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Research Article

Deep Tillage Improves Wheat Productivity and Net Returns by Affecting Weed Dynamics in Wheat-Based Cropping Systems

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Abstract

Appropriate combination of tillage and crop rotation can improve wheat productivity by affecting weed dynamics. In this two-year field study, wheat was sown using zero tillage (ZT), conventional tillage (CT) and deep tillage (DT) following rice and cotton crops. Interaction between different tillage practices and cropping systems had a significant effect ($p<0.05$) on weed diversity, total, broadleaved and grassy weeds density and biomass including yield-related traits of wheat. The ZT under rice-wheat system had higher weeds prevalence. The cotton-wheat system had some suppressive effect on weed infestation in all tillage systems. However, this system promoted broad leaved weeds whereas rice-wheat had a high infestation of grassy weeds. The DT in the cotton-wheat system had the highest grain yield due to a significant increase in yield-related traits, and less weeds infestation. Economic analysis affirmed that the DT found to be best tillage practice and resulted higher net income and BCR in both systems. Therefore, DT and CT practices may be adopted in different wheat-based cropping systems to lower weeds infestation and improve system productivity.

Keywords: tillage practices; wheat; weeds diversity; weeds density; cropping system

1. Introduction

Wheat (*Triticum aestivum* L.) provides 20% of the calories to the world's population and a similar proportion of daily protein for about 2.5 billion people in less-developed countries (Braun et al. 2010). The global wheat production amounts to an annual average of around 750 million tons (FAO 2019), which provides food over one-fifth human population of this globe (FAO 2017). The increasing global population requires to produce more wheat that will arguably have more influence on global food security (FAO 2017).

In Pakistan, wheat is grown under diverse cropping systems, such as cotton-wheat, rice-wheat, sugarcane-wheat, maize-wheat and fallow-wheat, etc. Of these, cotton-wheat and rice-wheat systems together account for about 60% of the total wheat cultivated area (Farooq et al. 2007). However, recurrent conventional tillage and practicing the same cropping patterns adversely affect the sustainability and productivity of cropping systems (Bertolino et al. 2010) due to soil compaction (Hamza and Anderson 2005) and deterioration (Hamza et al. 2011).

In rice-based cropping systems, puddling practice is done to break down the aggregate, destruct macro-pores and form a sub-surface dense layer. Although puddling helps in weed management and reduces water loss through percolation (Surendra et al. 2001; Farooq et al. 2011a), it deteriorates the soil environment for post-rice crops (Farooq et al. 2008). This results in erratic stand establishment of post-rice crops owing to poor contact of seed with soil (Ringrose-Voase et al. 2000; Farooq et al. 2008). Subsurface compaction of soil, caused by puddling, may induce the drought to post-rice crops by restricting the root development (Kukal and Aggarwal 2003). This has a positive impact on rice but impedes the performance of post-rice crops (Farooq et al. 2008).

In wheat-based cropping systems, the frequent use of CT for preparing a fine seedbed causes subsoil compaction which adversely affect the crop output (Bertolino et al. 2010; Shahzad et al. 2016a, b, 2021a). It disturbs the soil physical, chemical and biological health that obstructs root growth and crop yield (Hamza and Anderson 2005; Shahzad et al. 2016a). Although CT may reduce the weed pressure (Gajri et al. 1999), however, it

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accelerates soil degradation (World Resources Institute, 2000). This reduction in weeds by CT practices occurs in the early season of crop life cycle (Steckel et al. 2007), however, the problem of weed infestation is provoked during later crop growth stages in these tillage systems. These cropping systems favor the adapted weed species to flourish (Harker and Clayton 2004; Shahzad et al. 2016c, 2021b). These problems indicate that optimization of alternate tillage and cropping systems is needed to have high crop yield and ecosystem health.

Tillage systems may influence weed seed bank size and composition to a much greater extent than cropping system (Mirsky et al. 2010; Shahzad et al. 2016c). To sort out these problems, conservation agriculture (CA) is a good technology that improves the soil biological, physical and chemical properties by minimum disturbing the soil, maintenance of a permanent soil cover and utilization of varied cropping systems (FAO 2007; Farooq et al. 2011b).

Zero tillage (ZT), one of the pillars of CA technology reduces expenses for land preparation, fuel consumption, equipment uses, labor cost, and ensures good crop stand tied with conservation of soil and water (Farooq et al. 2011b; Jabran and Mehmood 2015). But it also restricts the growth of the main root axis at the initial stages of plant development (Lampurlanes et al. 2001). Such type of limitations reduces nutrient and water uptake by the plants which adversely affect crop productivity (Qin et al. 2006). The rice-wheat cropping system induces adverse environment for wheat due to puddling in rice which cannot be offset by ZT and results in a reduction of wheat yield (Tripathi et al. 2007).

