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Impact of tillage methods and nitrogen application rates on soil physical health indices, NO_3 content and yield related traits of wheat

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Abstract

A field study was conducted to investigate the effects of tillage and nitrogenous fertilizer on soil physical properties and crop yield of wheat. Tillage treatments in the study were conventional tillage (CT) and deep tillage (DT). Nitrogen in the form of Urea was applied @ 130 and 160 kg ha^{-1}, while control treatment received no N application. The statistical results of the study indicated that tillage methods significantly affected soil physical properties. Deep tillage and high nitrogen rates caused greater leaching of nitrate than the control at various depths. The statistical results of the study also indicated that nitrogen application significantly affected the agronomic parameters of wheat but had non significant effect on soil physical properties. The maximum value of grain yield and straw yield was observed in case of N_{160}. So to improve soil physical properties, to gain substantial yield of wheat as well as to check nitrate leaching, proper nitrogen rates in a planned manner should be applied rather than excessive use and indiscriminate tillage practices should also kept under consideration.

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Introduction

Wheat (*Triticum aestivum* L.) is the main staple food of Pakistan. It contributes 10.3% to the value added in agriculture and 2.2% to GDP. It was cultivated on an area of 9039 thousand hectares, showing a increase of 4.4% over last year's area of 8660 thousand hectares (Economic survey of Pakistan, 213-14).

Soil quality may be defined as the capacity of the soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health (Doran *et al.*, 1996). Careful soil management is the key to sustainable agricultural production. Soil tillage is among the important factors affecting soil physical quality indicators and crop yield. Among the crop production factors, tillage contributes up to 20% (Khurshid *et al.*, 2006).Choice of tillage system can affect soil properties depending on site, crop species, climate and the time the tillage system has been used (Rhoton, 2000; Martinez *et al.*, 2008). Although CT reduces compaction, provides favorable seed bed, enhances root growth and development, controls weeds and maintains crop yields (Bennie and Botha, 1986; Varsa *et al.*, 1997), it accelerates soil structural degradation, nutrient depletion and biochemical oxidation of soil organic matter (Dick, 1983; Islam and Weil, 2000).

Nitrogen is one of the major nutrients affecting soil fertility (Heumann *et al.*, 2002). Intensive tillage and excessive N fertilization can increase N leaching in groundwater, which is a major environmental concern (Liang and McKenzie, 1994;Al-Kaisi and Licht, 2004).Agriculture is a major source of nitrogen loss to the environment (Socolow, 1999) and directly responsible for more than 50% of the nitrogen that is leached into running waters because of mineral fertilizer application (Hansen *et al.*, 2000; Owens *et al.*, 2000; Sogbedji *et al.*, 2000).

Wheat is a type of shallow-rooted crop and the domain root zone is 0.2 m below the soil surface, which can lead to considerable nitrate loss by leaching under irrigated or high rainfall conditions (Ren *et al.*, 2003; Yu *et al.*, 2003). Increasing fertilizer N inputs to agricultural land beyond crop needs results in gaseous and leaching loss (Spalding and Exner, 1993). Deep accumulation of NO_3-N in the soil profile increases the potential for N leaching to shallow water tables (Keeney and Follett, 1991).At this time, a wide range of tillage methods and imbalanced nitrogenous fertilizers are being used in Pakistan without evaluating their effects on soil physical properties, nitrate leaching and crop yield. Therefore, the present investigation was planned to determine the effect of different tillage methods and nitrogen application rates on soil physical properties, nitrate content and crop yield of wheat in the semiarid climate of Pakistan.

