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RESPONSE OF WHEAT TO TILLAGE AND NITROGEN FERTILIZATION IN RICE-WHEAT SYSTEM

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In a rice-wheat system, rice stubbles remaining in the field often delay early planting of winter wheat to utilize residual soil moisture and reduce operating costs. A randomized complete block design in a split plot arrangement was conducted with four seasonal tillage methods [conventional tillage, CT; deep tillage, DT; zero tillage with zone disk tiller, ZDT; and happy seeder, HS] as main plots and five N levels [0, 75, 100, 125, and 150 kg ha^{-1}] as subplots during 2009 to 2010 and 2010 to 2011 wheat growing seasons. Results showed that DT significantly decreased soil bulk desnsity, penetration resistance, and volumetric moisture content compared with CT, ZDT and HS. However, wheat growth and yield parameter such as fertile tillers, plant height, root length, spike length, grain yields, and water and nutrient-use efficiency was significantly higher in DT compared with other tillage treatments. Wheat growth and yield was more increased by N fertilization at 125 kg ha^{-1} than other N rates. However, when the wheat plant productivity index was plotted over N rates, the non-linear relationship showed that N fertilization at 80 kg N ha^{-1} accounted for 85% of the variability in the plant productivity under DT and HS while ZDT had the same productivity at 120 kg N ha^{-1}.
Keywords: Bulk density, soil resistance, water content, grain yield, plant productivity index

INTRODUCTION

In Pakistan, wheat (*Triticum aestivum* L.) is generally grown under CT in post-harvest puddle rice fields. However, harvesting of certain late maturing specialty rice (*Oryza sativa* L.) varieties (such as basmati) due to their high economic values, rice stubbles remain in the field (10 to 15-cm tall) often causing problems in subsequent plowing and preparation of suitable seedbeds. Consequently, it delays the planting of wheat for a good stand.

Conventional management practices including frequent plowing, chemical fertilization, and pesticide application increases crop yields but exerts negative effects on soil productivity and farm economics. Plowing improves soil tilth for crop growth and yield, alleviates soil compaction and nutrient stratification, and suppresses weeds and soil-borne diseases (Boydas and Turgut, 2007). However, frequent plowing fragments and mixes crop residues, increases soil aeration and temperature, disperses soil structure, accelerates decomposition of crop residues and native soil organic matter (SOM), and causes an increase in CO_2 emissions into the atmosphere (Crovetto, 2006). Moreover, frequent plowing led to the formation of hardpan at the plow depths, decreases water infiltration with accelerated soil erosion (Alakukku *et al*., 2003).

In a rice-wheat cropping system, rice is mostly grown under puddle condition which leads to the dispersion of soil aggregates by plowing, sealing of pore spaces, and formation of a subsurface hardpan (Hassan and Gregory, 1999). The subsoil compaction reduced both the water- and nutrient-use efficiencies of subsequent wheat crop owing mostly to decreased root growth (Ishaq *et al*., 2001a,b). Wheat yield reduction and degradation of soil physical properties depend on the intensity and duration of puddling operations (Aggarwal *et al*., 1995).

Deep tillage of puddle soil reduces the compaction, increases rooting depth, and improves the yield of the rational wheat crop (Chaudhary *et al*., 1991). Deep tillage not only alleviates soil compaction also controls weeds through deep burial of weed seeds. In areas where continuous cropping is practiced deep tillage increases the surface area of the soil exposed to sunlight to control certain diseases, insects and weeds. Akinci *et al*. (2004) reported that two-passes of subsoiling were more effective than subsoiling with one-pass for not only overcoming the soil compaction also improving the soil tilth. Hong-lingl *et al*. (2008) reported that the soil moisture content at 50 to 100 cm depth under deep tillage was higher, while the water consumption was reduced in the 0 to 50 cm depth. However, frequent deep tillage operations are expensive in terms of fuel and time.

No tillage (NT) conversion of plowing is one of the strategies to decrease farming costs, reduce soil erosion, and improve ecosystem services (Sundermeier *et al*., 2011). With NT, surface accumulation of crop residues as mulch influences air, water, and energy exchange processes between the soil ecosystem and the atmosphere (Lobell *et al*., 2006). These processes reduce soil temperature and evaporation during summer months, retain soil moisture longer especially under dry conditions, and thereby improve crop productivity (Lobell *et al*., 2006). Long-term continuous NT has been reported to produce wheat yields equal to or even higher than that of annually plowed fields (Hemmat and Eskandari, 2004).

In rice-wheat cropping systems, rice is harvested by combines, which leave large amount of crop residues in the fields. However, the newly introduced Happy Seeder (HS) cuts and manages the standing stubble and loose straw in front of the furrow openers, retaining it as surface mulch and sows wheat in a single pass of the field. Moreover, costs for sowing wheat are 50 to 60% lower with HS than with conventional sowing. The HS technology provides an alternative to burning for managing rice residues and allows direct drilling of wheat in standing and fragmented residues (Gathala *et al*., 2009). However, most constraints in transitional NT or HS are high weed pressure, poor crop stands, soil compaction and stratification of nutrients, and N immobilization. The problem of nitrogen (N) immobilization is more acute in alternate year rice-wheat production systems due to greater deposition of high C:N ratio of crop residues.

