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Full Length Article

Influence of Various Tillage Practices on Soil Physical Properties and Wheat Performance in Different Wheat-based Cropping Systems

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Abstract

Excessive tillage in conventional agriculture systems may cause plough pan, which alters soil physical properties, and thus adversely affects the crop growth and productivity. This study was conducted to monitor the effect of different tillage practices in wheat-based cropping systems on soil physical properties, allometry and grain yield of wheat. Wheat was planted in different cropping systems (*viz*. fallow-wheat, rice-wheat, cotton-wheat, mungbean-wheat and sorghum-wheat with zero tillage, conventional tillage, deep tillage and on two types of beds (60/30 cm with four rows) and (90/45 cm with six rows). Interaction between different tillage practices and cropping systems had significant effect on soil bulk density and total porosity, wheat allometry and grain yield. Minimum bulk density tied with higher total porosity was recorded in both types of bed sowing followed by deep tillage. This improvement in soil physical properties caused improvement in leaf area index and duration, specific leaf area, crop growth, and net assimilation rates. As a result, the productivity of bed sown wheat was better; however, grain yield of zero tilled wheat was low due to poor crop growth and net assimilation rate. Wheat productivity was substantially low when planted after sorghum; nonetheless, and was quite high when sown after mungbean. In crux, wheat planting on beds after mungbean is the best option considering the long-term environmental sustainability of wheat-based cropping systems.

Keywords: Bed sowing; Crop allometry; Cropping systems; Particle density; Soil bulk density; Tillage

Introduction

Wheat grain is a source of calories for over 1.5 billion people in the world (Manske *et al*., 2001; Kilick, 2010). In wheat-based cropping systems, the continuous use of conventional tillage for preparing seedbed leads to the development of a plough pan. This plough pan may influence the crop productivity by altering soil physical properties (Bertolino *et al*., 2010; Akmal *et al*., 2015) and developing penetration resistance up to tilled depth (Micucci and Taboada, 2006). Plough pan layers are located shallow than the normal rooting depth and may become a barrier for roots due to low porosity and too high mechanical impedance (Bruand *et al*., 2004).

Conservation agriculture (CA) is a resource saving technology, which improves the soil biological, physical and chemical properties through minimal soil disturbance, maintenance of a permanent soil cover and utilization of varied crop rotations (Haggblade and Tembo, 2003; Farooq *et al*., 2011; Friedrich *et al*., 2011). The CA benefits include less fuel consumption (Baker *et al*., 2007; Tahir *et al*., 2008; Lithourgidis *et al*., 2009; Akbarnia and Farhani, 2014), reduced soil loss due to enhanced aggregate stability and the protective effect of crop residues left over the soil (Friedrich *et al*., 2011; Sanderson *et al*., 2013; Vanlauwe *et al*., 2014). It is more productive as compared to conventional tillage because it improves soil quality and water use efficiency of plants (Samarajeewa *et al*., 2006; Brunel *et al*., 2013; Muchabi *et al*., 2014). Conservation tillage creates more continuous pore systems and reduces the soil porosity for aeration but increase the capillary porosity, helps improving soil water holding capacity (Bhattachariya *et al*., 2008; Kishor *et al*., 2013).

However, CA has some adverse impact on soil physical properties like increased bulk density, lower soil temperatures and decreased oxygen diffusion rates (Lampurlanes *et al*., 2001) during initial years of adoption. The most obvious difference between zero and conventional

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tillage is the compaction of upper layer. More compacted upper layer in zero tillage (ZT) can reduce water infiltration and soil may become waterlogged in high rainfall situation (Martínez *et al*., 2008). Therefore, ZT is less suitable during wet years or in areas with high rainfall (Peigne *et al*., 2007). In ZT, root length density in upper layer is usually more than the conventional system (Qin *et al*., 2006). However, growth of the main root axis is adversely affected in ZT due to change in soil physical properties at the initial stages of plant development (Lampurlanes *et al*., 2001). Such type of limitations reduce nutrient and water uptake as well (Qin *et al*., 2006).