In addition, CA can increase the density of perennial weeds and some annual grasses than CT (Shahzad et al. 2016b). Annual broadleaf species tend to adapt better to frequently disturbed habitats and are therefore more abundant in CT systems (Streit et al. 2003). Also, greater diversity prevents the domination of a few problematic weeds (Macák et al. 2005). The perennial weeds flourishing in reduced-tillage systems would be difficult to manage with existing post-emergent herbicides (Swanton et al. 1993). Deep tillage (DT) improves soil aeration, water holding capacity, and soil porosity (Malhi et al. 2006). The DT breaks up high-density soil layers, improves water infiltration and movement in soil to support crop growth (Halvorson et al. 2002). It also decreases bulk density; compaction effects and increases nutrient uptake, saturation percentage and saturated hydraulic conductivity resulting in improved yields (Chan et al. 2002). It helps to break plough pan layer and improves the productivity of light soils in combination with manure application (Higashida and Yamagami 2003). For instance, the rice-wheat cropping system favors grassy weeds like little seed canarygrass (*Phalaris minor* L.) while it does not favor broad leaved weeds like wild oat (*Avena fatua* L.) ecologically (Walia 2006).

Tillage and cropping systems both influence crop productivity by altering the soil physical properties and changing the weed spectra in agricultural systems. Several studies have been done to find out the soil physical properties and weed dynamics under different tillage treatments but very little information is available about the interactive effect of wheat-based cropping systems and tillage practices on weed spectra and wheat productivity under rice-wheat and cotton-wheat cropping systems. Thus, this two-year field study was conducted to study the impact of different tillage practices on wheat productivity under both cropping patterns.

2. Materials and Methods

2.1. Experimental site description

The two-year field study was conducted to check the influence of the previous crops and the tillage systems on weed dynamics and productivity of wheat crop at Research Farm, Department of Agronomy, Bahauddin Zakariya University, Multan (71.43ºE, 30.2ºN and 122 meters a.s.l.), Pakistan. The experimental area was quite uniform having silty clay and slightly saline soil in nature. Soil physicochemical analysis was performed at the start of experimental sowing to assess the soil fertility of the three years and then the average was computed. The chemical analysis revealed that organic matter contents were 0.57%, pH was 8.37 and EC was 3.30 dS m^{-1}. Pre-sowing soil analysis revealed that the concentration of NPK in soil was as: total available nitrogen was 0.03%, total available phosphorus was 8.83 mg kg^{-1} and total available potassium was 189 mg kg^{-1}. The climate of the region is subtropical to semi-arid.

2.2. Experimental details

The study included three tillage practices *viz*. ZT, CT and DT, and two cropping systems *viz*. rice-wheat (RW) and cotton-wheat (CW). In ZT, wheat seeds were drilled directly into the soil with the help of a no-till sowing machine, without removing the stubbles of previous crops. In CT, the field was prepared by two cultivations with tractor-mounted cultivator followed by leveling. Similarly, two ploughings were done in DT with the help of a chisel plough followed by leveling. All the treatments were replicated three times with a net plot size of 5.0 m × 2.7 m. The experiment was laid out in randomized complete block design with split plot arrangement by keeping tillage practices in main plots and cropping systems in sub-plots.

3.3. Crop husbandry

Pre-soaking irrigation of 10 cm was applied. When soil reached to workable soil moisture level, the seedbeds were prepared according to specific treatments. Seed rates for wheat, cotton and rice (nursery) were kept 125 kg ha^{-1} and 25 kg ha^{-1}, 40 g m^{-2}, respectively. The varieties of wheat, cotton and rice used in this study were Punjab-2011, MNH-886 (Bt) and Basmati-2000, respectively. The production practices described by Shahzad et al. (2016b) were followed in this study. The crops were harvested at their maturity.

2.4. Observations recorded

2.4.1. Weeds

Weeds diversity was measured by visiting the research area during the winter season and weed density was recorded 60 days after sowing. Weed diversity was recorded by observing all weed species in 1 m^2 at three random places in each experimental unit and averaged. To measure the densities of total, broadleaved, grassy and individual weeds, the method adopted by Onen et al. (2018) was followed. All the weeds in the quadrate were harvested, identified and then counted. Thirteen weeds (including both broad leaf and grassy weeds) were identified during the whole period of research.

