sowing and harvesting of each cropping season. Samples for water content at different depths, king tube was used and for bulk density and aggregate stability samples were taken through core sampler.

Soil physical properties

Soil moisture contents were measured by using gravimetric method. So, the amount of soil samples was collected which was known and then by using beaker was dried in an oven for 24 h at 105°C. After drying loss in samples weight was considered as soil moisture contents and showed in dry soil weight as percent and water contents were measured (Ryan *et al.* 2001). By the method of (wet) sieving (Yoder 1936) the water-stable aggregates were assessed. Known sized and dimensions cores were used to measure soil bulk density from the soil samples, then weight of fresh soil was measured also with the soil core weight after sampling immediately. At 105°C soil cores were dried along with soil samples overnight and then soil bulk density was measured (Tan 1995).

Yield traits

Biomass and grain yield (crop production parameters) were measured by casting randomly a quadrate (3 m^2) in each replication of the crop sequence. Wheat crop was sun-dried after harvesting for three days, manually threshed, grains were separated and grain yield was calculated after weighing and expressed as t ha^{-1} by using unitary method. Biological yield (t ha^{-1}) was determined by manually harvesting whole of the above ground plant material from each replicated plot.

DSSAT model

Collection of data from experimental field for model input dataset: Crop management data as input file was used to generate a file for the model such as days to anthesis; biological yield and grain yield were used for model to create experimental data files. Soil hydraulic, physical and chemical properties are given (Table 2). All parameters used for model like drainage upper and lower limits, bulk density (g cm^{-3}), saturation%, root growth factor and saturated hydraulic conductivity (cm h^{-1}) were assessed by approaches (Rawls *et al.* 1982; Baumer and Rice 1988). Weather data such as rainfall (mm), maximum and minimum temperatures (°C) and solar radiation (J m^{-2}) for trial were documented from the station installed at University Research Farm (URF). Each day weather data was used to generate weather data input file in DSSAT model.

Parameterization and calibration for crops

The calibration of DSSAT model was done by grain yield of wheat and biomass yield of the wheat, mung bean and sorghum of the year 2015–2016. Genetic coefficients variously were made for the DSSAT parameterization such as P1V (Vernalization sensitivity coefficient), P5 (Thermal time from the onset of linear fill to maturity), P1D (Photoperiod coefficient for sensitivity), G1 (Number of kernel weight per unit stem/spike), G2 (Potential kernel growth/development rate), G3 (tiller death coefficient, stem/spike weight when elongation ends) and PHINT (Thermal time among the leaf tips appearance) (Table 3). After that, model assessment was prepared by matching observe and simulated results to check the appropriateness for specific estimations (Jones *et al.* 2003). The crop model must need to use CULTIVAR file and ECOTYPE file as identified for the DSSAT models, and an EVALUATE.OUT file must be generated for the defined DSSAT set up. To attain reasonable genetic coefficients an approach through error adjustments and trial up to get a match between the simulated and observed dates of anthesis, days to maturity, biological and grain yield. Results showed that calibration of the model was satisfactory. A strong association is shown between the observed and simulated values (Table 4).

The future rainfall, solar radiation and temperature comparing with baseline period (1980–2017) made in the model 4.7 weather file.

Crop model validation and sequence analysis

The input data and well-defined standards are needed, when calibrated model is evaluated. So, the working of the CERES-wheat, CROPGRO-mung bean and CERES-sorghum model was validated by applying data from years of an independent experiment that was not in use for model calibration (other than 2015). Accuracy is the ultimate test of a model (simulation) which used observed and simulated data for comparison (Willmott *et al.* 1985; Jones *et al.* 1986; Oreskes *et al.* 1994). For examining model performance lot of statistical methods are available such as the root mean square error (RMSE), percent error (% ERROR) and coefficient of determination (R^2) which are used for assessing the association between the simulated and observed values. The used formula was as:

$$\%Error = \left(\frac{Oi - Pi}{Pi} \; x \; 100\right) \qquad RMSE = \sqrt{\sum_{i=1}^{n} \frac{(Pi - Oi)^2}{N}}$$

N represents the number of observed values, Pi is predicted value, Oi is observed value.

Sequence analysis were completed in CERES-wheat, CROPGRO-mung bean and CERES-sorghum model to preeminent treatment management observations (reduced tillage 2015 with wheat, mung bean and sorghum) were used to generate model's seasonal file.