Cropping systems also affects the soil physical and chemical properties, which then affect the crop productivity (Ranamukhaarachchi *et al*., 2005). Cropping systems and management strategies like tillage and organic residues management have substantial impact on soil physical properties (Sharma *et al*., 1995; Sharma and Acharya, 2000; Bhushan and Sharma, 2002; 2005). Different cropping systems have differential impact on soil physical properties. For instance, there is edaphic conflict between rice and following wheat crop in conventional rice-wheat cropping system. Actually puddling in rice destroys the soil structure, which cannot be offset by ZT, and the yield of wheat in this cropping system is substantially reduced (Tripathi *et al*., 2007).

It is obvious that both the tillage and cropping systems strongly affect the soil physical properties and the crop productivity. Several studies have been conducted to consider the soil physical properties under different tillage treatments but the information about the interactive effects of different wheat-based cropping systems and tillage practices on soil physical properties, crop allometry and wheat productivity is rarely available. Thus, this study was conducted to evaluate the soil physical properties and, wheat allometry and productivity in different wheat-based cropping systems of Multan, Punjab, Pakistan under conservation and conventional tillage practices.

Materials and Methods

Experimental Site Description

This two-year field experiment was conducted during 2012–2013 and 2013–2014 at Research Farm, Department of Agronomy, Bahauddin Zakariya University, Multan (71.43°E, 30.2°N and 122 m asl), Pakistan. The experimental area was silty clay, slightly saline soil in nature and belonged to Sindhlianwali soil series (fine silty, mixed, hyperthermic, sodichaplocambids in USDA classification). The chemical analysis of the soil showed a narrow variation in pH (8.35–8.42), EC (3.29–3.31 dS m^{-1}), organic matter content (0.54–0.59%), total N (0.03 ppm), total P (8.75–8.87 ppm) and total K (180–195 ppm) during both years. The weather data of the experimental site are given in Table 1.

Experimental Details

Wheat was planted in different cropping systems (*viz*. fallow-wheat, rice-wheat, cotton-wheat, mungbean-wheat and sorghum-wheat with zero tillage (ZT), conventional tillage (CT), deep tillage (DT) and on two types of beds (60/30 cm with four rows) and (90/45 cm with six rows). In ZT, wheat seeds were drilled (with the help of a zero tillage drill machine) directly into the soil without removing the stubbles of previous crops. Tillage practices were applied only for wheat crop while all the kharif season crops were planted following CT practices (Table 2). In CT, seedbed was prepared by two cultivations by tractor mounted cultivator (Model HFI-38, Hanif Farm Industries, Multan, Pakistan) followed by planking. In deep tillage, two ploughings were done with chisel plough (Model HFI-01, Hanif Farm Industries, Multan, Pakistan) and then seedbed was prepared by two cultivations by tractor mounted cultivator followed by planking. In both bed sowing treatments, field was prepared in the same fashion as in CT and then beds were constructed as per treatment using a manual bed shaper. The experiment was conducted in randomized complete block design with split plot arrangement by keeping tillage practices in main and cropping systems in sub-plots with three replications. The size of main and sub-plots were 25 m × 17 m, and 5 m × 2.7 m, respectively.

Crop Husbandry

Pre-soaking irrigation of 10 cm was applied to the entire field. When soil reached to moisture suitable for cultivation, the seedbeds were prepared as per treatment. All the crops included in the study were sown according to their recommended package of production technology. Detail of crop husbandry practices, for different crops, in the study is given in Table 2. Fertilizer was applied at 150 and 100 kg ha^{-1} nitrogen (N) and phosphorus (P), respectively by using urea and triple super phosphate as a source. Half N and full dose of P were applied as basal application (band placement by using drill), while remaining N was applied at the time of first irrigation. Overall four irrigations were applied to wheat crop to avoid moisture stress for the normal crop growth. Weeds were not controlled in any treatment in both years of experiment. The crop was harvested manually at harvest maturity.

Observations

Soil physical properties: To analyze soil bulk density, particle density and total porosity, the soil sampling was done with soil core sampler immediately after wheat harvesting during both years. Three samples from different locations from each experimental unit were taken from 0–10 cm depth of soil, mixed and then oven dried at 105°C for 24 h. Bulk density was estimated as a ratio of soil weight and soil volume including pore spaces.