Sustainable crop production depends on the efficient use of N fertilizers. In wheat production, N plays an important role in crop growth and yield. Most of the wheat varieties grown in Pakistan require substantial quantities of N because soil organic matter content is very low. High price and excessive use of N fertilizers as an insurance against crop failures have caused widespread environmental pollution and public health concern that emphasized the need for nitrogen-use efficiency. There are also needs to evaluate the potential effects of surface residues on N transformations and crop development (Weisz *et al*., 2001). Tillage operations influence the soil N dynamics because the crop residues which are incorporated in the soil by plowing decompose faster than the residues which remain on the surface under NT and HS (Christensen, 1986). In NT, N release from the crop residues is slow due to partial anaerobesis and/or due to N immobilization (Schomberg *et al*., 1994) than in tilled systems. However, when applied in excess of crop requirements NT system has a greater loss of N fertilizer by leaching and volatilization than in CT. Current recommendations of N fertilization developed for annually plowed systems which may not be adequate for optimum production of wheat under NT. Therefore, the information on the effects of variable tillage and N fertilization on wheat production in post-harvest puddled rice fields is critical to evaluate the sustainability of the rice-wheat production systems.

The objectives of the study were to evaluate the effects of conventional tillage, deep tillage, zone disk, and happy seeder with different rates of N fertilization on (1) soil bulk density, volumetric water content, and penetration resistance, and (2) growth and yield components of irrigated wheat under a semiarid climate.

MATERIALS AND METHODS

***Site study*:** The study was conducted in a rice-wheat system at the research farm of the university (latitude 31˚26'N and 73˚06'E, altitude 185 m) in 2009-10 and 2010-11 growing seasons. The climate of the region is subtropical semi-arid with annual average rainfall of 490±5 mm, and more than 70% of the rainfall occurs during June–September with mean monthly minimum temperature of 13˚C in January and maximum temperature of 45˚C in July.

The soil of the experimental site was the Hafizabad series (fine-loamy, mixed, hyperthermic, Typic Calciargids) and the soil texture was sandy clay loam. Selected chemical and physical characteristics were: pH 7.7, electrical conductivity 2.82 dS m^{-1}, soil organic matter content 0.73%, total N 0.04%, available phosphorus 62 mg kg^{-1}, exchangeable potassium 83 mg kg^{-1}, and sand 53, silt 20 and clay 27%, respectively.

***Experimental design and cultural practices*:** A randomized complete block design in a 4 x 5 split plot arrangement with three replications was established in 2009 in post-harvest puddle rice fields. Four tillage systems (conventional tillage, CT; deep tillage, DT; zero tillage with zone disk tiller, ZDT; and happy seeder, HS) were randomized in the main plots while five levels of nitrogen [0, (N_0); 75 (N_{75}); 100 (N_{100}); 125 (N_{125}); and 150 (N_{150}) kg ha^{-1}] were applied in 5.4 m by 8 m as subplots. Wheat (var. Saher 2006) was planted at 125 kg ha^{-1} in the third week of November 2009 at 23 cm apart between rows having 24 rows in each replicated plot. Phosphorous and potash fertilizers were applied at 100 and 60 kg ha^{-1}, respectively. A full rate of phosphorous and potash and half of the N were applied at planting. The remaining half of the N was applied with first irrigation. The herbicide Topic (Clodinafop propargyl) at 1.25 kg powder/ha was applied at tillering stage to control weeds.

While CT operations consisted of two disk harrows, two rotavator and two planking, DT operations comprised two 30 to 40 cm deep mould board plow, two rotavator and two planking with a wooden planker. For NT, only zone disk tiller and happy seeder drill was used. Hoeing (one) along with herbicides was used to control weeds in all tillage systems. The evapo-transpiration and rainfall was measured at a field weather station to calculate total water requirement for wheat. Wheat was irrigated (a total of about 400 ± 35 mm water) using nearby canal water and the irrigation was applied (tillering, booting, milking and grain formation) using a cut-throat flume (90 cm × 20 cm).

***Growth and yield parameters, water- and nutrient-use efficiency of wheat*:** Agronomic parameters of wheat, including plant height, fertile tillers, spike length, 1000-

grains weight, and grain and total yields (grain plus straws), water and nutrient use efficiency were recorded. To measure root length, five plants were dug-out from the field, roots were separated from the soil and other residues by gentle washing under a flow of water, and the root length was measured (Tennant, 1975). Water use efficiency (WUE) was calculated by dividing the grain yields with the total volume of water used by the crop:

WUE (kg/mm) = [Grain yield / (Irrigation + rainfall)]

Nutrient-use efficiency (NUE) of wheat was also determined:

NUE (kg kg^{-1}) = [Fertilized grain yields – control grain yields] / Applied nutrients]

***Calculation of plant productivity index*:** The deductive (crop parameters) additive approach was modified to calculate an overall plant productivity index (PP_{Index}), based on "higher values of any growth and yield parameters of crops are better indicators of productivity" at any time (Aziz *et al*., 2011). Datum of each individual wheat growth and yield parameter (X_o) measured such as seed germination, fertile tillers, plant height, spike length, spikelet per spike, grains per spike, 1000-grain weight, total yield, grain yield, straw yield, and harvest index was normalized (X_i) in a scale [> 0 - <1] relative to the maximum value of the particular growth and yield parameter of wheat (X_{max}) in the dataset, $X_i = (X_o X_{max}^{-1})$. By summing all the X_i's and then dividing by the total number (n) of X_i's, the PP_{Index} was calculated:

$PP_{Index} = \Sigma (X_o X_{max}^{-1}) n^{-1}$

***Soil collection and analysis*:** Composite soil samples were collected from 0 to 20 cm depths prior to establishing the experiment (2009) and after the crop harvest in 2011. Soil samples were air dried and ground to pass through a 2 mm sieve. Soil chemical properties determined were; pH by the glass electrode method, electrical conductivity of the saturation paste by the electrical conductivity method, total N by the microkjeldhal method, 0.5 M $NaHCO_3$ extracted P by the method of Olsen and Sommers (1982), exchangeable K by the flame photometric method, and soil organic matter content by loss of ignition according to the method described by Ryan and Estefan (2001). Soil bulk density was measured using the standard core method. The volumetric water content of soil was determined gravimetrically. Soil penetration resistance was measured with a standard cone penetrometer.