Statistical analysis

According to the plot design, the data for various parameters were analyzed to check the overall significance of data while comparison between means of treatments were compared at 5% level of probability using LSD (least significance difference) test (Steel *et al.*1997). Graphical presentation of the data was done by Microsoft Excel program and Sigma plot.

Results

Soil profile water contents

Soil profile water contnets (0–90 cm) were significantly affected by different tillage systems. More water content was measured in RT (18.5%) plots under all cropping systems and least water content was observed in ZT (13%). Among crop sequences differences were not statistically appreciable however numerically higher water content (19%) was observed in fallow-wheat than other sequences (Fig. 2). Thus, the combination of RT and fallow-wheat had higher moisture in all soil depths (19, 22 and 16%, respectively in 0–30, 30–60 and 60–90 cm depths).

Table 2: Soil properties for experiments conducted at University Research Farm (Koont) Rawalpindi and used in simulation studies

Properties	Depths					
	0–15	15–30	30–45	45–60	60–75	75–90
pH	7.4	7.5	7.9	8.2	8.4	8.4
EC (dS m^{-1})	0.23	0.2	0.2	0.21	0.22	0.21
Nitrate-nitrogen (mg kg^{-1})	6.4	5.9	5.3	5	4.2	4.1
Available phosphorus (mg kg^{-1})	3.1	2.9	3.3	3.2	2.3	2.2
Available potassium (mg kg^{-1})	120	135	159	165	158	180
Organic carbon (%)	0.54	0.46	0.5	0.47	0.35	0.32
Silt (%)	20	19	20	20	20	21
Sand (%)	52	51	51	52	52	50
Clay (%)	28	30	29	28	28	29
Bulk density (g cm^{-3})	1.53	1.5	1.49	1.48	1.47	1.46
SLL (cm^3 cm^{-3})	0.07	0.09	0.09	0.09	0.09	0.09
SDUL (cm^3 cm-^{3})	0.34	0.24	0.25	0.26	0.23	0.23
Saturated SW (cm^3 cm^{-3})	0.46	0.39	0.38	0.3	0.33	0.31
Sat. Hydrau. Cond. (cm h^{-1})	1.06	0.87	0.79	0.67	0.65	0.63
SRGF (Root growth factor)	1	0.9	0.75	0.5	0.25	0
SSAT (upper limit Saturated)	0.35	0.36	0.38	0.38	0.39	0.41
SCEC (CEC, Cmol kg^{-1})	9.8	8.4	7.7	7.2	5.1	5.1

Where SLL: Soil lower limit (Wilting point); SDUL: Soil drain upper limit (Field Capacity); EC: Electrical conductivity

Table 3: Genetic coefficients of crops adjusted during CROPSIM-CERES Wheat, CROPGRO-Mung bean and CERES-Sorghum

Cultivars	Genetic coefficients used for calibration									
Wheat Chakwal-50	P1V	P1D	P5	G1	G2	G3	PHINT	--	--	--	--
	9	48	488	12	37	3	100	--	--	--	--
Sorghum (Sudan Grass)	P1	P2	P2O	P2R	PANTH	P3	P4	P5	PHINT	G1	G2
	215	102	12.5	1	617.5	152.5	81.5	490	49	10	6
Mung bean NM-06	CSDL	PPSEN	EM-FL	FL-SH	FL-LF	LFMAX	SLAVR	SIZLF	XFRT	WTPSD	PODUR
	16.78	0.349	21.5	1	0.01	5.03	300	980	5.09	9.99	5.9

P1V: Vernalization sensitivity coefficient; P5: Thermal time from the onset of linear fill to maturity; P1D: Photoperiod coefficient for sensitivity; G1: Number of kernel weight per unit stem/spike; G2: Potential kernel growth/development rate; G3: Tiller death coefficient, stem/spike weight when elongation ends; PHINT: Thermal time among the leaf tips appearance

Table 4: Observed and simulated variable comparison of Wheat, Mung bean and Sorghum related to growth, phenology and grain yield in model

