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Tillage and Nitrogen Fertilization Impact on Irrigated Corn Yields, and Soil Chemical and Physical Properties Under Semi-arid Climate

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Abstract

This study evaluated the effects of tillage (deep tillage (DT), conventional tillage (CT), minimum tillage (MT) and no-till (NT)), and nitrogen (N) rates (0 (N0), 200 (N200), 250 (N250), and 300 (N300) kg ha^{-1}) on: i) corn growth and yields, ii) some soil chemical properties (total soil carbon, nitrogen, and available nutrient stocks), and iii) selected soil physical properties (bulk density, total porosity, and infiltration) under semiarid climate. Total carbon (Corg), total nitrogen (TN), nitrate, available phosphorus (AP), exchangeable potassium (K), bulk density (ρb), penetration resistance (PR) and soil infiltration rates were measured. No-till had significantly higher Corg (9%) but lower TN (5%) as compared to CT. Deep tillage decreased ρb (2 to 5%) and PR (35 to 60%) compared to other tillage practices. The highest level of N had higher Corg (20%), TN (30%) and nitrate (35%) compared to the control treatment. The Highest N rate under DT has higher harvest index than those of CT, MT, and NT treatments. The nitrogen rate of 240 kg ha^{-1} produced near maximum yields (~90%) in DT and CT than the 260 kg ha^{-1} N – MT treatment and the 270 kg ha^{-1} N-NT treatment.

Introduction

Agricultural sustainability depends on soil quality. While conventional tillage and frequent use of chemical fertilizers and pesticides increased crop yields and enhanced food security, conventional management practices have affected soil quality as well as productivity (McGarry et al., 2000, Islam and Weil, 2000, Sundermeier et al., 2011). Tillage operations and fertility management often influence soil properties, nutrient availability, and crop yields. Tillage is one of the important factors that influence soil properties and crop yields (Bennie and Botha, 1986; Islam and Weil 2000; Khurshid et al., 2006). Khurshid et al. (2006) reported that tillage contributes up to 20% of the crop production factors. The type and intensity of tillage affects the agricultural sustainability through its influence on soil properties (McGarry et al., 2000; Sundermeier et al., 2011). While CT decreases soil compaction, provides favorable seed bed preparation, enhances root growth and development, controls weeds, and maintains crop yields (Bennie and Botha, 1986; Varsa et al., 1997), frequent plowing is responsible for soil structural degradation, accelerated erosion, loss of soil organic matter (SOM), and disruption in air, water and nutrient cycles (Sundermeier et al., 2011). Moreover, tillage pans (e.g. plow pan a15 to 20 cm depth) resulting from the frequent use of tillage tools often led to crop yield reductions.

Conservation tillage practices such as no-tillage or minimum tillage that allow crop residues deposition on the soil surface have resulted in accumulation of soil organic matter (SOM), improved aggregate stability and water infiltration, and increased biological efficiency (Liebig et al., 2004; Sundermeier

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et al., 2011). However, surface compaction resulting from the use of agricultural machineries and greater immobilization of nitrogen (N) from surface accumulation of crop residues under transitional NT or MT are associated with crop yield reductions. Several studies suggested using sub-soiling or deep tillage to break-down surface and shallow tillage pans and improve soil water-air systems, reduce compaction, and increase root growth and crop yields (Bennie and Botha, 1986; Varsa et al., 1997; Pikul and Arase, 1999). It is reported that soils under NT had greater bulk density than those soils under CT and mould-board plowing (Salinas-Garcia et al., 1997). However, Sundermeier et al. (2011) reported that long-term continuous NT (44+ years) had lower or similar bulk density comparable to CT. Improved soil physical conditions is one of the components of soil quality management for economic crop production.

Nitrogen fertilization plays a significant role in improving soil fertility and increasing crop productivity (Habtegebrial et al., 2007). It is reported that N fertilization increased grain yield by 43 to 68% and biomass production by 25 to 42% (Ogola et al., 2002). Moreover, N fertilization contributes to increase (18 to 34%) soil residual N contents (Yang et al., 2007). Several factors including tillage intensity, crop rotation, and irrigation often influenced soil N cycling. While transitional NT reportedly immobilizes N and subsequently, affects crop yields, CT accelerated SOM decomposition and mineralization of nutrients especially N. The objectives of the study were to evaluate the effects of tillage and N fertilization on: i) corn growth and yields, ii) soil chemical properties (total soil carbon, nitrogen, and available nutrient stocks), and iii) some soil physical properties (bulk density, total porosity, and infiltration) under semiarid climate.