The same soil samples were further used for measuring particle density. The particle density was determined as a ratio of mass of dry soil and volume of soil particles only (Blake and Hartge, 1986). Total soil porosity was estimated following Vomocil (1965).

Allometric Traits of Wheat

Leaf area index (LAI) of wheat crop was measured at a regular interval of fifteen days. The sampling was started 60 days after sowing (DAS) of wheat and ended at 105 DAS, that is, from 9 to 11.1 stages according to Feekes scale (Large, 1954). All the plants in random selected area of 0.5 m^2 from each subplot were harvested, leaves were separated and leaf area was calculated by leaf area meter (DT Area Meter, model MK2). After that, LAI was calculated as a ratio of leaf area to ground area as described by Madison and Watson (1947). Specific leaf area (SLA) was estimated as leaf area per unit leaf dry weight. Leaf area duration, crop growth rate and net assimilation rate were calculated as described by Hunt (1978).

Wheat Grain Yield

At harvest maturity, two central rows from each plot of wheat crop were harvested, sun-dried for three days, threshed manually, grains were separated and weighed to calculate grain yield which was expressed as t ha^{-1} by using unitary method. Grain yield was then adjusted at 10% grain moisture contents.

Statistical Analysis

The data collected during both years were analyzed statistically by Fisher's analysis of variance technique and least significant difference (LSD) test was used for mean separation at 5% probability (Steel *et al*., 1997). Graphical presentation of the data was done by Microsoft Excel program.

Results

Soil Physical Properties

Interaction of different tillage practices and cropping systems had significant ($p< 0.05$) effect on soil physical properties such as bulk density and total soil porosity while effect on soil particle density was non-significant (Table 3). Soil bulk density was higher in ZT under fallow-wheat cropping system during both years of study (Table 3). However, soil bulk density was lower in deep tillage (DT) and bed sowing under fallow-wheat, mungbean-wheat and cotton-wheat cropping systems during both years of experiment (Table 3). During 2012–2013, bed sowing had significantly higher total soil porosity in fallow-wheat, mungbean-wheat and cotton-wheat cropping systems, while ZT had the lowest total soil porosity in all cropping systems except mungbean-wheat system (Table 3). However, higher soil porosity was observed in DT and both types of beds sowing under fallow-wheat and mungbean-wheat cropping systems; whereas the lowest soil total porosity was recorded in case of ZT under fallow-wheat and rice-wheat cropping systems (Table 3).

Crop Allometry

Bed sowing had better LAI and LAD while zero tilled wheat had the minimum LAI and LAD under all cropping systems at 60, 75, 90 and 105 DAS during both years (Fig. 1, 2). Sorghum-wheat cropping system had the minimum LAI in this regard (Fig. 1); whereas sorghum-wheat and fallow-wheat had minimum LAD; while rice-wheat and mungbean-wheat had maximum LAD (Fig. 2). Bed sown wheat (90/45) had higher SLA against the minimum in ZT wheat at 60, 75, 90 and 105 DAS in all cropping systems during both years of study (Fig. 3). Periodic data indicated that LAI and crop growth rate (CGR) progressively increased up to 75 DAS and then started to decline during both years of study (Fig. 1, 4).

Wheat sown under all tillage systems, except ZT, had higher CGR during both years of experimentation (Fig. 4). However, the specific leaf area (SLA) of crop fluctuated to some extent but remained constant throughout the growing period of crop. Net assimilation rate (NAR) gradually decreased during the course of growing season in both years (Fig. 5). Wheat sown under both types of beds had lowest NAR; while CT had maximum NAR during both years of study (Fig. 5). Moreover, sorghum-wheat and fallow-wheat cropping systems had maximum NAR; whereas mungbean-wheat cropping system had the minimum NAR during both years of experimentation (Fig. 5).

Grain Yield

The interaction between wheat-based cropping systems and tillage practices had a significant effect on the grain yield of wheat (Table 4). Maximum grain yield was recorded from both types of bed sowing under all cropping systems except sorghum-wheat while the minimum grain yield was recorded in ZT under all cropping systems. Moreover, grain yield under fallow-wheat was lower during second year of study (Table 4).