Calibration Parameters used in study	Wheat				Mung bean				Sorghum			
	Obs.	Sim.	RMSE	% Error	Obs.	Sim.	RMSE	% Error	Obs.	Sim.	RMSE	% Error
Days to anthesis (days)	139	142	3	2.16	66	69	3	4.55	72	74	2	2.78
Days to maturity (days)	175	181	6	3.43	89	95	6	6.74	105	108	3	2.86
Grain yield (kg ha^{-1})	2663	2984	321	12.05	--	--	--	--	--	--	--	--
Biological yield (kg ha^{-1})	11313	10552	761	-6.73	17344	16051	1293	-7.46	33933	33122	811	-2.39

RMSE: Root mean square error; % ERROR: Percent error

Water stable aggregates and soil bulk density

Water stable aggregates (WSA) in response to tillage practices were significantly influenced especially in ZT and RT (Fig. 3). The significantly higher WSA were observed in ZT (35%) closely followed by RT (29%) than MT (23%) and CT (22%) treatments. Among crop sequences Fallow-wheat and mung bean-wheat showed more WSA which were 2.1 and 2.5% higher than sorghum-wheat respectively. Likewise, in both years, numerically higher bulk density (1.53 Mg ha^{-1}) was measured in ZT plots than all other tillage treatments. Crop sequences showed non-significant response of bulk density but somewhat lesser bulk density was measured in mung bean-wheat plots (Fig. 4).

Biomass of mung bean and sorghum

Tillage systems had significant effect on biomass yield of summer crops *i.e.*, mung bean and sorghum. The biomass of both mung bean and sorghum crops was the highest with RT tillage in both the experimental years while the lowest biomass of both the crops was recorded with ZT tillage (Fig. 5).

Grain yield of wheat

Among the tillage systems, the highest grain yield of wheat was produced with RT closely followed by CT while the lowest grain yield was recorded with ZT (Fig. 6). Among the crop sequences, a gradual decrease in wheat grain yield was observed from Fallow-wheat to mung bean green manure-wheat and then to sorghum fodder-wheat. Among the interactions, combination of reduced tillage with fallow-wheat and mung bean green manure-wheat gave higher wheat yield (Fig. 6).

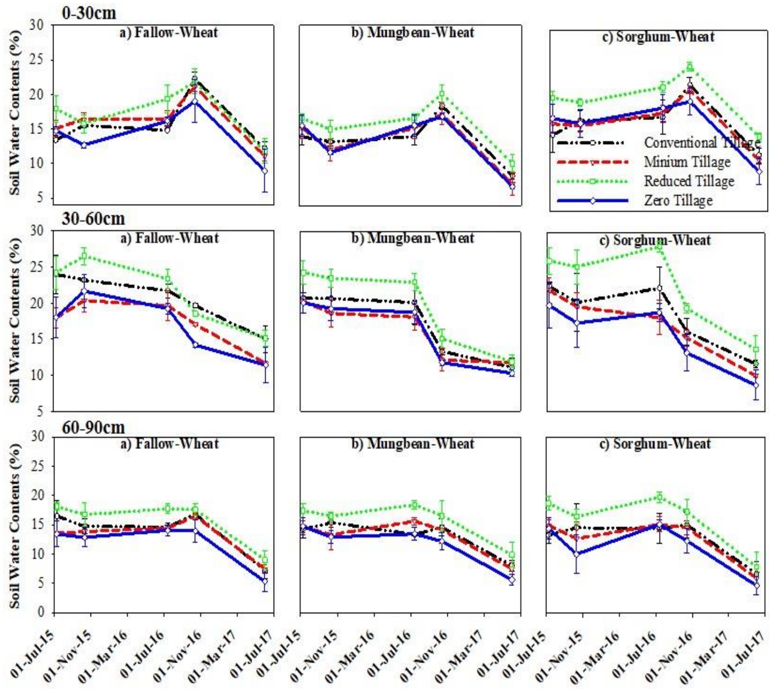

Fig. 2: Effect of different tillage practices on soil profile water content (0-30 cm, 30-60 cm and 60-90 cm soil depths) under different tillage and crops sequences