Materials and Methods

Study Site and Experimental Treatments

The study was conducted at the research farm (latitude 31°26'N and 73°06'E, altitude 185 m above mean sea level) of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan in 2007 and 2008. Soil is a well-drained Hafizabad sandy clay loam (mixed, semi-active, isohyperthermic typic Calciargids). Selected chemical and physical characteristics of soil are: pH 7.7±0.1; electrical conductivity (Ec) 2.82±0.3 dS m^{-1}; sand 52.8%; silt 19.7%; and clay 27.5%. The climate of the region is subtropical semi-arid with an annual average rainfall of 490 mm and more than 70% of the rainfall occurs during June–September. Mean monthly minimum temperature is 13°C in January and maximum temperature is 45°C in July. Major crops are irrigated corn, wheat, cotton, sugarcane, rice, fodder, and pulses.

A randomized complete block design with four tillage systems (DT, CT, MT, NT) and four N levels at 0, 200, 250 and 300 (N_0, N_{200}, N_{250}, and N_{300}, respectively) kg ha^{-1}, respectively in a split-plot combination was established. Tillage was used as a main plot and N level as a subplot. Each treatment was replicated three times in 5.5 m X 10 m plots. In NT treatments, herbicides were used to control weeds whereas in MT, the field operations comprised of two plowing and two planking operations. Conventional tillage consists of one disk plowing, four cultivations, and two planking. Hoeing along with herbicides was used to control weeds in CT. In DT, the field operation comprised two 30 to 40 cm deep chiseling with three shovels spaced at 45 cm apart followed by four narrow tine cultivations and two planking with a wooden plank. Chiseling was done annually.

Corn (hybrid var. DK-919) was planted at 25 kg seed ha^{-1} in July and the planting was done manually using dibble with 70 cm spacing between rows and 20 cm between plants. Recommended doses of phosphorus (P) and potassium (K) (150-105 kg ha^{-1}) were applied as triple super-phosphate and sulfate of potash at time of planting, while N as urea was applied in three splits. One third of each N level was applied at planting and seedbed preparation, one month after germination, and at tussling stage. Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine), a pre-/post-emergence broadleaf weed control herbicides, at 1250 ml ha^{-1} was applied to control weeds. Agronomic parameters including plant height, 1000-grains weight, and grain and total yields were recorded.

Soil Collection and Analysis

Soil samples at 10 cm intervals from the top 40 cm depth were collected randomly before planting and immediately after crop harvest from six different locations in each replicated plot and mixed to obtain a composite sample. Field-moist samples were analyzed for nitrate, available phosphorus, and exchangeable potassium. A portion of the soil samples were air-dried at room temperature (~25^{0}C) and ground to pass a 2 mm sieve before analyzing for C_{org} and TN, pH, EC, and sand, silt, and clay contents. The C_{org} was determined by following the Walkey-Black standard wet oxidation method; soil pH was measured by a glass electrode pH meter; soil EC was determined by a conductivity meter; nitrate concentration following the method detailed by Sims and Jackson (1971); available P by the standard ascorbic acid method; K by flame photometry; particle size analysis by the standard hydrometer method; bulk density by standard core method; water infiltration with double ring infiltrometer; and soil strength with a cone penetrometer;
The stocks of C_{org}, TN, nitrate, AP, and K were calculated by multiplying their concentrations with the sampling depth and ρb. All the results were expressed on the basis of oven-dried (~1050C) weight of soil.

Statistical Analysis

Data were analyzed in a split-plot arrangement of randomized complete block design using the analysis of variance procedure of SAS v. 9.13 (SAS Institute, 2008) with tillage as a main plot and nitrogen as a sub-plot. The blocks, tillage x blocks and nitrogen x blocks were considered as random effects, and the tillage, nitrogen soil depth and their interaction were considered as fixed effects. Significant differences in soil chemical and physical properties attributed to the effects of main-plot, sub-plot, block, and their interactions were evaluated by the least significant difference (LSD) test. Means were separated with a probability level of <0.05 unless otherwise mentioned. Relative

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yield of corn was regressed on N levels using boundary line technique (Webb, 1972) to calculate optimum N fertilization under different tillage systems for achieving at-least 95% of irrigated corn yields.

Results and Discussion

Bulk Density, Soil Strength, and Water Infiltration

Tillage and N fertilization had significant effect on ρb, soil strength, and water infiltration characteristics without an interaction (Fig. 1 to 4). Deep tillage results in 4 to 9% decrease in ρb compared to CT, MT and NT, respectively (Fig. 1). However, the decrease of ρb values as a result of tillage was most visible for the top 20-cm depth. Soil strength was highest in NT, intermediate in MT and CT, and lowest in DT. On average, the NT had 63% higher soil strength than DT (Fig. 3). DT had 53% higher infiltration rates than that of NT (Fig. 4). Similarly, bulk density was reduced by 1 to 9% in N_{200}, N_{250} and N_{300} treatments compared to control (Fig. 2). However, soil strength was 2 to 3% higher in the control treatment compared to N_{200}, N_{250}, and N_{300} treatments, respectively. Mean water infiltration rates were higher in the treatments with higher levels of N fertilization. Irrespective of tillage or N treatments, ρb increased with increasing soil depth.