***Statistical analysis*:** Data were analyzed statistically using SAS (SAS Institute, 2008). The effects of tillage and N levels, soil depth and their interaction were evaluated by the least significant difference (LSD) test at $p \leq 0.05$ unless otherwise mentioned. The PP_{Index} of wheat was regressed on N levels under different tillage systems using boundary line technique to calculate optimum N fertilization under different tillage systems for achieving at-least 80% of the irrigated wheat productivity (Webb, 1972).

RESULTS AND DISCUSSION

***Tillage and nitrogen fertilization effects on soil physical properties*:** Tillage had significant effects on soil bulk density (ρb), penetration resistance and volumetric water (θv) content (Table 1, Fig. 1). The ρb significantly decreased over time under all tillage treatments except ZDT. In the 2009 to 2010 growing season, the ρb under DT was decreased by 5 to 11% as compared to that of ZDT and HS. Similar effects of tillage on ρb were also observed in the 2010 to 2011 growing season. Averaged across years, the ρb was significantly lower in DT than in other tillage treatments. In both growing seasons, soil penetration resistance was highest in ZDT, intermediate in HS and CT, and lowest in DT (Fig. 1). On average, the ZDT had 4% higher penetration resistance than in DT (Fig. 1). However, the ZDT had 45 and 63% more θv in both growing seasons than in CT and DT, respectively. Irrespective of tillage operations, the ρb, penetration resistance and θv significantly increased with soil depth. However, tillage x soil depth did not exert any significant effects on ρb, penetration resistance and θv.

In contrast, nitrogen fertilization had non-significant effects on ρb, penetration resistance and θv in both growing seasons (Table 2). The interaction of nitrogen and soil depth did not exert any significant effects on ρb, penetration resistance, and θv. Moreover, tillage x N fertilization had non-significant effects on ρb, penetration resistance, and θv (Table 3).

Significantly lower values of ρb, penetration resistance, and θv under DT were due to greater soil inversion and mixing by plowing. DT decreases the ρb and penetration resistance by increasing soil porosity which exposes the surface area of the moist soil to the sunlight and subsequently reduces the ability of the soil to hold moisture content over time (Osunbitan *et al*., 2005). In contrast, significantly higher values of ρb, penetration resistance and θv under ZDT than other tillage operations were due to lack of disturbance, surface deposition of crop residues as mulch, and reduced evaporation (Alvarez and Steinbach., 2009; Fuentes *et al*., 2009). In the rice-wheat system, the NT wheat crop, along with residue retention (Mohanty *et al*., 2007) and synthetic fertilizer had a positive effect on soil physical properties and water infiltration and storage capacity (Zeleke *et al*., 2004).

***Tillage and nitrogen fertilization effects on wheat growth and yields*:** Tillage and N fertilization had significant effects on wheat growth and yield parameters (Table 4-6). In the 2009 to 2010 growing season, DT had significantly higher plant height over others (Table 4). The DT had 4 and 3% higher plant height than in CT and ZDT. Plant height of DT and HS was at par with each other. Similarly, plant height of DT and HS were 3% higher than in CT and ZDT during the 2010-11 growing season. Averaged across years, plant

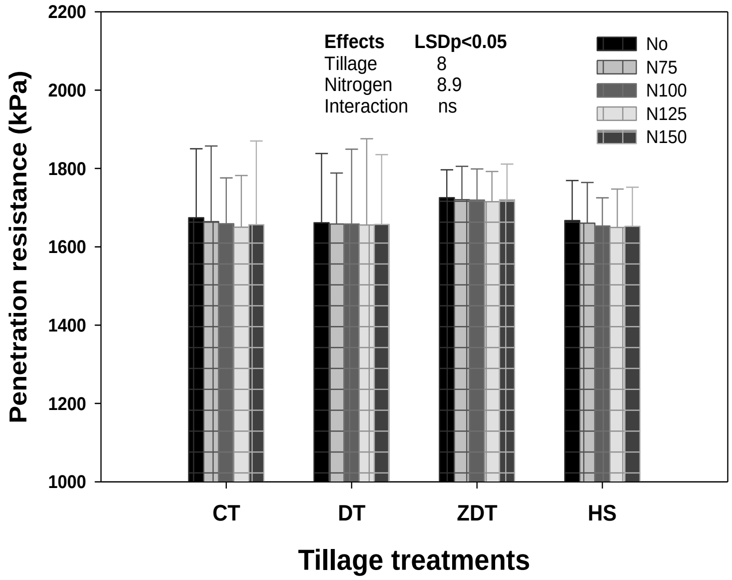

Figure 1. Tillage and nitrogen effect on soil penetration resistance (2009-10 and 2010-11 growing seasons) (CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disc tiller, HS=Happy seeder) (N levels [0, 75, 100, 125, and 150 kg ha^{-1}).