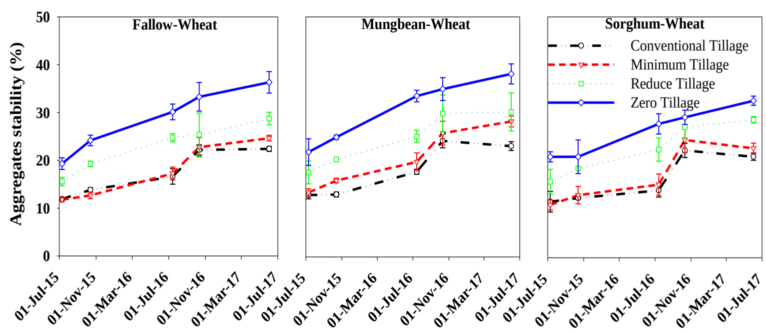

Fig. 3: Effect of different tillage practices and crop sequences on aggregate stability

Long-term simulations for mung bean, sorghum and wheat yields

Long term simulated biomass yield at maturity stage fitted well with observed biomass yield. Long term simulated yield results showed increasing trend with the passage of time (Fig. 7). The difference was very less at start of simulation among the tillage treatments but with the passage of time higher differences among treatments was predicted (in RT, 15–27.5 and 38–59 t ha^{-1}) for both mung bean and sorghum crops, respectively. Application of different tillage systems changed wheat grain yield in long-term simulation prediction. Higher grain yield of wheat (4.9 t ha^{-1}) was simulated in RT system. Crop sequence mung bean-wheat showed higher grain yield (4.9 t ha^{-1}) than other crop sequences (Fig. 8).

Discussion

The two-year field experiment showed that ZT and RT practices had major influence on soil chemical and physical properties and crop yields compared to CT and MT practices. The reason for higher moisture contents in RT with chisel plow (tillage depth of 45 cm) was that it had broken the surface compacted layer as indicated by reduced bulk density. Moreover, it also encouraged soil water infiltration during monsoon which ultimately result higher water contents storage. Results showed that conservation tillage practices (RT, chisel plow) gave better results than the soil tilled with moldboard. Such as reduced tillage gave better results in soil moisture contents where soil was lesser tilled as RT helps in breaking the sub-surface hard pan (Khurshid *et al.* 2006).

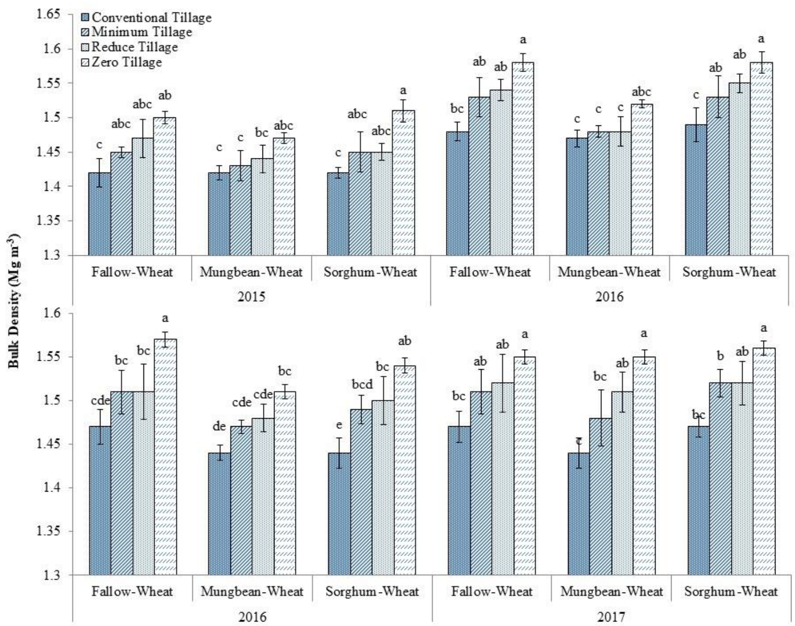

Fig. 4: Soil bulk density under different tillage practices and crops sequences
Means ± SE with different case letters differ significantly from each other at $P \leq 0.05$