Significantly higher ρb values measured in transitional NT followed by MT are due to the absence of tillage operations and compaction caused by agricultural machinery and natural processes (Unger and Jones, 1998; Khurshid et al., 2006). In contrast, tillage resulted a mixing of soil and temporarily increased total soil porosity leading to minimum soil strength. The effects of tillage especially DT in reducing ρb was attributed to an increase in porosity and water infiltration but decrease in soil strength. In other words, decreased ρb and soil strength associated with higher water infiltration rates. The lower soil strength with DT was likely the result of tillage-induced soil loosening caused by deeper penetration of tillage implements. These results are similar to Lampurlanes and Cantero-Martinez (2003) who reported higher soil strengths in NT than in sub-soiling and MT. These results are in agreement with those of Ishaq et al. (2002). Highest water infiltration rates in DT than in NT are due to greater soil porosity and the breaking-up of hard pan to improve water movement within soil profile (Ishaq et al., 2002; Lampurlanes and Cantero-Martinez, 2003). Moreover, the DT

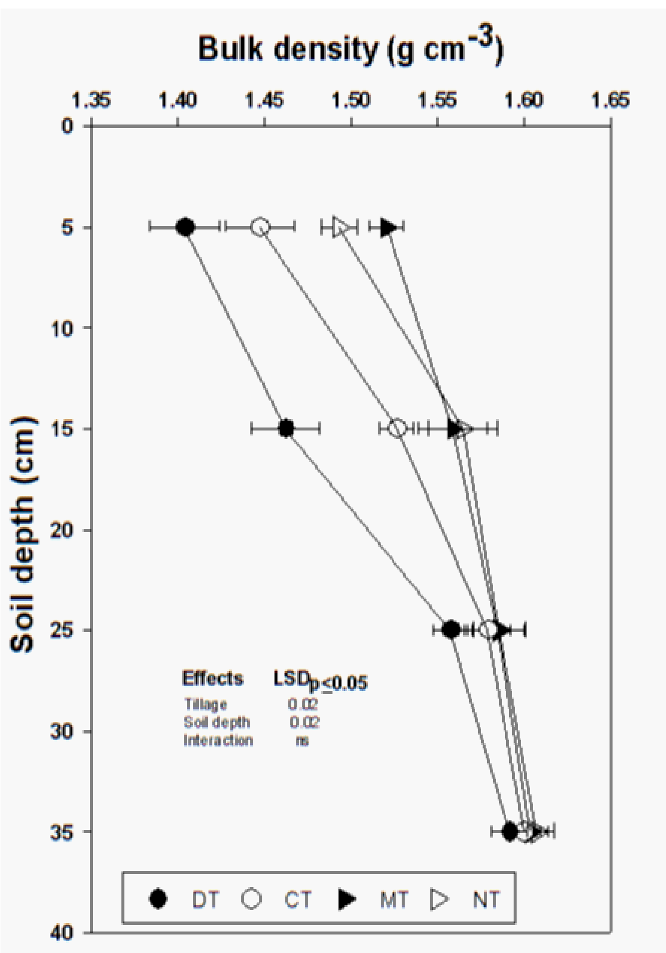

Figure 1. Tillage effects on bulk density at different depths of soil.