Table 1. Effect of tillage on bulk density and volumetric water content at different depths of soil

Tillage System	**Soil depth (cm)**	**Bulk density (g cm^{-3})** 2009-10	2010-11	2009-11	**Volumetric water (mm cm^{-1})** 2009-10	2010-11	2009-11
$CT_{Initial}$	0-10	1.39C$^{\Psi}$	---	---	1.7	---	---
CT	0-10	1.47B§	1.46B	1.47C	1.2C	1.1C	1.2C
DT	0-10	1.40C	1.39C	1.40D	0.8D	0.7D	0.8D
ZDT	0-10	1.59A	1.58A	1.59A	2.2A	2.1A	2.2A
HS	0-10	1.56A	1.55A	1.56B	1.8B	1.7B	1.8B
			Tillage x Soil depth				
$CT_{Initial}$	0-5	1.44	---	---	1.0	---	---
	5-10	1.51	---	---	1.5	---	---
DT	0-5	1.36	1.35	1.36	0.6	0.4	0.5
	5-10	1.43	1.43	1.43	1.0	0.9	1.0
ZDT	0-5	1.56	1.55	1.56	2.0	1.9	2.0
	5-10	1.62	1.62	1.62	2.4	2.3	2.4
HS	0-5	1.52	1.52	1.52	1.6	1.5	1.6
	5-10	1.60	1.59	1.60	1.9	1.9	1.9
LSDp≤ 0.05							
Soil depth		0.05	0.04	0.05	0.4	0.3	0.4
Tillage x Soil depth		ns	ns	ns	ns	ns	ns

CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disk tiller (zero tillage drill), HS=Happy seeder (zero tillage drill) and ns=Non-significant.

$^{\Psi}$*Means separated by upper case letter in each column are not significantly different at p≤0.05.*

Table 2. **Effect of nitrogen fertilization on bulk density and volumetric water content at different depths of soil**

Nitrogen rates	Soil depth (cm)	Bulk density ($g\ cm^{-3}$) 2009-10	2010-11	2009-11	Volumetric water ($mm\ cm^{-1}$) 2009-10	2010-11	2009-11
0	0-10	1.52A[Ψ]	1.51A	1.52A	1.7A	1.5A	1.6A
75	0-10	1.51A	1.50A	1.51A	1.5A	1.4A	1.5A
100	0-10	1.50A	1.49A	1.50A	1.5A	1.3A	1.4A
125	0-10	1.50A	1.49A	1.50A	1.4A	1.3A	1.4A
150	0-10	1.51A	1.49A	1.50A	1.5A	1.4A	1.5A
		Nitrogen X Soil depth interaction					
0	0-5	1.48	1.47	1.48	1.5	1.3	1.4
	5-10	1.55	1.55	1.55	1.9	1.7	1.8
75	0-5	1.48	1.46	1.47	1.3	1.1	1.2
	5-10	1.54	1.53	1.54	1.7	1.6	1.7
100	0-5	1.47	1.46	1.47	1.3	1.1	1.2
	5-10	1.54	1.53	1.54	1.7	1.6	1.7
125	0-5	1.46	1.45	1.46	1.1	1.1	1.1
	5-10	1.53	1.52	1.53	1.6	1.5	1.6
150	0-5	1.47	1.46	1.47	1.3	1.2	1.3
	5-10	1.54	1.53	1.54	1.7	1.6	1.7
LSD $p\leq 0.05$							
Soil Depth		0.06	0.05	0.06	0.4	0.3	0.4
Nitrogen x Soil depth		ns	ns	ns	ns	ns	ns

CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disk tiller (zero tillage drill), HS=Happy seeder (zero tillage drill) and ns=Non-significant.
[Ψ]*Means separated by upper case letter in each column are not significantly different among nitrogen rates at p≤ 0.05.*

Table 3. Effect of tillage and nitrogen interaction on soil bulk density and volume metric water content average across soil depth over time

Tillage System	Nitrogen rates	Bulk density ($g\ cm^{-3}$) 2009-10	2010-11	2009-11	Volumetric water ($mm\ cm^{-1}$) 2009-10	2010-11	2009-11
CT	0	1.49	1.48	1.49	1.4	1.3	1.4
	75	1.48	1.47	1.48	1.3	1.1	1.2
	100	1.47	1.46	1.47	1.2	1.1	1.2
	125	1.46	1.45	1.46	1.0	1.0	1.0
	150	1.48	1.46	1.47	1.1	1.1	1.1
DT	0	1.41	1.40	1.41	0.9	0.7	0.8
	75	1.40	1.39	1.40	0.9	0.7	0.8
	100	1.39	1.38	1.39	0.8	0.6	0.7
	125	1.39	1.38	1.39	0.8	0.6	0.7
	150	1.39	1.38	1.39	0.7	0.7	0.7
ZDT	0	1.60	1.60	1.60	2.5	2.3	2.4
	75	1.59	1.58	1.59	2.2	2.0	2.1
	100	1.58	1.58	1.58	2.1	2.1	2.1
	125	1.58	1.57	1.58	2.0	2.0	2.0
	150	1.59	1.58	1.59	2.2	2.0	2.1
HS	0	1.57	1.57	1.57	1.9	1.9	1.9
	75	1.56	1.56	1.56	1.8	1.7	1.8
	100	1.57	1.55	1.56	1.8	1.7	1.8
	125	1.55	1.54	1.55	1.6	1.6	1.6
	150	1.57	1.55	1.56	1.8	1.7	1.8
LSD $p\leq 0.05$							
Tillage x Nitrogen	ns	ns	ns	ns	ns	ns	

CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disk tiller (zero tillage drill), HS=Happy seeder (zero tillage drill) and ns=Non-significant

Table 4. Effect of tillage and nitrogen interaction on plant height, fertile tillers, spike length, 1000 -garin weight, root length, total and grain yields, and water and nutrient use efficiency of irrigated wheat (2009-10 growing season)

Tillage Trts.	N rate ($kg\ ha^{-1}$)	Plant ht. (cm)	Tillers (m^{-2})	Spike length (cm)	1000-grain wt. (g)	Root length (cm)	Total yield	Grain yield	WUE ($kg\ mm^{-1}$)	NUE ($kg\ kg^{-1}$)
							($Mg\ ha^{-1}$)			
	0	94e[Ψ]	181d	14.3d	43.5c	12.4d	5.9d	3c	5.4c	0c
	75	95.5d	235c	15.3c	45.5ab	14c	10.4c	4.1b	9.7b	24.1a
	100	101.6c	247b	15.4b	44.7bc	15.6b	11.6b	4.6a	11a	23.4a
	125	103b	264a	15.5a	45.6ab	16.7a	12.4a	4.9a	11.6a	21.3a
	150	104.9a	249b	15.4b	46.5a	15.7b	11.4b	4.6ab	10.8a	15.1b
				Tillage x N interaction						
CT	0	90.9	203	14.1	42.7	14	5.4	2	4.9	0
	75	94.2	227	15.1	44.2	15.1	9.8	3.8	9.1	23.8
	100	99.2	221	15.3	44.3	16.3	10	3.9	9.3	18.5
	125	100.2	251	15.4	45.5	17.5	10.3	4.1	9.7	16.3
	150	103.7	241	15.3	46.1	16.4	9.5	3.8	8.9	11.4
	Mean	97.6C[§]	229D	15D	44.5A	15.9B	9C	3.5B	8.4B	14B
DT	0	96.2	170	14.4	42.3	15.1	4.9	1.9	4.5	0
	75	98.1	248	15.5	45.7	18.3	11.6	4.6	10.9	36.3
	100	103.1	260	15.5	44.7	20.4	13.2	5.3	12.6	34.2
	125	104.8	277	15.5	46.1	21.4	14.5	5.8	13.7	31.3
	150	106.5	280	15.5	45.1	20.4	13.7	5.5	13	24
	Mean	101.8A	247A	15.3A	44.8A	19.1A	11.6A	4.6A	10.9A	25.2A
ZDT	0	92.7	176	14.2	44	9.2	6	2.4	5.6	0
	75	93.1	236	15.2	45.1	10.3	9	3.6	8.5	16.6
	100	101.7	250	15.3	43.8	11.5	10.8	4.3	10.3	19.9
	125	102.3	257	15.5	45.5	12.7	11.5	4.6	10.9	18.1
	150	103.2	235	15.4	48.6	11.6	10	3.9	9.3	10.6
	Mean	98.6C	231C	15.1C	45.4A	11.1D	9.4B	3.8B	8.9AB	13B
HS	0	96.3	176	14.4	44.8	11.2	7.3	2.9	6.9	0
	75	96.5	228	15.5	46.8	12.2	11	4.4	10.4	19.8
	100	102.5	258	15.5	46.8	14.2	12.4	5	11.8	21
	125	104.5	270	15.6	45	15.1	13.3	5.3	12.6	19.4
	150	106.5	242	15.5	46	14.3	12.7	5.1	12	14.6
	Mean	101.3A	234B	15.2B	45.7A	13.4C	11.4A	4.5A	10.7A	15B
LSD p? 0.05										
Tillage x N		0.7	4	0.01	ns	0.35	1.1	ns	ns	ns

CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disk tiller (zero tillage drill), HS=Happy seeder (zero tillage drill), WUE=Water -use efficiency, NUE=Nutrient-use efficiency, and ns=Non-significant.

[Ψ]Means separated by lower case letter in each column are not significantly different among Nitrogen fertilization rates at p ?0.05. [§]Means separated by upper case letter in each column are not significantly different among tillage treatments at p?0.05.

Table 5. Effect of tillage and nitrogen interaction on plant height, fertile tillers, spike length, 1000 -garin weight, root length, total and grain yields, and water and nutrient use efficiency of irrigated wheat (2010-11 growing season)