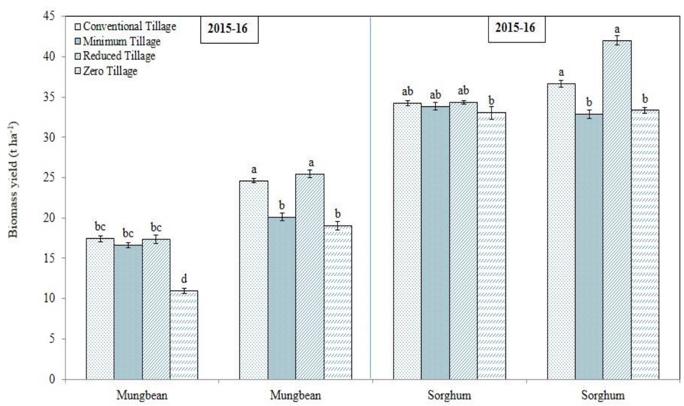

Fig. 5: Effect of different tillage systems and cropping sequences on biomass yeild for mungbean and sorghum during summer (2015–16)
Means ± SE with different case letters differ significantly from each other at $P \leq 0.05$

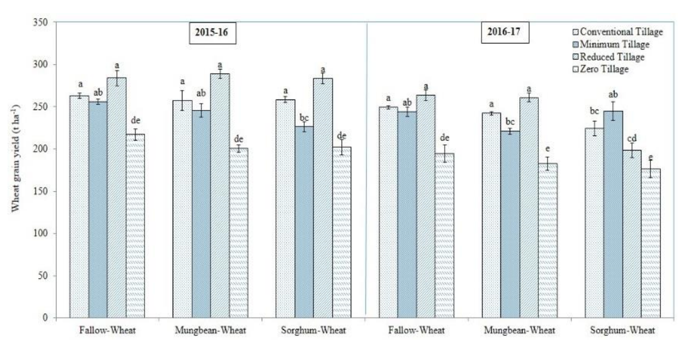

Fig. 6: Effect of different tillage systems and crop sequence on wheat yield
Means ± SE with different case letters differ significantly from each other at $P \leq 0.05$

Likewise, Makki and El-amin-Mohamed (2008) witnessed the maximum moisture preservation in soil with chisel plow cultivation related to other equipment of tillage. So, lesser water contents and WSA were measured in sorghum-wheat subplots which are due to rooting effects of sorghum during whole experiment. The greater amount of aggregate

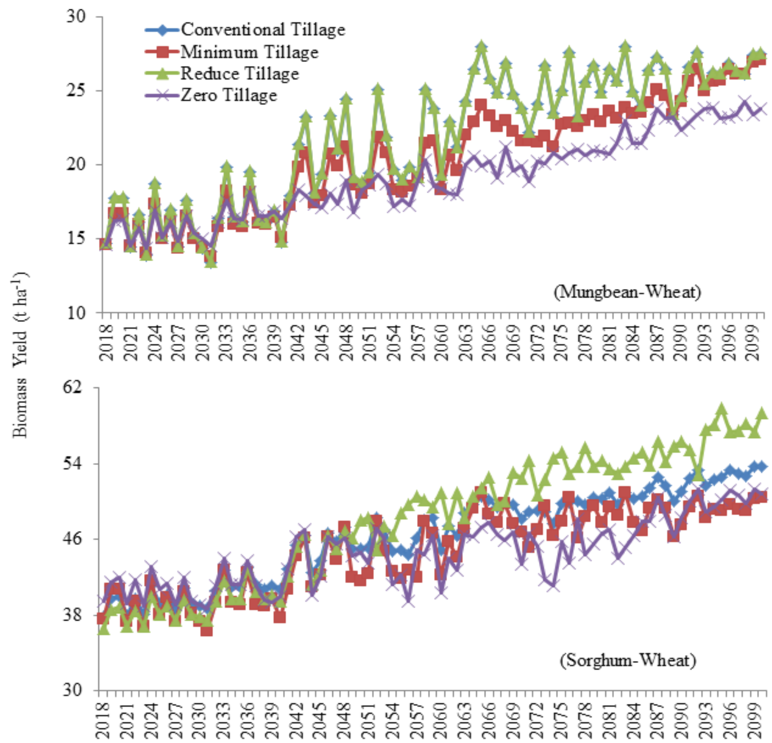

Fig. 7: Simulated biomass yield in different tillage systems and crop sequences

detected in wet-sieved in contrast to the dry sieved ones, because wet-sieving process inclines to shift more aggregates to their lesser fractions while sieving, which might not be the situation with dry-sieving method. Pagliai (2005) found that due to aggregate break down in tillage process stable macro-aggregate in wet-sieving of tilled soil is lower than that of no tilled soil. No-tilled soil remained denser than the tilled one however, its bulk density was high as before sowing in all treatments. Soil bulk density is an important indicator of change in physical health of the soils and water holding capacity of soil (Jin *et al.* 2007). Depth of tillage seems to play more important prominent role to improve soil structure and also change in bulk density (Shahzad *et al.* 2016a). Conventional tillage using a moldboard plow turns a hunk of deep soil to the surface, which leads to the creation of large pores in the plow layer and hence reduction of bulk density and escalation of soil porosity (Mousavi *et al.* 2012).