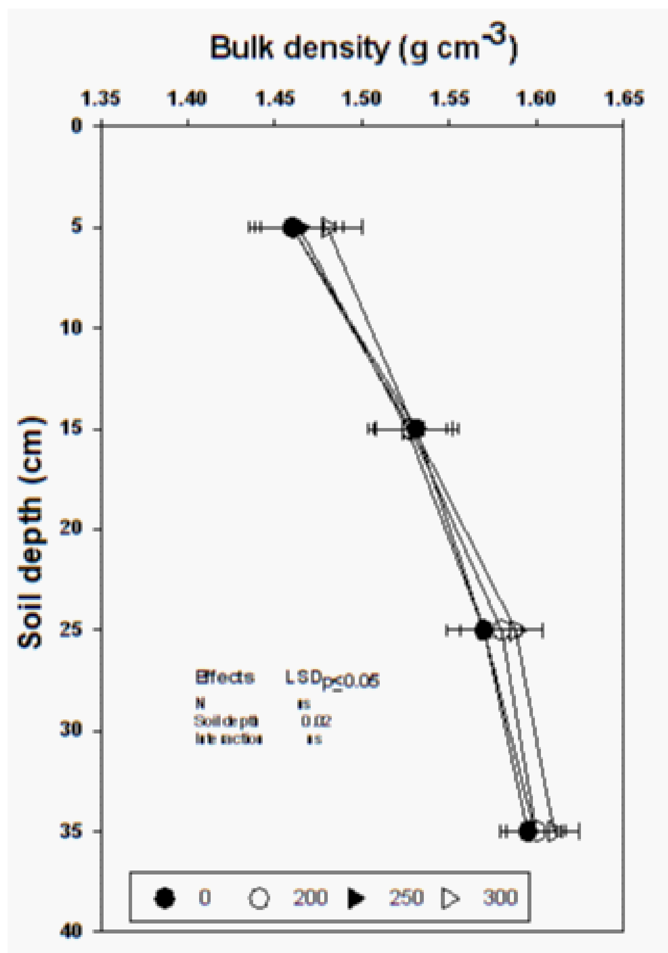

Figure 2. Nitrogen fertilization effects on bulk density at different depths of soil.

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Table 1. Tillage and nitrogen treatments interaction on total carbon, total nitrogen, nitrate, available phosphorus and exchangeable potassium concentration and soil bulk density under irrigated corn.

Treatment Combinations		C_{org}	TN	NO_3	AP	K	ρb
		______ g kg^{-1} ______		______ mg kg^{-1} ______			g cm^{-3}
Main plot: Tillage							
NT		3.7a§	0.39b	35b	12a	110a	1.56a
MT		3.6a	0.39b	39b	12a	109a	1.57a
CT		3.4b	0.40ab	38b	13a	110a	1.54b
DT		3.5ab	0.41a	46a	13a	107a	1.50c
Sub-plot: Nitrogen (N @ kg ha-1)							
N0		3.2dφ	0.32d	29b	11a	109a	1.55a
N200		3.5c	0.38c	41a	12a	109a	1.54b
N250		3.6b	0.43b	43a	13a	109a	1.54b
N300		3.8a	0.46a	45a	14a	109a	1.54b
Tillage x Nitrogen (N) Interaction							
NT	N0	3.4	0.33	27	11	113	1.57
	N200	3.6	0.36	38	12	110	1.56
	N250	3.7	0.42	36	13	108	1.56
	N300	3.9	0.44	40	13	109	1.56
MT	N0	3.3	0.32	27	11	106	1.57
	N200	3.7	0.37	38	12	105	1.56
	N250	3.6	0.43	45	13	114	1.57
	N300	3.8	0.46	45	13	111	1.57
CT	N0	3.1	0.31	29	12	109	1.55
	N200	3.3	0.38	39	12	114	1.54
	N250	3.5	0.43	41	14	110	1.53
	N300	3.6	0.46	43	14	108	1.54
DT	N0	3.0	0.32	34	11	109	1.53
	N200	3.5	0.40	50	13	106	1.50
	N250	3.7	0.44	49	14	105	1.50
	N300	3.9	0.48	52	14	110	1.49
$LSD_{p\leq0.05}$							
Tillage x Nitrogen		0.2	ns	4.0	ns	3.6	0.01

DT=Deep tillage, CT=Conventional tillage, MT=Minimum tillage, NT=No-till, C_{org}=Total carbon, TN=Total nitrogen, NO_3=Nitrate, AP=Available phosphorus, and K=Exchangeable potassium. §Means in each column followed by different lower case letters are different at $p\leq0.05$ among the tillage treatments (main plot). φMeans in each column followed by different lower case letters are different at $p\leq0.05$ among nitrogen fertilization treatments (sub-plot).