Tillage Trts.	N rate ($kg\ ha^{-1}$)	Plant ht. (cm)	Tillers (m^{-2})	Spike length (cm)	1000-grain wt. (g)	Root length (cm)	Total yield ($Mg\ ha^{-1}$)	Grain yield ($Mg\ ha^{-1}$)	WUE ($kg\ mm^{-1}$)	NUE ($kg\ kg^{-1}$)
	0	95c[Ψ]	223e	14.3e	43.6b	12.5e	8.5c	3.3d	7.4d	0d
	75	95.1c	261d	15.3d	47.1a	14.1d	13.7b	5.4c	12c	27.9a
	100	102b	278b	15.4c	47.6a	15.6c	15.6a	6.2b	13.9b	29.2a
	125	103.1b	291a	15.5a	48.3a	16.7a	16.4a	6.5a	14.6a	26.1b
	150	104.4a	272c	15.4b	47.3a	15.8b	15.3a	6.1b	13.6b	18.6c
					Tillage x N interaction					
CT	0	91.2	210	14.1	42.9	14.2	7.8	3	6.7	0
	75	94.5	251	15.1	46.8	15.5	13.5	5.3	11.8	30.1
	100	100.1	264	15.4	47.5	16.4	15.3	6	13.4	29.8
	125	100.3	283	15.5	48.5	17.8	16.2	6.4	14.4	27.3
	150	103.5	254	15.4	46.9	16.6	14.1	5.6	12.5	17.1
	Mean	97.9B[§]	252D	15.1D	46.5A	16.1B	13.4A	5.3B	11.6B	20.9A
DT	0	98.3	230	14.5	42.3	15.2	9.2	3.6	8	0
	75	96.4	270	15.5	47.1	18.2	13.7	5.4	12.2	25.1
	100	103.2	287	15.5	47.6	20.1	15.8	6.3	14.1	27.5
	125	104.9	295	15.6	48.6	21.4	16.6	6.6	14.8	24.6
	150	105.5	289	15.5	47.7	20.3	16.2	6.5	14.4	19.4
	Mean	101.7A	274B	15.3A	47A	19A	14.3A	5.7A	12.7A	19.3A
ZDT	0	93.2	215	14.3	42.9	9.2	8	3.1	6.9	0
	75	92.8	247	15.3	47.4	10.5	13.4	5.3	11.8	29.1
	100	101.8	270	15.4	47.7	11.4	15.4	6.2	13.8	30.8
	125	102.6	289	15.5	48.5	12.5	15.9	6.3	14.2	26
	150	103.3	259	15.5	46.6	11.7	14.3	5.7	12.7	17
	Mean	98.7B	256C	15.2B	46.6A	11.1D	13.4A	5.3B	11.9B	20.6A
HS	0	97.2	236	14.4	44.2	11.2	9	3.5	7.8	0
	75	96.6	276	15.5	47.2	12.2	14	5.6	12.4	27.5
	100	103.1	290	15.6	47.6	14.3	15.9	6.4	14.2	28.5
	125	104.6	295	15.6	47.5	15.1	17	6.8	15.1	26.2
	150	105.4	284	15.5	47.9	14.4	16.5	6.6	14.7	20.5
	Mean	101.4A	276A	15.3A	46.9A	13.4C	14.5A	5.8A	12.9A	20.5A
LSD p? 0.05										
Tillage x N		3.5	3	0.02	ns	0.27	ns	0.3	0.7	ns

CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disk tiller (zero tillage drill), HS=Happy seeder (zero tillage drill), WUE=Water-use efficiency, NUE=Nutrient-use efficiency, and ns=Non-significant.

[Ψ]Means separated by lower case letter in each column are not significantly different among Nitrogen fertilization rates at p ?0.05.

[§]Means separated by upper case letter in each column are not significantly different among tillage treatments at p ?0.05.

Table 6: Tillage and nitrogen interaction on plant height, fertile tillers, spike length, 1000 -garin weight, root length, total and gr ain yields, and water and nutrient use efficiency of irrigated wheat (combined over 2009-2010 and 2010-2011 growing seasons)

Tillage Trts.	N rate (kg ha^{-1})	Plant ht. (cm)	Tillers (m^{-2})	Spike length (cm)	1000-grain wt. (g)	Root length (cm)	Total yield (Mg ha^{-1})	Grain yield (Mg ha^{-1})	WUE (kg mm^{-1})	NUE (kg kg^{-1})
	0	94.5d[Ψ]	202d	14.3e	43.5b	12.4e	7.2d	2.8d	6.4c	0c
	75	95.3d	248c	15.3d	46.3a	14d	12c	4.7c	10.9b	26a
	100	101.8c	263b	15.4c	46.1a	15.6c	13.6b	5.4b	12.4a	26.3a
	125	103b	277a	15.5a	46.9a	16.7a	14.4a	5.7a	13.2a	23.7a
	150	104.7a	260b	15.4b	46.9a	15.7b	13.4b	5.3b	12.2a	16.8b
					Tillage x N interaction					
CT	0	91	207	14.1	42.8	14.1	6.6	2.5	5.8	0
	75	94.4	239	15.1	45.5	15.3	11.7	4.6	10.4	27
	100	99.7	243	15.3	45.9	16.4	12.7	5	11.3	24.1
	125	100.2	267	15.4	47	17.7	13.2	5.2	12	21.8
	150	103.4	248	15.4	46.5	16.4	11.8	4.7	10.7	14.2
	Mean	97.7C[§]	241C	15D	45.5A	16B	11.2B	4.4B	10.1B	17.4B
DT	0	97.3	200	14.4	43.3	15.1	7.1	2.8	6.2	0
	75	97.3	259	15.5	46.4	18.2	12.7	5	11.5	30.7
	100	103.2	273	15.5	46.2	20.2	14.5	5.8	13.3	30.9
	125	104.9	286	15.6	47.4	21.4	15.5	6.2	14.2	28
	150	106	284	15.5	46.4	20.4	14.9	6	13.7	21.7
	Mean	101.7A	261A	15.3A	45.9A	19.1A	12.9A	5.1A	11.8A	22.2A
ZDT	0	93	195	14.3	43.5	9.3	7	2.7	6.2	0
	75	93	241	15.3	46.3	10.4	11.2	4.5	10.1	22.8
	100	101.6	260	15.4	45.8	11.5	13.1	5.3	12	25.3
	125	102.5	273	15.5	47	12.6	13.7	5.5	12.6	22
	150	103.3	247	15.4	47.6	11.7	12.1	4.8	11	13.9
	Mean	98.7B	243C	15.1C	46A	11.1D	11.4B	4.5B	10.4B	16.8B
HS	0	96.8	206	14.4	44.5	11.2	8.2	3.2	7.3	0
	75	96.6	252	15.4	47	12.2	12.5	5	11.4	23.6
	100	102.8	274	15.5	46.8	14.3	14.2	5.7	13	24.8
	125	104.6	282	15.6	46.3	15.1	15.2	6.1	13.9	22.8
	150	106	262	15.5	47	14.3	14.6	5.9	13.4	17.5
	Mean	101.4A	255B	15.2B	46.3A	13.4C	12.9A	5.2A	11.8A	17.8B
LSD p? 0.05										
Tillage x N		1.2	14	0.1	ns	0.21	ns	ns	ns	ns

CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disk tiller (zero tillage drill), HS=Happy seeder (zero tillage drill), WUE= Water -use efficiency, NUE=Nutrient-use efficiency and ns=Non-significant.

[Ψ]Means separated by lower case letter in each column are not significantly different among Nitrogen fertilization rates at p ? 0.05.

[§]Means separated by upper case letter in each column are not significantly different among tillage treatments at p ? 0.05.

height of DT and HS was significantly higher than in other tillage treatments. In 2009 to 2010, the DT produced the 7, 6 and 5% more fertile tillers than in CT, ZDT and HS, respectively. However, the HS produced the 7 and 8% more fertile tillers than in ZDT and CT. Average across year, the DT produced the highest number of fertile tillers over others. In both seasons, DT had the longest root length of wheat compared with CT, ZDT and HS. The spike length of DT was higher than in CT, ZDT and HS. In the 2009-10 season, wheat grain yield was significantly higher (4.6 Mg ha^{-1}) in DT followed by HS (4.5 Mg ha^{-1}) as compared with CT and ZDT. DT gave 17 to 23% higher grain yields than ZDT and CT while HS had 15 to 22% higher grain yield than ZDT and CT. In contrast, wheat grain yield was significantly higher (5.8 Mg ha^{-1}) in HS followed by DT (5.7 Mg ha^{-1}) compared with CT and ZDT during 2010 to 2011 growing season. Similarly, highest total yields (11.6 and 11.4 Mg ha^{-1}) were attained in DT and HS over other treatments in both years. In the 2009 to 2010 growing season, water-use efficiency was significantly higher in DT and HS than other treatments. DT was 18 to 22% higher than in ZDT and CT while HS was 16 to 21% higher than in ZDT and CT. Similarly, nutrient-use efficiency was significantly higher in DT that was 40, 44 and 48% than in HS, CT and ZDT, respectively.

Nitrogen fertilization significantly influenced the growth and yield of irrigated wheat in both the growing seasons (Table 4-6). Averaged across years, the highest number of fertile tillers was recorded at N_{125} that were 27, 10, 5 and 5% greater than in N_0, N_{75}, N_{100} and N_{150}, respectively. However, maximum plant height of wheat was noted in N_{150} that were 9, 8, 2, and 1% greater than the plant height of N_0, N_{75}, $N_{100,}$ and N_{125}, respectively. Similarly, the longest root length was measured in N_{125} that was 25, 16, 6 and 5% greater than in N_0, N_{75}, N_{100} and N_{150}, respectively in both years. Spike length was also consistently higher in N_{125} that was 7 to 1% greater than in N_0, N_{75}, N_{100} and N_{150}, respectively. However, 1000-grain weight of wheat did not vary consistently in response to N fertilization over time. Wheat grain yield was significantly higher in N_{125} that was 49, 16, 4 and 4% greater than in N_0, N_{75}, N_{100} and N_{150}, respectively. Total yield was high in N_{125} that was 50, 16, 5 and 5% greater than in N_0, N_{75}, N_{100} and N_{150}, respectively. Water-use efficiency of wheat was consistently higher in N_{125} that was 51 and 17% higher than in N_0 and N_{75}. However, NUE was higher at lower N rates. At N_{100} and N_{75} were significant higher and at par with each other and had 10 to 36% higher than in N_{125} and N_{150}, respectively.

In the year 2009-10, tillage x nitrogen interaction significantly influenced the wheat plant height, number of fertile tillers, spike length, root length, and total yields except 1000-grain weight, grain yields, WUE and NUE (Table 4). Tillage x nitrogen had significant interaction on plant height, fertile tillers, spike length, root length and grain yield and water use efficiency except 1000-grain weight, total yield and NUE during the 2010 to 2011 growing season. Averaged across years, tillage x nitrogen had significant effect on plant height, fertile tillers, spike length, root length except 1000-grain weight, total and grain yield, WUE and NUE. However, N_{125} under DT produced significantly higher growth and yield of wheat followed by HS over other tillage x nitrogen combinations.