Conservation tillage usually has positive repercussions on yield components and soil quality (Nawaz *et al*. 2017) mainly due to the enhancements attained in soil moisture storage, under conditions of drought particularly in regions where this parameter is regularly restrictive. To reach physiological development, delay in days with deep tillage practices might delay the formation of pods and also delayed in days to flowering (Amanullah *et al.* 2014). Availability of additional nitrogen which was available for plants and better water storage that delayed the phonological development under deep tillage system in mung bean (Amanullah *et al.* 2014; Shahzad *et al.* 2016b).

Under RT plots the better yield of grains by chisel plough can be attributed to sub-surface hard pan breaking that increases the depth of water penetration during fallow period thus promoting root development in lower depth and helped for better crop establishment. Under drought situations more valuable was deep tillage with more quantity of water saving (Patil *et al.* 2005). Increased crop yields, in this study, was due to the developed soil physical and chemical properties in conservation practices (ZT and RT) under mung bean-wheat and fallow-wheat crops sequence. At the global level, conservation tillage on legume cropping sequence-based systems has apparently produced more wheat yield than traditional tillage because of N fixed by a leguminous crop and residual effects.

Gradual increase in biomass and grain yield increased in long-term model simulated results. The yield was linearly increased by model. Moreover, seasonal changes influence the crop yield in hot and cool weather (Craufurd and Wheeler 2009). Boote *et al.* (2018) reported the same results that there is increase in biomass yield with suitable soil conditions. The production of wheat in response to future climate is estimated to rise from 2018 to 2100, beneath DSSAT 4.7. Wolf *et al.* (2005) projected that wheat production can be reduced by extreme rise in temperature although its production can be increased within the increase levels of precipitation and CO_2.

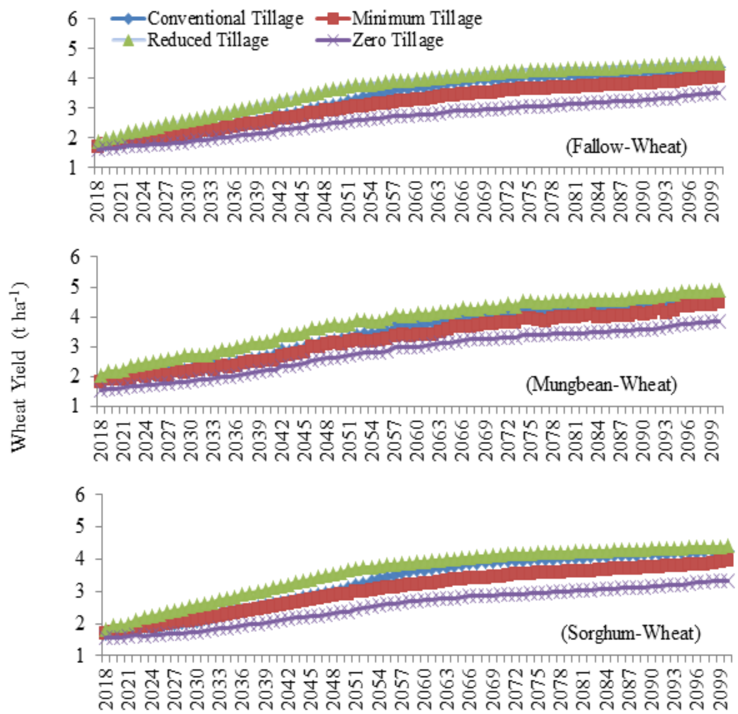

Fig. 8: Simulated wheat grain yield different tillage systems and crop sequences

Conclusion

Reduced tillage enhances soil moisture conservation and its structural stability which support higher biomass of summer crops and better grain yield in winter wheat than conventional tillage. Simulated results predict that long term application of reduced tillage will enhance crop productivity in subtropical dryland conditions.

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