Discussion

In this study, highest soil bulk density, and lowest particle density and soil porosity were recorded with ZT; conversely the bed sowing (BS) and deep tillage (DT) had the lowest soil bulk density and highest soil porosity. Indeed, lack of mechanical operations under ZT leads towards progressive densification and reduced pore volume (Du *et al*., 2010; Jemai *et al*., 2012), which enhances the soil bulk density (Xu and Mermoud, 2001; Thomas *et al*., 2007) due to soil compaction.

Table 1: Weather data at the experimental station during both experimental years (2012-2013 and 2013-2014)

Weather element	Years	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Mean temperature (°C)	2012-13	32.5	34.0	33.5	31.8	29.4	25.3	19.9	14.8	12.3	16.0	22.0	26.9
	2013-14	32.9	34.0	34.0	31.6	30.3	28.3	20.0	14.9	13.0	14.9	19.8	25.8
Average relative humidity (%)	2012-13	55.8	61.1	66.6	74.1	83.5	72.5	84.1	83.5	80.4	87.3	76.1	60.9
	2013-14	55.0	67.9	64.5	72.2	71.7	71.4	79.4	82.4	79.3	81.8	74.2	58.5
Sunshine (hours)	2012-13	8.5	8.2	7.8	7.0	7.0	8.3	6.1	6.1	5.6	5.7	8.4	7.7
	2013-14	9.8	8.2	7.9	7.1	8.7	7.1	5.7	4.9	5.5	6.4	6.7	6.3
Rainfall (mm)	2012-13	1.1	0.0	16.9	10.9	167	3.2	0.0	4.0	0.0	72.9	16.7	1.3
	2013-14	0.0	50.7	16.9	74.2	0.0	0.0	0.0	0.0	0.0	18.0	33.4	7.1

Source: Central Cotton Research Station (CCRI) Multan, Pakistan

Table 2: Details of crop husbandry practices used, for different crops, in the study

Crops	Sowing date	Cultivar	Seed rate (kg ha^{-1})	Tillage practices	Fertilizer NPK (kg ha^{-1})	P-P (cm)	R-R (cm)	Harvesting time
Wheat	15th Nov	Punjab-2011	125	3 cultivations followed by planking	150-100-0	-	25	15th April
Cotton	15th May	MNH-885 (Bt.)	25	3 cultivations followed by planking	250-200-0	20	75	30th October (Last picking)
Sorghum	15th June	JS-2002	10	3 cultivations followed by planking	100-60-0	15	60	30th October
Mungbean	15th June	AZRI-Mung 2006	20	2 cultivations followed by planking	20-60-0	10	30	30th September
Rice i. Nursery ii. Transplanting	25th May 25th June	Basmati-2000	0.5 kg per 25 m^{-2} 125 m^2 nursery ha^{-1}	3 cultivations in standing water followed by planking to create puddling	- 150-85-67	- 22.5	- 22.5	30th October

P-P = Plant – plant distance; R-R = Row – row distance

Table 3: Influence of conservation and conventional tillage practices on soil bulk and particle densities, and total porosity in different wheat-based cropping systems