Significantly higher plant height of wheat under DT was associated with better seedbed preparation, higher soil porosity and greater water and nutrient availability (Khan *et al*., 2001). In contrast, the lower plant height of wheat under CT was due to subsurface compaction which may have hindered root growth and affected water and nutrient uptakes. Similarly, higher percentage of fertile tillers in DT than in CT and ZDT was due to greater water and nutrient availability to plants (Mrabet, 2002). It is also reported that DT and zero tillage produced the maximum spike lengths than the CT. Significantly longer root lengths of wheat observed in DT than in HS and ZDT was due to transitional soil compaction and higher values of bulk density (Beulter and Centurion, 2004). It is suggested that the shorter root length of crops in NT than in CT was due to surface soil compaction (Lopez-Bellido *et al*., 2007a,b).

Consistently higher total and grain yields in HS and DT than in CT were reported in several studies (Sip *et al*., 2009). Rashidi and Keshavarzpour (2007) suggested that DT creates a finer and loose soil condition, which in turn, positively influences the seedling emergence and establishment to support higher crop yields. In contrast, soils under ZDT and HS are cooler and moist compared to CT and DT. Cooler temperatures and higher moisture content often improve water-use efficiency of crops. Hong-lingl *et al*. (2008) reported that soil water storage under DT was more, however, significantly higher WUE is reported under HS than all other tillage systems (Su *et al.*, 2007). Our findings were similar on WUE of wheat in zero tillage and DT due to high water storage (Mrabet, 2002). Moreover, significant difference in wheat grain yields between growing seasons was due to the variations in air temperatures, amount of rainfall and relative humidity. The weather of the 2010 to 2011 growing season was more favorable to irrigated wheat growth and WUE as compared to the weather conditions in 2009-10.

Significant effects of N fertilization on the plant height, number of fertile tillers, root growth, spike length, and 1000-grain weight of wheat were reported in other studies (Hussain *et al*., 2006). Since increasing levels of N is associated with more vegetative development, N fertilization up to a certain level such as N_{125} was found to be optimum. Nitrogen also has significant effect on the spike length but excess of N decreased the spike length (Hussain *et al*., 2006). Higher 1000-grain weight was recorded at higher N fertilizer rates (Hussain *et al*., 2006). Higher N fertilization increased the root length compared with lower ones (Galantini *et al*., 2000). It is reported that total and grain yields increased by increasing N fertilization, but excess of nitrogen often decreased the yields because other yield components of wheat are decreased with an associated increase in vegetative growth (Khan *et al*., 2000). Similarly, Tavakoli and Oweis (2004) reported that with irrigation, the response of winter wheat to N significantly increased up to 60 kg of grain yields ha^{-1}. Although N fertilization has positive effects on the WUE but the NUE decreased with the increased N application rates (Zhao *et al*., 2007).

Significant interaction of tillage x N fertilization on the growth and yields of irrigated wheat suggested that N_{125} under DT performed best, followed by HS compared with other tillage x N combinations. Since DT provides a higher amount of subsoil moisture to wheat, N fertilization at 125 kg ha^{-1} was enough to produce high yields.

***Tillage and nitrogen fertilization effect on wheat plant productivity index*:** The plant productivity index (PP_{Index}) based on growth and yield components of wheat showed a significant response to tillage operations and N fertilization (Fig. 2). Results showed that PP_{Index} of wheat in all tillage treatments responded non-linearly by N fertilization. The DT and HS showed better response to N fertilization than CT and ZDT. Nitrogen fertilization at 80 kg ha^{-1} accounted 85% of the variability in the PP_{Index} under DT and HS. In contrast, N fertilization at 125 kg ha^{-1} accounted 85% of the variability in PP_{Index} under CT and ZDT. In other words, about 45 kg less N is required to obtain similar wheat yields than in CT and ZDT.

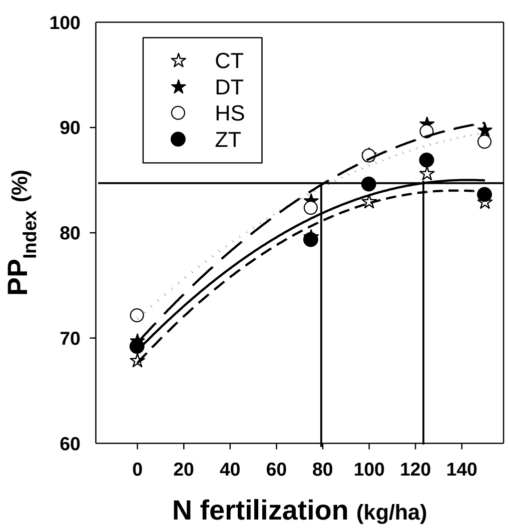

Figure 2. Tillage and N fertilization effect on plant productivity index of wheat (2009-10 and 2010-11 growing years)(CT=Conventional tillage, DT=Deep tillage, ZDT=Zone disc tiller, HS=Happy seeder)(N levels [0, 75, 100, 125, and 150 kg ha^{-1}).

Conclusion: Deep tillage and use of the Happy seeder improved soil physical properties under irrigated wheat after puddled rice. Nitrogen fertilization at 125 kg ha^{-1} under deep tillage and happy seeder produced the similar growth and yields of wheat than in conventional tillage and zone disc tiller. Moreover, when the plant productivity index was plotted over N fertilization rates, the non-linear relationship suggested that N fertilization at 80 kg ha^{-1} accounted for 85% of the variability in plant productivity of wheat while ZDT and CT provided the same productivity at 120 kg N ha^{-1}.

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