Materials and methods

A two year field experiment was conducted to evaluate the effect of different tillage methods and nitrogen rates on soil physical properties, nitrate content and crop yield of wheat during 2009 and 2010 growing seasons at Research Site of Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad. The site is located at latitude of 72°-01' N and longitude of 73°-40' E and is 84 m above mean sea level, in semiarid climate of Pakistan, where the summers are dry and hot while the winters are cool. The soil of the experimental site was medium textured, Typic Calciargids sandy clay-loam soil having a pH of 7.8; EC_e 2.88 dS m^{-1}; saturation percentage of 36.6%. It also contained organic matter 4.0 g kg^{-1}; total N 0.042 %, available P 13.0 mg kg^{-1} and available K 160.0 mg kg^{-1} soil.

The experiments were laid out in a randomized complete block design (RCBD) with spilt plot arrangement keeping tillage in main and nitrogen application rates in sub-plots. Each treatment was replicated thrice.

Tillage treatments included 1) deep tillage with chisel plough, 30 cm deep, three shovels spaced 45 cm apart followed by narrow tine cultivator and planking, 2) conventional tillage included four ploughing with narrow-tine cultivator followed by planking. Nitrogen was applied at 130 and 160 kg ha^{-1} in form of Urea, while control treatment received no nitrogen.

Recommended rate of P_2O_5:K_2O (85:62 $kgha^{-1}$) were applied as TSP and SOP, respectively. Whole of P and K were added at the time of sowing. Nitrogen was applied in three splits, i.e. 1/3rd of required N as per treatment was applied before sowing and remaining N was applied at 2nd and 3rd irrigation. For irrigation, canal water was applied when required. Wheat was planted at the rate of 115 kg ha^{-1} at the end of November. Wheat (*Triticum aestivum* L. cv. Sahar) was sown by drill method, keeping 9 inches row-to-row distance. Pest and weed controls were performed according to general local practices and recommendations. All other necessary operations except those under study were kept normal and uniform for all the treatments.

Standard procedures were adopted for recording the data on various growth and yield parameters. Agronomic parameters including plant height, number of spikelets $spike^{-1}$, number of tillers m^{-2}, grain yield and straw yield were recorded at harvest. Soil physical properties e.g. infiltration rate, field saturated hydraulic conductivity and penetration resistance were measured at crop harvest by using double ring infiltrometer, Guelph Permeameter and cone Penetrometer. Similarly soil samples were collected from different depth and analyzed for bulk density, soil organic carbon contents and NO_3 concentration by following standard procedures. Soil Samples for organic carbon concentration were collected with auger before sowing and at harvest from 0-5, 5-10 cm depths from each treatment. Soil samples collected from 0-10, 10-25, 25-40 and 40-100 cm depth before sowing and at crop harvest will be analyzed for NO_3^-concentration. Data was statistically analyzed by using Costate-2001(Steel *et al.*, 1997).

Results

Crop yield and yield components of wheat

Different nitrogen rates application had significant effect on growth and yield components of wheat. However, the effect of tillage methods and interaction between tillage and nitrogen were non-significant except plant height in which interaction is significant (Table 1).

Table 1. Agronomic and yield related traits as affected by tillage methods and nitrogen rates in wheat.

Treatments			Plant height (cm)	Tiller number (m^{-2})	Spikelets per spike	Grain yield ($Mg\ ha^{-1}$)	Straw yield ($Mg\ ha^{-1}$)
Tillage systems (T)	CT	T_1	92.7 A	270 A	20 A	4.87 A	6.66 A
	DT	T_2	94.5 A	277 A	19 A	5.18 A	7.02 A
Nitrogen ($kg\ ha^{-1}$) (N)	0	N_1	89.0 C	228 C	18 B	3.7 C	5.03 C
	130	N_2	95 B	280 B	19 B	5.3 B	7.42 B
	160	N_3	96 A	313 A	20 A	6.07 A	8.07 A
T×N		T_1N_1	85.47 b	224.7 c	19.3 a	3.50 d	4.70 b
		T_1N_2	99.17 a	275.3 ab	19.33 a	5.17 c	7.27 a
		T_1N_3	93.47 a	310.3 a	20.0 a	5.93 ab	8.00 a
		T_2N_1	92.3 ab	230.7 bc	17.33 a	3.90 d	5.37 b
		T_2N_2	92.60 a	285.3 a	19.33 a	5.433 bc	7.57 a
		T_2N_3	98.50 a	314.7 a	20.76 a	6.2 a	8.13 a

† CT: Conventional Tillage; DT: Deep Tillage

† Mean for each treatment within column followed by the same letter are not significantly different at P≤0.05.