2.4.2. Agronomic and yield related traits of wheat

Productive tillers (m^{-2}) were counted from a randomly selected area of 1 m^2 at three positions from each plot and then averaged. At the time of maturity (Feekes scale 11), twenty randomly selected spikes from each plot were used to estimate the number of grains per spike. Five samples of 1000-grains were taken from each seed lot, weighed on an electrical balance and averaged for 1000-grain weight. Sun-dried samples were threshed and yield per plot was converted into grain yield t ha^{-1}.

2.5. Economic analysis

The economic analysis was done following CIMMYT (1988). Total income of a cropping system was calculated by adding the income of grain and straw yields of each summer and winter crop. Net benefit returns were obtained by subtracting the total expenditures of a particular treatment from the relevant total income. Benefit-cost ratio (BCR) was calculated by dividing the total income by total expenditures.

2.6. Statistical analysis

The data collected during both years of the experiment were pooled and analyzed statistically using two-way ANOVA and LSD test at 5% probability to compare the differences among means of treatments (Steel et al., 1997). The interactive effect among cropping systems and tillage practices was significant. The data were presented graphically by using the Microsoft Excel program.

3. Results

3.1. Weed diversity, density and biomass

The eight broadleaf weeds identified in the study were fat hen (*Chenopodium murale* L.), common goosefoot (*Chenopodium album* L.), horseweed (*Conyza stricta* L.), garden spurge (*Euphorbia granulate* L.), broad-leaved dock (*Rumex obtusifolius* L.), yellow sweet clover (*Melitous indica* L.), false daisy (*Eclipta prostata* L.) and perennial sow thistle (*Sonchus arvensis* L.), whereas five grassy weeds were identified as salt marsh (*Scirpus maritimus* L.), rabbit foot grass (*Polypogon monspeliensis* L.), bermuda grass (*Cynodon dactylon* L.), corn spurry (*Spergula arvensis* L.) and little seed canarygrass (*Phalaris minor* L.).

Cropping system and tillage techniques had a significant interactive effect on weed diversity in this study (Figure 1). Cotton-wheat (CW) cropping system combined with zero tillage (ZT) and conventional tillage (CT) had higher weed diversity than rice-wheat (RW) cropping system (Figure 1). However, the cotton-wheat cropping system had the same weed diversity as the RW cropping

Table 1: Impact of different cropping systems on total, broad leaved and narrow leaved weed density (number m^{-2}) and biomass (g m^{-2}) under various tillage techniques

Tillage system	Cropping systems					
	Total weeds (m^{-2})		Broad-leaved weeds (m^{-2})		Grassy weeds (m^{-2})	
	RW	CW	RW	CW	RW	CW
Zero tillage	128.83 a	69.83 b	20.16 b	33.00 a	108.66 a	36.8 b
Conventional tillage	18.00 c	14.50 cd	8.67 c	7.33 cd	9.33 c	7.16 c
Deep tillage	9.50 de	6.66 e	3.83 d	3.00 e	5.66 d	3.66 d
LSD at p 0.05	7.02		3.82		4.52	
	Total Weed biomass (g m^{-2})		Broad leaved biomass (g m^{-2})		Narrow leaved biomass (g m^{-2})	
Zero tillage	86.11 a	47.59 b	9.15 b	14.73 a	76.96 a	32.86 b
Conventional tillage	8.67 c	7.075 d	3.15 d	5.04 c	5.52 c	2.03 de
Deep tillage	4.47 e	3.46 e	1.54 e	1.75 e	2.93 d	1.71 e
LSD at p 0.05	0.99		0.31		1.04	

RW= rice-wheat; CW = cotton-wheat

Means not sharing the same letter, within a column or row, differ significantly from each other at 5% probability level system under deep tillage (DT). The same trend was noticed in both years of study (Figure 1).

Cropping system and tillage techniques had a significant interactive effect on weed incidence (Table 1). The CW cropping systems had a lower total weed density and weed biomass under CT and DT tillage systems (Table 1). The same system had a meager effect on weed density and biomass when practiced under ZT whereas RW under ZT enhanced weed density and weed biomass (Table 1). The ZT with RW had a higher weed density and weed dry weight than ZT with CW (Table 1). However, the DT combined in both cropping systems significantly decreased weed density and weed dry weight as compared to other tillage system and cropping systems (Table 1).

The CW cropping systems under ZT had enhanced broadleaved weed density and dry weight than other crop system and tillage systems (Table 1). On the other hand, RW system with ZT had helped to suppress the broadleaved weeds (Table 1). Moreover, DT irrespective of cropping system had reduced the weed density and weed biomass than any other combinations (Table 1). The RW cropping systems with ZT increased weed infestation and their dry weight (Table 1). However, the CW system with all tillage treatments (ZT, DT and CT) had a negative impact on weed infestation and their weight than others (Table 1). The DT under both systems had a suppressive effect in narrow leaved weeds (Table 1).