Cropping systems	2012-2013					2013-2014				
	ZT	CT	DT	BS (60/30)	BS (90/45)	ZT	CT	DT	BS (60/30)	BS (90/45)
	Bulk density (g cm^{-3})									
Fallow-wheat	1.51 a	1.45 ef	1.45 ef	1.45 ef	1.44 fg	1.52 a	1.45 ef	1.45 ef	1.44 fg	1.44 fg
Rice-wheat	1.49 b	1.49 b	1.48 bc	1.46 de	1.46 de	1.49 b	1.48 bc	1.47 cd	1.46 de	1.46 de
Cotton-wheat	1.47 cd	1.45 ef	1.45 ef	1.45 ef	1.44 fg	1.48 bc	1.46 de	1.46 de	1.46 de	1.45 ef
Mungbean-wheat	1.47 cd	1.46 de	1.45 ef	1.45 ef	1.44 fg	1.47 cd	1.46 de	1.45 ef	1.44 fg	1.44 fg
Sorghum-wheat	1.48 bc	1.46 de	1.46 de	1.46 de	1.45 ef	1.48 bc	1.47 cd	1.46 de	1.46 de	1.45 ef
LSD (p 0.05)	0.01					0.01				
					Particle density (g cm^{-3})					
Fallow-wheat	2.56	2.63	2.62	2.65	2.68	2.60	2.62	2.64	2.65	2.66
Rice-wheat	2.55	2.58	2.60	2.58	2.63	2.59	2.61	2.59	2.60	2.61
Cotton-wheat	2.53	2.59	2.61	2.63	2.67	2.61	2.59	2.61	2.63	2.60
Mungbean-wheat	2.58	2.60	2.62	2.66	2.70	2.61	2.63	2.66	2.63	2.65
Sorghum-wheat	2.54	2.55	2.57	2.57	2.59	2.60	2.58	2.59	2.61	2.64
LSD (p 0.05)	NS					NS				
					Total porosity (%)					
Fallow-wheat	41.16 j	44.60 cd	44.64 cd	45.40 a-c	46.12 ab	41.67 j	44.59 c-e	45.04 a-d	45.42 a-c	45.89 a
Rice-wheat	41.69 ij	42.39 hi	43.26 f-h	43.32 e-h	44.31 c-f	42.25 ij	43.33 f-h	43.48 f-h	43.82 e-h	44.18 d-g
Cotton-wheat	41.77 ij	43.89 d-g	44.47 c-e	44.94 b-d	45.91 ab	43.33 f-h	43.40 f-h	44.20 d-g	44.66 b-e	44.28 d-f
Mungbean-wheat	43.00 gh	43.96 d-g	44.55 cd	45.53 a-c	46.59 a	43.83 e-h	44.64 b-e	45.41 a-c	45.17 a-d	45.68 ab
Sorghum-wheat	41.61ij	42.54 hi	43.13f-h	43.32 e-h	43.99 d-g	43.08 hi	43.17 g-i	43.64 e-h	44.10 d-h	45.00 a-d
LSD (p 0.05)	1.23					1.07				

Means sharing a letter in common, for a parameter during a year, do not differ significantly at p 0.05
ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing; NS = Non-significant

Table 4: Influence of conservation and conventional tillage practices on wheat grain yield (t ha^{-1}) in different cropping systems

Cropping systems	2012-2013					2013-2014				
	ZT	CT	DT	BS (60/30)	BS (90/45)	ZT	CT	DT	BS (60/30)	BS (90/45)
Fallow-wheat	3.41 ij	5.50 fg	5.91 c-g	6.27 a-d	6.37 a-c	1.92 k	5.42 g	5.84 c-e	6.18 a-c	6.21 ab
Rice-wheat	3.90 h	5.46 g	5.87 d-g	6.21 a-e	6.34 a-c	4.03 h	5.42 g	5.86 c-e	6.13 a-d	6.18 a-c
Cotton-wheat	3.85 hi	5.50 fg	5.98 b-e	6.35 a-c	6.43 ab	3.91 hi	5.46 fg	5.73 e-g	6.23 ab	6.24 ab
Mungbean-wheat	3.35 j	5.76 e-g	6.08 a-e	6.34 a-c	6.45 a	3.18 j	5.80 d-f	6.11 b-e	6.30 ab	6.47 a
Sorghum-wheat	3.45 h-j	5.77 e-g	5.98 b-e	5.95 c-f	5.98 b-e	3.55 ij	5.79 d-g	5.99 b-e	6.09 b-e	6.11 b-e
LSD (p 0.05)	0.46					0.35				

Means sharing a letter in common, during a year, do not differ significantly at p 0.05
ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing

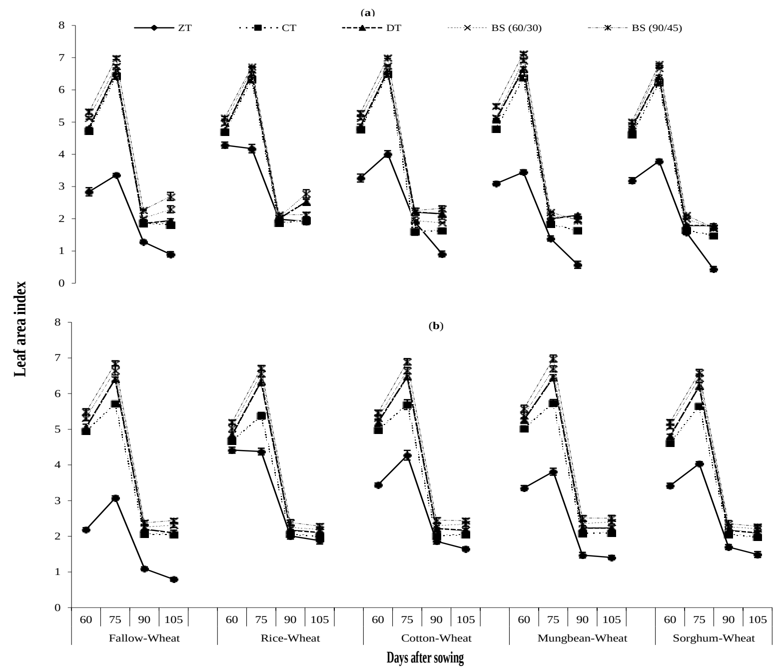

Fig. 1: Influence of conservation and conventional tillage practices on leaf area index of wheat in different wheat-based cropping systems during (a) 2012-2013 and (b) 2013-2014 ± S.E

ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing

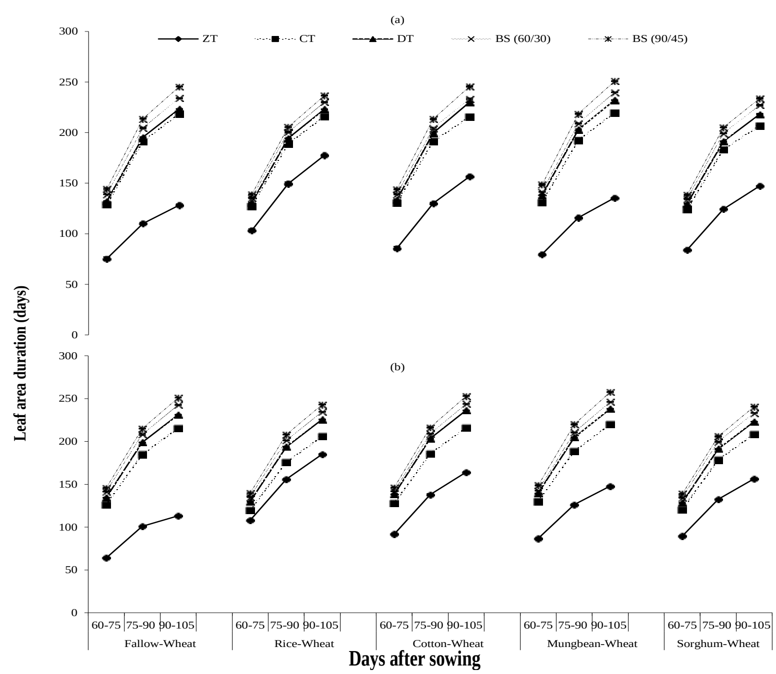

Fig. 2: Influence of conservation and conventional tillage on leaf area duration (days) of wheat in different wheat-based cropping systems during (a) 2012-2013 and (b) 2013-2014 ± S.E

ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing

ZT induces more soil compaction in the upper layer than CT (Braim *et al*., 1992; Thomas *et al*., 2007). In contrast, frequent cultivation under DT and BS tends to disturb the soil structure by breaking clods and reducing bulk density and mechanical impedance (Chatterjee and Lal, 2009), with simultaneous improvement in soil porosity (Meek *et al*., 1992; Rashidi and Keshavarzpour, 2011), as was observed in this study.