The highest plant height (96 cm) was recorded in N_3 treatment and lowest (89 cm) in control. The interactive effect of tillage × nitrogen rates were significant, maximum mean value of plant height (99.5 cm) was observed in T_2N_3 followed by (84.5 cm) in T_1N_1. Different nitrogen rates application significantly affected no. of tillers m^{-2}. The highest no. of tillers m^{-2} (313) was recorded in N_3 treatment and lowest (228) in control. The highest numbers of spikelets per spike 20 were obtained in N_3 treatment followed by (18) in control. The highest grain yield of 6.07 Mg ha^{-1} was obtained for N_3 treatment and lowest (3.7 Mg ha^{-1}) for control. The effect of different tillage treatments on grain yield was found non-significant However, maximum grains yield 5.18 Mg ha^{-1} was in DT treatment followed by 4.87 Mg ha^{-1} in CT. The effect of different nitrogen treatments on straw yield was also found significant. The highest grain yield of 8.07 Mg ha^{-1} was obtained for N_3 treatment and lowest (5.03 Mg ha^{-1}) for control.

Table 2. Soil physical properties as affected by tillage methods and nitrogen rates in wheat.

Treatments			Hydraulic Conductivity (mm hr^{-1})	Soil Strength (KPa)	infiltration rate (mm hr^{-1})	Bulk Density (Mg m^{-3}) 0-10 cm	Bulk Density (Mg m^{-3}) 10-20 cm	Bulk Density (Mg m^{-3}) 20-30 cm
Tillage systems (T)	CT	T1	53.48 B	916.1 A	57.5 B	1.45 A	1.46 A	1.58 A
	DT	T2	62.39 A	756 B	64.38 A	1.39 B	1.44 A	1.57 A
Nitrogen (kg ha^{-1}) (N)	0	N1	55.7 A	906.5 A	60.6 A	1.42 A	1.44 A	1.58 B
	130	N2	57.8 A	805.3 B	61.3 A	1.42 A	1.46 A	1.58 AB
	160	N3	60.4 A	796 B	60.9 A	1.415 A	1.46 A	1.59 A
T×N	T_1N_1		52.37 a	945 a	57.3 b	1.45 ab	1.44 a	1.58 c
	T_1N_2		3.033 a	915.57 a	58.30 b	1.45 ab	1.47 a	1.587 a
	T_1N_3		55.03 a	887.67 a	56.90 b	1.46 a	1.47 a	1.587 a
	T_2N_1		59.03a	868 a	63.89 a	1.38 c	1.43 a	1.570 d
	T_2N_2		62.47 a	695 b	64.37 a	1.39 bc	1.45 a	1.580 b
	T_2N_3		65.67 a	705 b	64.9 a	1.4 abc	1.46 a	1.587 a

† CT: Conventional Tillage; DT: Deep Tillage

† Mean for each treatments within column followed by the same letter are not significantly different at P≤0.05.

Soil physical quality indictors

Tillage methods had significant effect on soil physical properties. It is mechanical manipulation of soil which improves soil structure and health. Soil physical properties were non-significantly affected by nitrogen application rates and interaction between tillage and nitrogen rates (Table 2). Field saturated hydraulic conductivity was significantly affected by tillage system during 2009-10 and highest value 62.39 mm hr^{-1} was found in DT. Although the interaction effects of tillage and N fertilizer were statistically at per, yet maximum value of hydraulic conductivity 65.67 mm hr^{-1}was recorded in T_2N_3 treatment.