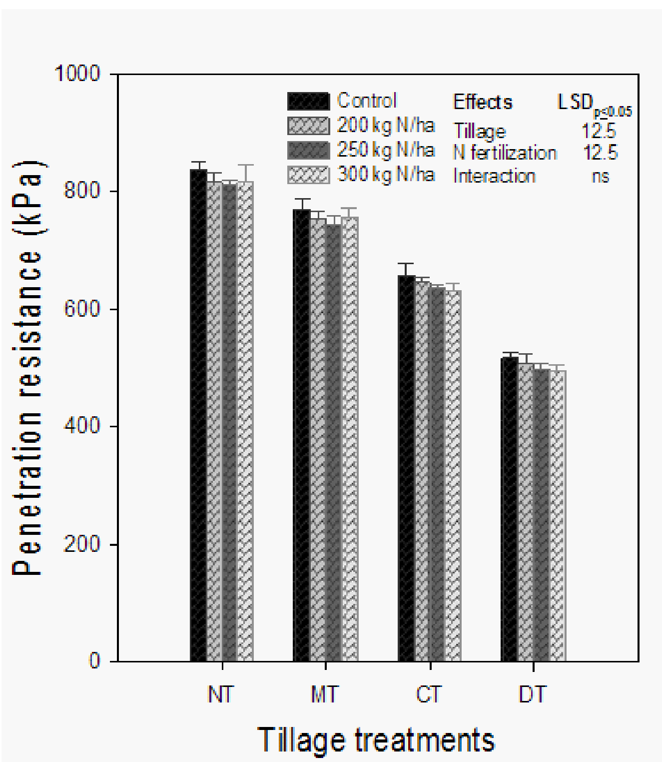

Figure 3. Tillage and nitrogen interaction on penetration resistance (strength) of soil [DT, deep tillage; CT, conventional tillage; MT, minimum tillage; and NT, no-till] under irrigated corn.

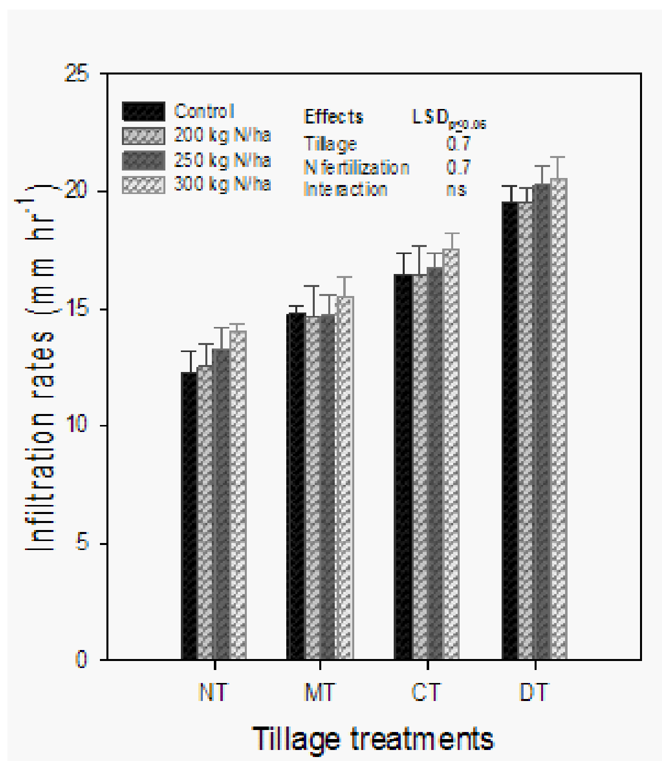

Figure 4. Tillage and nitrogen interaction on water infiltration characteristics of soil [DT, deep tillage; CT, conventional tillage; MT, minimum tillage; and NT, no-till] under irrigated corn.

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Table 2. Tillage and soil depth interaction on total carbon, total nitrogen, nitrate, available phosphorus and exchangeable potassium concentration and soil bulk density under irrigated corn.

Tillage System	Depth (cm)	C_{org}	TN	NO_3	AP	K	ρb
		g kg^{-1}		mg kg^{-1}			g cm^{-3}
NT	0 to 10	4.7	0.54	38	16	135	1.49
	10 to 20	4.0	0.46	39	14	117	1.56
	20 to 30	3.3	0.35	31	11	100	1.59
	30 to 40	2.7	0.21	33	8	88	1.61
MT	0 to 10	4.4	0.54	50	16	133	1.52
	10 to 20	3.9	0.46	41	14	116	1.56
	20 to 30	3.3	0.35	31	11	99	1.58
	30 to 40	2.7	0.21	34	8	87	1.60
CT	0 to 10	3.9	0.55	42	17	135	1.45
	10 to 20	3.6	0.47	40	15	118	1.53
	20 to 30	3.4	0.36	33	11	100	1.58
	30 to 40	2.6	0.21	36	8	88	1.60
DT	0 to 10	3.8	0.57	39	17	132	1.40
	10 to 20	3.6	0.48	52	15	115	1.46
	20 to 30	3.3	0.37	45	11	97	1.56
	30 to 40	3.4	0.22	48	9	86	1.59
LSD $_{p\leq0.05}$							
Soil depth		0.1	0.01	1.8	0.5	1.7	0.02
Block		ns	0.01	1.6	ns	2.8	ns
Tillage x soil depth		0.2	ns	4.0	ns	ns	0.04
Tillage x Block		ns	0.015	ns	0.7	ns	ns

DT=Deep tillage, CT=Conventional tillage, MT=Minimum tillage, NT=No-till, C_{org}=Total carbon, TN=Total nitrogen, NO_3=Nitrate, AP=Available phosphorus, and K=Exchangeable potassium.

disperses soil aggregates, consequently, increased water infiltration rates.