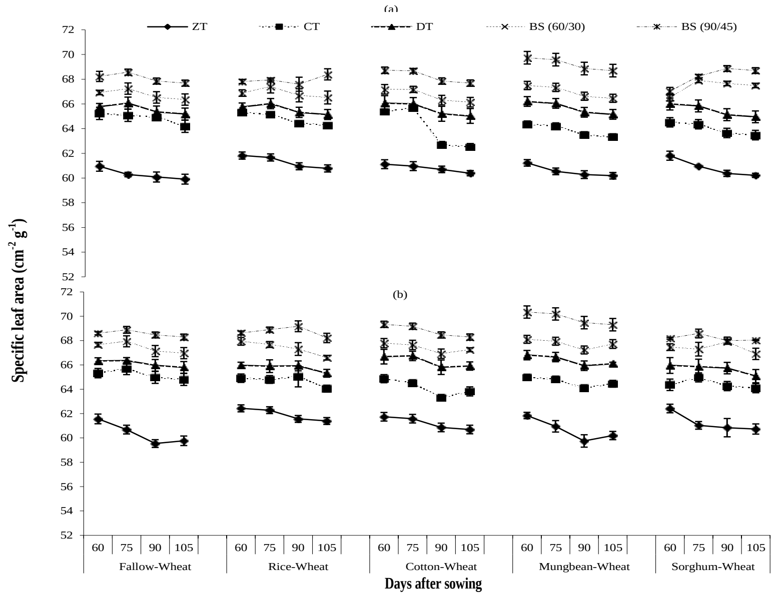

Fig. 3: Influence of conservation and conventional tillage practices on specific leaf area (cm^{-2} g^{-1}) of wheat in different wheat-based cropping systems during (a) 2012-2013 and (b) 2013-2014 ± S.E

ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing

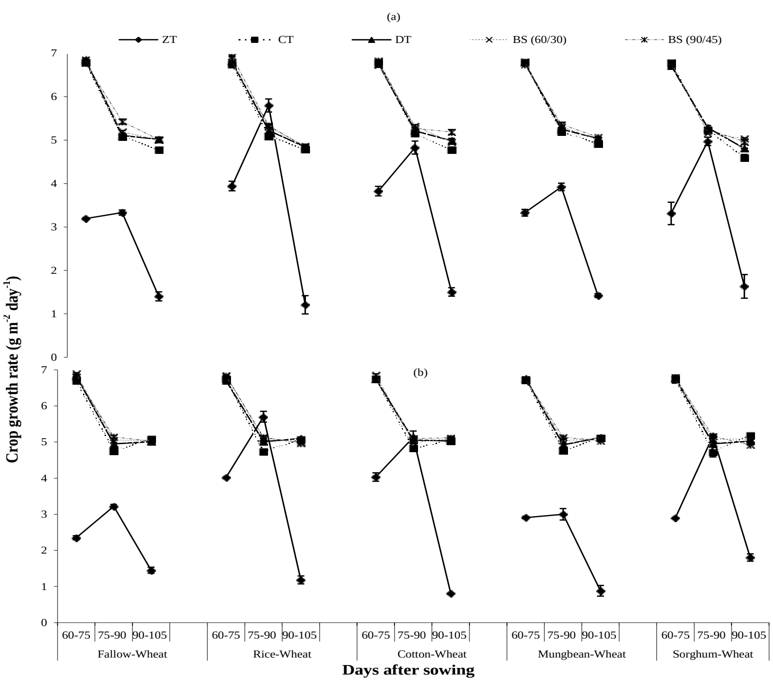

Fig. 4: Influence of conservation and conventional tillage practices on crop growth rate (g m^{-2} day^{-1}) of wheat in different wheat-based cropping systems during (a) 2012-2013 and (b) 2013-2014 ± S.E

ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing

Among the cropping systems, highest soil bulk density and lowest soil porosity were observed with rice-wheat and sorghum-wheat cropping systems; while lowest bulk density and highest soil porosity were observed in mungbean-wheat and fallow-wheat cropping systems. Inclusion of legume in cropping systems improves soil physical quality by decreasing soil compaction or soil cone index, while addition of flax, canola or wheat, owing to strong deep tap/fibrous root system, increases soil compaction (Doan *et al*., 2005; Hamza and Anderson, 2005; Ranamukhaarachchi *et al*., 2005). Moreover, the crops like wheat and sorghum are exhaustive in nature with no residue return into the soil,