Table 3. SOC and nitrate contents as affected by different tillage system and nitrogen rates.

Treatments			Soil organic carbon (g/kg) 0-5 cm	Soil organic carbon (g/kg) 5-10 cm	Nitrate contents (mg/kg) 0-10 cm	Nitrate contents (mg/kg) 10-25 cm	Nitrate contents (mg/kg) 25-40 cm	Nitrate contents (mg/kg) 40-100 cm
Tillage systems (N)	CT	T_1	0.44 A	0.432 A	42.67 A	38.79 B	31.84 B	23.67 A
	DT	T_2	0.38 B	0.364 B	40.06 A	52.33 A	42.95 A	24.67 A
Nitrogen (kg ha^{-1}) (N)	0	N_1	0.388 C	0.372 C	28.75 B	30.33 C	42.92 C	25 A
	130	N_2	0.412 B	0.40 B	47.8 A	50.96 B	38.35 B	24 AB
	160	N_3	0.438 A	0.422 A	47.5 A	55.4 A	40.34 A	23.5 B
T×N		T_1N_1	0.43 bc	0.04bc	31.5c	24.18 e	30.297 d	27 a
		T_1N_2	0.44 ab	0.43 ab	44.5 b	42.6 c	32.61 d	23 c
		T_1N_3	0.467 a	0.453 a	52 a	49.6 b	32.6 d	21 d
		T_2N_1	0.35 e	0.33 e	26 d	36.47 d	36.7 c	23 c
		T_2N_2	0.39 d	0.37cd	51.2 a	59.33 a	44 b	25 b
		T_2N_3	0.41 cd	0.39 d	43 b	61.21 a	48 a	26 ab

† CT: Conventional Tillage; DT: Deep Tillage

† Mean for each treatments within column followed by the same letter are not significantly different at P≤0.05.

The soil penetration resistance decreased with the degree of soil manipulation during tillage practices. Tillage methods, nitrogen rates and their interaction had highly significant effect on soil penetration resistance. The minimum penetration (756 kPa) was found in DT while in CT (916.1). In case of the nitrogen rates, the maximum soil strength (906 kPa) was observed in N_1 and minimum (796 kPa) in N_3. The mean maximum penetration resistance was found in T_1N_1 (945 kPa) compared to other treatments in which soil disturbance was minimum. Mean maximum infiltration rate was found in DT (64.4mm hr^{-1}) followed by CT (57.5 mm hr^{-1}). Different tillage treatments significantly affected soil bulk density at different soil depth. Higher mean value for bulk density (1.45 Mg m^{-3}) was observed with CT at 0-10 cm depth followed by DT (1.39Mg m^{-3}). At 10-20 and 20-30 cm depth, higher mean value for bulk density (CT; 1.46), (CT; 1.58) were observed with conventional tillage followed by (DT; 1.4) and (DT; 1.4) respectively.

Soil organic carbon and Nitrate contents

Data showed that soil organic carbon and nitrate contents were significantly affected by tillage methods and nitrogen application rates at different depths. As they enhanced mineralization of organic carbon and leaching losses in soil (Table 3).

The maximum SOC contents of the soil at wheat harvest were observed in CT (4.41g/kg) and (4.01 g/kg) at 0-5 and 5-10 cm depth followed by DT (3.80 g/kg) and (3.63 g/kg). Maximum OC contents of the soil at wheat harvest were observed with N_3 which were12.3 and 14% at 0-5 and 5-10 cm depths respectively compared to control.