3.2. Yield related traits of wheat

Cropping system and tillage practices had a significant interactive effect on yield-related traits of wheat. The DT under both cropping systems had more productive tillers than other tillage practices under RW and CW cropping systems (Table 2). Moreover, CW system under DT performed better in this regard. Contrarily, both cropping systems with ZT had an adverse effect on productive tillers (Table 2). Tillage practice i.e., DT in CW had a positive effect on the number of grains compared with other tillage systems (CT and ZT) under both cropping systems (Table 2). In contrast to this, ZT with both cropping systems had a negative impact on the number of grains than other tillage practices under both systems (Table 2). The RW and CW systems practiced under ZT had a lower 1000-grain weight compared with other combinations (Table 2). The DT under CW had a higher 1000-grain weight than other tillage practices irrespective of all cropping systems (Table 5). Moreover, the DT under all cropping systems had a higher grain yield than any other tillage practices with any cropping sequence. However, ZT plots under both cropping systems recorded the minimum grain yield of wheat (Table 2).

Table 2: Impact of different cropping systems on yield related parameters of wheat crop under various tillage techniques

Tillage system	Cropping systems							
	Number of productive tillers (m^{-2})		Number of grains per spike		1000- grain weight (g)		Grain yield (t ha^{-1})	
	RW	CW	RW	CW	RW	CW	RW	CW
Zero tillage	211.7 c	211.6 c	48.75 d	49.65 d	38.94 c	40.94 c	3.74 c	3.95 c
Conventional tillage	268.8 b	272.3 ab	54.74 c	55.51 b	41.20 b	42.84 b	5.49 b	5.71 ab
Deep tillage	274.0 ab	279.1 a	56.79 b	56.85 a	42.19 b	44.23 a	5.81 ab	6.04 a
LSD at p 0.05	7.3		0.88		1.01		0.40	

RW= rice-wheat; CW = cotton-wheat

Means not sharing the same letter, within a column or row, differ significantly from each other at 5% probability level

Table 3: Economic analysis of different cropping system under various tillage techniques

Tillage system	Cropping system							
	Total expenditure (US$ ha^{-1})		Gross income (US$ ha^{-1})		Net income (US$ ha^{-1})		BCR	
	RW	CW	RW	CW	RW	CW	RW	CW
Zero tillage	1919.8	2032.9	5024.4	3278.4	3104.6	1245.5	2.62	1.61
Conventional tillage	2064.8	2187.9	5557.8	3858.1	3493.0	1670.2	2.69	1.76
Deep tillage	2079.0	2202.0	5725.4	4049.1	3646.4	1847.1	2.75	1.84

RW= rice-wheat; CW= cotton-wheat; BCR= Benefit: cost ratio

3.3. Economic analysis

Economic analysis also confirmed that less net income and BCR was observed in ZT under both cropping systems i.e., RW and CW (Table 3). Nonetheless, the DT found to be best tillage practice and resulted higher net income and BCR under both systems. Among cropping systems, RW system recorded higher net income and BCR during both study years (Table 3).

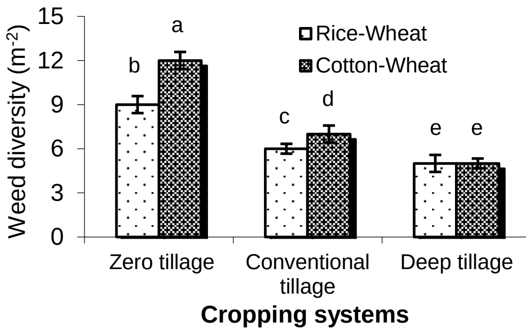

Fig. 1: Impact of different cropping systems on weed diversity under various tillage techniques ± S.E.

Bars not sharing the same letter differ significantly from each other at 5% probability level.

4. Discussion

Different cropping and tillage systems had a variable effect on weeds infestation and wheat grain yield. Generally, ZT had higher weed infestation when practiced under RW cropping systems, but it was lower in the CW system. However, the DT when put under any cropping systems helped to lower the total weed density and dry weight. The CW cropping system under ZT had more broadleaved weed density and dry weight. On the other hand, RW system under ZT had more grassy weeds density and dry weight (Table 1).