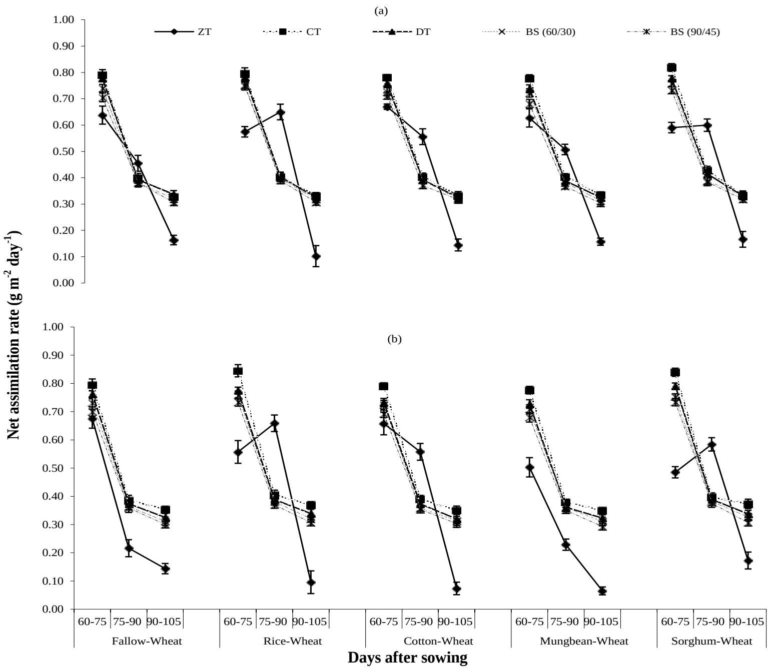

Fig. 5: Influence of conservation and conventional tillage practices on net assimilation rate (g m^{-2} day^{-1}) of wheat in different wheat-based cropping systems during (a) 2012-2013 and (b) 2013-2014 ± S.E
ZT = Zero tillage; CT = Conventional tillage; DT = Deep tillage; BS = Bed sowing

while the legumes are restorative as they shed the leaves and twigs into soil, thus improving the soil physical environment, as observed in this study. Lampurlanes *et al.* (2001) also reported that inclusion of a fallow season in a cropping system can also be effective in reducing soil compaction. Likewise, poor physical environment in post rice wheat in this study might be due to dispersion of soil particles and soil shrinkage at lower moisture (Behera *et al*., 2009), which ultimately enhanced the soil bulk density (Sharma *et al*., 2005). However, addition of mungbean in wheat based cropping system improved the soil physical environment. Alam *et al*. (2013) also argued that addition of sesbania (*Sesbania rostrata*) and mungbean (*Vigna radiata* L. Wilczek) biomass into the soil may help reducing the bulk density, increasing the soil porosity and available water content with in soil.

Better physical environment after mungbean (Table 3) led towards highest wheat grain yields (Table 4), while poor soil physical environment in post rice and post sorghum wheat reduced the wheat grain yield (Table 4). Indeed, addition of legumes in the cropping systems improves the soil physical and biological environment, which results in the enhancement of soil fertility, better crop growth and yields (Kumbhar *et al*., 2007; Alam *et al*. 2013). On the other, poor soil physical structure due to compacted soil restricts the root penetration and plant growth, which causes substantial reduction in crop yield (Duiker, 2004), as was observed in case of rice-wheat and sorghum-wheat cropping systems in this study. Wheat yields were lower when sown after sorghum. Sorghum contains certain allelochemicals, which upon release into the soil suppresses the growth of other plants (Farooq *et al*., 2013), as has been observed in this study. Crop performance was poor in ZT plots which might be attributed to highest bulk density and lowest soil porosity in these plots (Farooq and Nawaz, 2014), and higher weeds infestation (data not given), which might have restricted the root growth of wheat thus reducing water and nutrient uptake.

Weather data, remained almost same during both years of study (Table 1). Therefore changes in crop performance were either due to tillage systems or cropping systems studied. Moreover, there is no contradiction between weather data and the grain yield data during both years of study.

Conclusion

Wheat planting with ZT had substantially low crop growth and grain yield owing to more bulk density and lower total porosity; nonetheless bed sown wheat performed better due to better soil physical health. Wheat growth and yield was substantially low when was planted after sorghum due to its allelopathic affects; nonetheless, mungbean favored the wheat growth and yield. Therefore, wheat planting on beds after mungbean is the best option for the long-term environmental sustainability in Multan, Punjab, Pakistan.

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