Depth had significant effect on NO_3concentration. Higher values of NO_3concentration were observed at 10-25 than 0-10 cm and lowest at 40-100 cm soil depth. At 0-10 cm, as regard tillage method, the maximum value of NO_3concentration (42.6mg kg^{-1}) was recorded in CT and minimum (40 mg kg^{-1}) DT. The highest NO_3 concentration (47.8mg kg^{-1}) was observed for N_2 and the lowest (28.7 mg kg^{-1}) for control. At 10-25 cm depth, the maximum value of NO_3concentration (52.3mg kg^{-1}) was observed in DT and minimum in CT (38.7 mg kg^{-1}) and maximum value of NO_3concentration (55.4 mg kg^{-1}) was observed in N_3 followed by (51.03 mg kg^{-1}) in N_2 while minimum in control (30.3 mg kg^{-1}). In interaction maximum NO_3concentration at wheat harvest (61.2mg kg^{-1}) was observed in T_2N_3 while minimum in (24.1 mg kg^{-1}) in T_1N_1.

Discussion

Yield components

Results showed a significant ($P \leq 0.05$) response in the growth and yield parameters of wheat and physical properties of soil. The statistical results of the study indicated that nitrogen rates significantly affected plant height, tillers per plant, spikelets per spike, straw yield and grain yield but there were no significant differences in these yield components under different tillage systems and without any interaction. The maximum value of plant height (96 cm), tillers per plant (313), spikelets per spike (20), straw yield (8.07 Mg ha^{-1}) and grain yield (6.1 Mg ha^{-1}) was recorded in case of N_3 treatment in which nitrogen was applied @160 kg ha^{-1}. These results are also in line with the results reported Maali and Agenbag (2003) that tillage methods had a significant effect on the number of tillers m^{-2} and spikelets per spike. Ali *et al.* (2005) also confirmed these results that higher levels of nitrogen 210 kg ha^{-1} gave higher number of tillers and fertile tillers. These results are supported by Hussain *et al.* (2006) who confirmed these results that higher levels of nitrogen (200 kg N ha^{-1}) had significant effects on straw yield. These results are in agreement with those of Fallahi *et al.* (2008), who concluded that agronomic traits and yield components were positively influenced by nitrogen application.

Soil properties

The statistical results of the study indicated that tillage methods have significant effect on soil physical properties as they increased saturated hydraulic conductivity, infilteration rates, decrease soil penetration resistance and bulk density while nitrogen rates have non-significant effect on soil physical properties except penetration resistance. The soil of the DT treatment had consistently the highest hydraulic conductivity (62.39 mm hr^{-1}) and infiltration rates (64.4 mm hr^{-1}) and lowest soil penetration resistance (756KPa).The deep tillage (DT) significantly reduced the bulk density 1.39 Mg m^{-3} at 0-10cm depth. Mean decrease in bulk density observed was 4% in DT at 0-10 cm depths compared to CT, indicating that DT decreases the bulk density because soil disturbance was more. Alternatively, the soil of the CT treatment had the lowest saturated hydraulic conductivity (53.48 mm hr^{-1}) and infiltration rates (57.5 mm hr^{-1}) and highest penetration resistance (916 KPa) and bulk density (1.45 Mg m^{-3}) at 0-10cm depth but without any interaction. Nitrogen application rates did not significantly affect these soil physical properties both in CT and DT treatments.

Wheat tillage

It was reported that a temporal variation in tillage operations often altered the depth distribution of ρb (Salinas-Garcia *et al.*, 1997). Several studies reported that ρb significantly increased when the tillage intensity decreased (Diaz-Zorita, 2000). Zhang *et al.* (2002) determined an important increase in the soil penetration resistance and increase in share stress with increase in bulk density and they were reported this to lower saturation of the soil with high bulk density compared with the low density soil at the same potential and this tend to increase its adhesion on the soil with bulk density. These results were in agreement with those of Iqbal *et al.* (2005) also found that tillage methods significantly affected soil physical properties as they increased field saturated hydraulic conductivity while decrease bulk density of soil. This is in line with the results reported by Khurshid *et al.* (2006) also reported that bulk density was significantly decreased by enhancing tillage practices.