Total Carbon and Nitrogen, and Available Nutrients

Tillage significantly influenced C_{org}, TN, and nitrate contents except AP and K (Table 1). Averaged across depths, NT and MT had 6 to 9% more C_{org} than in CT and DT. However, the C_{org} content in NT, MT, and DT did not vary significantly. In contrast, TN was significantly higher (~5%) in DT higher than in NT and MT, respectively. Similarly, nitrate was higher in DT than in MT, CT, and ZT, respectively. Irrespective of tillage treatments, C_{org}, TN, nitrate, AP, and K decreased significantly with increasing depths. However, C_{org} and nitrate contents were significantly influenced by tillage x depth interaction. NT and MT had greater C_{org} at 0 to 10-cm depth compared to DT and MT. Moreover, the depth distribution of C_{org} and nitrate under DT did not vary significantly compared to NT, CT, and MT, respectively. Nitrate was higher at 30 to 40 cm depth in DT than in CT, MT, and NT.
The C_{org}, TN, and nitrate contents were significantly influenced by N levels except AP and K (Table 1). The C_{org} and TN contents increased progressively with higher N rates. While C_{org} increased by 1.2 to 1.5 times, TN increased by 1.7 to 2.6 times with increasing rates of N fertilization. Moreover, N fertilization results an increase in nitrate contents by 15 and 14% in N250 and N300 treatments compared to control. N level significantly influenced the depth distribution of C_{org} and nitrate contents.

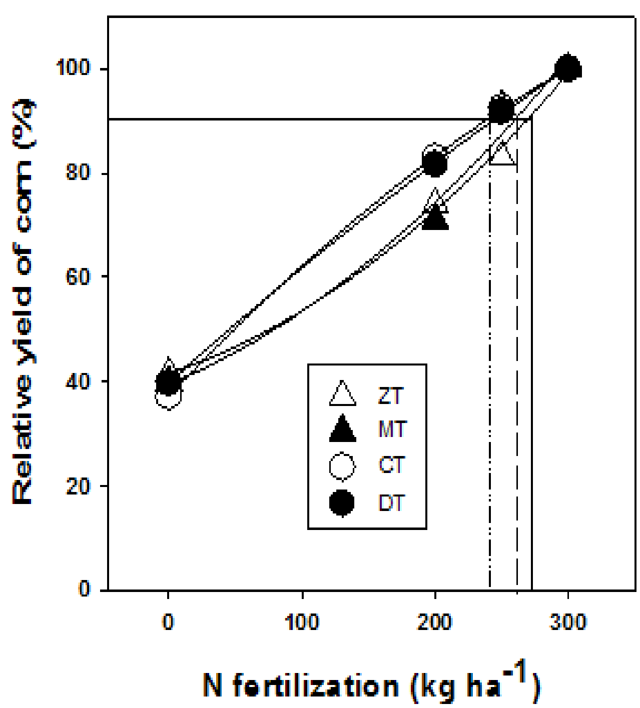

Figure 5. Tillage and nitrogen interaction on relative yield of irrigated corn [DT, deep tillage; CT, conventional tillage; MT, minimum tillage; and NT, no-till] (data combined over 2006 and 2007).

Table 3. Nitrogen and soil depth interaction on total carbon, total nitrogen, nitrate, available phosphorus and exchangeable potassium concentration and soil bulk density under irrigated corn.

N rate (kg ha^{-1})	Depth (cm)	C_{org}	TN	NO_3	AP	K	ρb
		______ g kg^{-1}	_____	___________	mg kg^{-1}	________	g cm^{-3}
N_0	0 to 10	3.3	0.44	28	14	134	1.48
	10 to 20	3.3	0.38	28	13	116	1.53
	20 to 30	3.3	0.29	29	10	99	1.59
	30 to 40	2.9	0.17	31	7	87	1.61
N_{200}	0 to 10	4.2	0.52	47	16	133	1.46
	10 to 20	3.8	0.44	47	14	116	1.53
	20 to 30	3.3	0.34	46	11	98	1.57
	30 to 40	2.7	0.21	37	8	87	1.60
N_{250}	0 to 10	4.5	0.60	46	17	134	1.46
	10 to 20	3.9	0.50	48	15	116	1.53
	20 to 30	3.4	0.39	37	12	99	1.58
	30 to 40	2.7	0.23	40	9	87	1.60
N_{300}	0 to 10	4.8	0.64	49	18	134	1.46
	10 to 20	4.1	0.54	49	16	116	1.53
	20 to 30	3.3	0.42	40	12	98	1.57
	30 to 40	2.9	0.25	42	9	87	1.60
$LSD_{p\leq0.05}$							
N x soil depth		0.2	ns	4.0	ns	ns	0.04
N x Block		ns	0.015	ns	ns	2.8	ns

DT=Deep tillage, CT=Conventional tillage, MT=Minimum tillage, NT=No-till, C_{org}=Total carbon, TN=Total nitrogen, NO_3=Nitrate, AP=Available phosphorus, and K=Exchangeable potassium.