Soil disturbance has a strong influence on the size, profile distribution and species density of weed seed bank (Grundy 2003). The seed bank is the main source of propagates for annual weeds and a very important one for biennials and perennial species. The weed seeds tend to come on the surface in zero tilled soils while ploughed soils do not permit them to flourish. Ploughless soils are more compact as compared to ploughed ones. This compaction of soils enhanced the abundance of some perennial weeds (Bachthaler 1985). It was noted that weed presence and diversity in ploughless soils were often greater than ploughed soils (Gruber et al. 2000). It may be due to higher weed seed density which was observed in the upper soil surface of ploughless soils (Torresen et al. 2003; Shahzad et al. 2016c). Altering tillage practices changes weed seed depth in soil which may affect the profusion of weed species in the field (Chauhan et al. 2006). Many weed seedlings do not emerge if seeds are buried deeply (Chauhan and Johnson 2008). Tillage systems that have weed seeds close to the soil surface, may show relatively high weed emergence compared to the system that does not accumulate seeds at the surface (Mohler 1993). It was found that before any tillage operation, weed seeds were present in the soil layer up to 10 cm, while after tillage it is thoroughly distributed over the upper 20 cm of soil (Buhler et al. 2001). Altering tillage practices changes the horizontal and vertical distribution of weed seeds in the soil (Chauhan et al. 2006) and determines weed emergence and species composition (Murphy et al. 2006). Ploughless soils left most of the weed seeds in the top 1.0 cm of the soil profile (Cardina et al. 1991) while DT significantly reduced weed population due to the inversion of soil which resulted in the deeper placement of most of the weed seeds that could not emerge out (Shahzad et al. 2016c). This idea is supported by results of present study in which DT invert the soil layers and ultimately placed weed seed bank deep in the soil, resultantly weeds did not emerge easily.

The CW systems had a suppressive effect on weed infestation. The possible reasons may be the use of crop sequence that creates varying patterns of soil disturbance, resource competition, mechanical damage and allelopathic interference which eventually results in an uneven and frequently hostile environment for the propagation of a weed species (Weiner et al. 2001; Ugen et al. 2002). It caused large variability in the type and timing of soil, crop, and weed management practices; there are more opportunities for weed mortality events in systems than in monoculture (Martin and Felton 1993). As, R-W crop sequence showed less weed diversity, but more weed density as compared to C-W cropping system in our research because greater diversity prevents the domination of a few problematic weeds (Macák et al. 2005). Moreover, the RW cropping system promotes grassy weeds and restricts broad leaved weeds than CW system in this study. The RW cropping system favors grassy weeds like little seed canary grass while it does not favor broad leaved weeds like wild oat ecologically (Walia 2006). However, wild oat (a grassy weed) is a serious problem in non-paddy wheat cropping systems (Walia 2006).

Higher weed density and biomass were noticed in R-W cropping systems combined with ZT that may be due to higher water availability and less soil disturbance which ultimately had minimally affected weed seed bank and resulted in more weed emergence. In general, ZT (practiced with any system) had an adverse effect on yield and related parameters while DT had an opposite effect on these traits. The reduction in these traits of wheat sown under ZT may be due to soil compaction and weed infestation (Shahzad et al. 2016b, c). The DT can lead to a better spatial distribution of roots, improving the nutrient and water uptakes, hence improved productivity (Singh and Malhi 2006; Nakamoto et al. 2006). This coupled with lower weed infestation had further positive effects on crop growth and yield (Zimdahl 2004). Some researchers have noted that the growth of winter wheat was promoted because of DT (Higashida and Yamagami 2003).

Moreover, economic analysis affirmed the supremacy of DT as indicated by higher net income and BCR in both systems. Higher net income and BCR due to DT is the direct outcome of higher wheat yield under both systems (Table 2).

5. Conclusions

Zero tilled and conventionally tilled soils had higher weeds diversity while DT reduced weed diversity and weed prevalence with either of the systems. Wheat sown following cotton with ZT had more density of broadleaved weeds while wheat sown after rice under the same tillage system promoted the grassy weeds. Deep tillage under C-W system had higher grain yield due to significant expansion in yield-related traits, and less weed infestation but it was at par with CT under cotton-wheat system. Nonetheless, the DT found to be best tillage practice and resulted in higher net income and BCR under both systems.

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Author Contributions

Conceptualization, M.H. and M.F.; methodology, M.S.; software, M.S.; validation, M.S., M.A.H. and M.H.; formal analysis, M.A.S.; investigation, M.S.; resources, M.H.; data curation, M.S.; writing—original draft preparation, M.S. and M.A.S.; writing—review and editing, M.H. and M.F.; visualization, M.H.; supervision, M.H. and M.F.; project administration, M.H.; funding acquisition, M.H. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

Ethics approval is not applicable.

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