Nitrogen rates and tillage system

There was a significant effect of tillage and nitrogen rates ($P \leq 0.05$) on soil organic carbon at 0-5 and 5-10 cm depth but without any significant interaction (Table 3). SOC contents of the soil were decreased in DT 13.3 and 15% at 0-5 and 5-10 cm depths compared to CT. The maximum OC contents of the soil at wheat harvest were observed in CT (4.41g/kg) and (4.01) at 0-5 and 5-10 cm depth followed by DT (3.80 g/kg) and (3.63). Deep tillage is mechanical manipulation of soil which enhances the mineralization of SOC. This seems consistent with the understanding that OC is not oxidized as quickly in CT treatment compared to DT. Increasing nitrogen application rates significantly increased the SOC contents which were 12.3 and 14% at 0-5 and 5-10 cm depths for N_3 treatment followed by N_2 (5.6 %) and (8.6 %) compared to control. These results are in accordance with Rasool *et al.* (2008) who concluded that SOC concentration increased up to 21% by balance application of chemical fertilizer ($N_{100}P_{50}K_{50}$). These results are supported by Mallory and Griffin (2007) that the SOC contents are more at shallow or upper depth than the lower depths. The minimum SOC was recorded in deep tillage treatment but some scientists have suggested that tillage treatments had variable effects on soil C and N contents (Ellis and Howse, 1980; Reicosky and Lindstrom, 1995).

Nitrate leaching losses increased with increasing rates of N application and intensity of tillage methods. The tillage systems influenced the average N-NO_3 content in the soil during the growing season in 0-10, 10-25, 25-40 and 40-100 cm soil depths. In particular DT plots showed a higher content of N-NO_3. At 10-25 cm depth maximum nitrate leaching was observed in (35 %; DT) than CT. Taking into account the N-NO_3 dynamic during the two-year studying period, the N_3 plots showed higher values than control at all the sampling depth, but the difference became greater (82.79 %) at 10-25 cm depth. The interactions between tillage and nitrogen rates were also significant at all depths. Maximum nitrate contents (61.2mg kg^{-1}) were found at 10-25 cm depth in T_2N_3 and minimum (24.1 mg kg^{-1}) was in T_1N_I. Depth had significant effect on NO_3concentration. There was a significant positive correlation between the quantity of NO_3-N stock and the nitrogen fertilizer application rates and tillage methods. It might be due to higher application rate that enriched the soil NO_3-N concentration and tillage enhances the mineralization of nitrogen, result in nitrate leaching. These results are in accordance with Zhu *et al.* (2003) who found NO^{-}_3-N leaching was significantly increased with increasing N-rate (at 0, 100, and 200 kg N ha^{-1}). Nitrate leaching was affected by tillage system and a higher NO_3-N amount was found with increasing depth (Halvorson *et al.*2001; Mc Conkey *et al.* 2002).

Conclusion

Two years study of tillage and nitrogen rates application had exerted variable effects on soil physical properties and wheat yield. The effect of nitrogen rates application on agronomic and yield related traits of wheat were more consistent than tillage. Nitrogen applied @ 160 kg ha^{-1} increased plant height (8 %), no. of tillers (37 %), spikelets per spike (13.9 %), grain yield (64 %) and straw yield (58.8 %) than control treatment. Deep tillage significantly improved infiltration rate (12 %) and hydraulic conductivity (27 %) with decrease in penetration resistance (25 %) and bulk density (4.6 %) than CT. The greatest nitrate concentration, which was found with deep tillage, can be attributed to the lesser degree of alteration in soil physical properties and favorable for building up SOC and nitrate leaching at different depths in soil.

The SOC was consistently improved (14 %) by high nitrogen rates application. CT favors the accumulation of organic matter in soil, therefore 15 % more SOC found in CT than DT. NO_3 leaching was enhanced in case of indiscriminate tillage and heavy dose of N fertilizer. So to improve soil physical properties, to gain substantial yield of wheat as well as to check nitrate leaching proper nitrogen rates in a planned manner should be applied with rather than excessive use and indiscriminate tillage practices.

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