Tillage and N level had significant interaction on C_{org}, TN, nitrate, and K contents (Table 1). C_{org} was significantly higher in MT, NT, and DT with increasing levels of N fertilization as compared to CT. Similarly, TN increased with higher rates of N fertilization under DT than in other treatments. N fertilization increased nitrate content under DT as compared with CT, MT, and NT, respectively. Tillage and depth had significantly influenced TN, nitrate content and K (Table 2). The extent of all these parameters was in in order of 0-10 > 10-20 > 20-30 > 30-40 cm depth.

Results on significant increase in C_{org} content are in consistent with the findings of other studies (Khurshid et al. 2006, Liebig et al., 2004), where C_{org} content increased in NT surface than in DT and CT. Greater C_{org} contents in 0 to 20 cm with NT may have resulted from slow crop residue decomposition due to the placement of crop residue on the soil surface and the decreased contact of crop residues with soil microorganisms (Salinas-Garcia et al., 1997), or can be attributed to the reduced mineralization of native soil organic matter (SOM) due to decreased soil aeration and temperature, greater of C_{org} fractions within NT aggregates (Eghball et al., 1994). In contrast, greater incorporation of crop residues into the soil by plowing may have resulted in accelerated decomposition of crop residues, and thus decreased C_{org} and TN contents. However, a higher C_{org} content in DT at deeper depths than in other tillage treatments might be due to inversion of nutrient-rich topsoil and less exposure of the plant residues and native SOM to microbial decomposition. Similarly, a higher nitrate concentration at deeper depths of DT was probably due to leaching through changes in the soil structure and macrospores continuity (Golabi et al., 1995; Sadej and Przekwas, 2008). However, these results are in contradiction to Machraoui et al. (2010) who reported that tillage significantly improved K, P and N contents.

Significantly higher C_{org} content with increasing levels of N fertilization corresponds to the C: N stoichiometry of soil organic matter. These results on increased C_{org} content related to increasing N fertilization are in agreement with those reported by other studies (Pernes-Debuyser and Tessier, 2004, Liu et al., 2005, Blair et al., 2006). Increase in TN content with increasing N rates in the uppermost depth of has been reported (Sadej and Przekwas, 2008). Similarly, increasing levels of N fertilization are associated with increased nitrate concentration. These results are in with those who reported that higher concentration of C_{org}, N, P, and K was observed in higher levels of N fertilization compared to control treatment (Huang et al., 2010). Greater C_{org} and TN under NT and MT with increasing levels of N fertilization may be associated with (i) higher biomass production, (ii) surface placement of crop residues, (iii) the lack of residue redistribution and disturbance, (iv) greater protection of crop residues and native SOM, and (v) undisturbed habitat for efficient biological activity (Eghball et al., 1994; Salinas-Garcia et al., 1997; Liu et al., 2005; Blair et al., 2006; Sundermeier et al., 2011).

Corn Growth and Yield

Tillage and N fertilization significantly influenced the corn plant height (Table 4). Maximum plant height (206 cm) was observed in DT followed by CT (198 cm) and minimum (176 cm) was recorded in NT. Overall, plant height was 18% higher in DT

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Table 4. Tillage and nitrogen interaction on plant height, grain and total yields, and harvest index of irrigated corn (data combined over 2006 and 2007).

Treatment Combinations		Plant ht. (cm)	1000-grain weight (g)	Grain yield	Total yield	HI (%)
				(Mg ha^{-1})		
Main plot: Tillage						
NT		176d§	256d	5.7d	14.1d	41.1b
MT		190c	265c	6.3c	15.1c	41.7b
CT		198b	295b	7.3b	15.8b	45.7a
DT		206a	305a	7.7a	16.8a	44.9a
Sub-plot: Nitrogen (N, kg ha^{-1})						
N0		157dφ	194d	3.5d	8.4d	42.5b
N200		177c	291c	6.9c	16.1c	42.4b
N250		204b	309b	7.9b	17.8b	44.4a
N300		232a	327a	8.8a	19.5a	45.0a
Tillage x Nitrogen (N) Interaction						
NT	N0	138	171	3.2	7.1	44.6
	N200	165	261	5.7	14.2	40.0
	N250	186	287	6.4	16.6	38.4
	N300	214	304	7.7	18.6	41.4
MT	N0	156	175	3.3	7.9	42.0
	N200	172	272	5.9	15.6	38.2
	N250	203	292	7.7	17.6	43.9
	N300	229	320	8.3	19.4	42.8
CT	N0	164	210	3.5	8.4	41.5
	N200	181	305	7.8	17.1	45.7
	N250	209	326	8.7	18.4	47.2
	N300	239	339	9.4	19.4	48.3
DT	N0	169	222	3.9	10.3	38.0
	N200	192	323	8.0	17.5	45.8
	N250	220	332	9.0	18.6	48.2
	N300	244	344	9.8	20.6	47.6
LSD $p \leq 0.05$						
Tillage x Nitrogen		ns		ns		2.0

DT=Deep tillage, CT=Conventional tillage, MT=Minimum tillage, NT=No-till, and HI=Harvest index. §Means in each column separated by different upper case letters are different at $p \leq 0.05$ among the tillage treatments (main plot). φMeans in each column separated by different lower case letters are not significantly different at $p \leq 0.05$ among the nitrogen treatments (sub-plot).

compared to NT. The DT had 19, 15, and 4% more 1000-grain weight than NT, MT and CT, respectively. Grain yield was highest (7.7 Mg ha^{-1}) in DT followed by CT (7.3 Mg ha^{-1}) and NT had the lowest (5.7 Mg ha^{-1}). The DT had 35% more grain production compared to NT. Maximum total yield (16.8 Mg ha^{-1}) was attained in DT while lowest (14.1 Mg ha^{-1}) was in NT. The harvest index (HI) was significantly higher in CT than in DT and MT.

Nitrogen levels significantly influenced the growth and yield of irrigated corn (Table 4). Corn plant height was significantly higher by 13, 31 and 48% in N_{200}, N_{250} and N_{300} compared to control. Similarly, N fertilization at 300, 250 and 200 kg ha^{-1} resulted in 68, 59 and 49% increase in 1000-grain weight compared to control. Increasing N levels out yielded grain yields by 2, 2.3, and 2.5 times compared with control. Total yields follows similar pattern in response to N fertilization. Tillage x N fertilization interaction significantly increased the HI under DT and CT but decreased HI under NT and MT.

Significantly higher plant growth and yields are in conformity with other studies (Khan et al., 2001), who reported that corn plant height increased with DT and CT and decreased with MT and NT. Higher plant height and yield of corn under DT and CT may be attributed to reduced compaction, higher porosity, and more uniform distribution of nutrients in the soil profile. These results are also in agreement with those of Khan et al. (2001), who reported that annual plowing facilitates a favorable seedbed preparation to support for crop growth and nutrient-use. Rashidi and Keshavarzpour (2007) suggested that plowing produce a finer and loose soil structure, which in turn, positively influence the seedling emergence and establishment to support higher crop yields. Iragavarapu and Randall (1995) reported that moldboard plow produces higher yields than with NT. Mechanical difficulties affecting seed placement in addition to increased immobilization of N have often been considered responsible for the low crop yields with reduced and transitional NT compared to CT and DT (Lopez-Fando and Almendros, 1995).

A significant increase in plant height and crop yields of corn is attributed to the increased cell division and enlargement by N fertilization. Several studies have reported that N fertilization significantly increased plant height, grain yields, number of grains per cob, and grain weight per cob of corn plants (Prihar and Stewart, 1990; Shivay and Singh, 2000). A strong inference exists for HI to increase with increasing grain yield and decreasing crop stresses such as deficient nutrients and water (Prihar and Stewart, 1990). Balanced and adequate fertility (~250 kg N/ha) for any crop reduces stress, improves physiological resistance, and decreases disease risk (Krupinsky et al., 2002).

When plotted the relative corn yields over N fertilization levels, tillage showed variable but non-linear responses (Fig. 5). The extrapolation of the relationship suggested that N fertilization at 240 kg ha^{-1} with DT and CT is required for near maximum production (~90%) of corn yields. In contrast, the relationship between N fertilization and relative yield showed that 90% of the corn yield was produced when N applied at 260 kg ha^{-1} in MT and 270 kg ha^{-1} in NT. Reduced rates of N fertilization (240 kg ha^{-1}) in DT and CT are probably due to higher background levels of available N from mineralization of native SOM and crop residues by annual and deep tilling the soil. A higher rate of N fertilization in transitional NT and MT is required to produce near maximum yields of corn (~90%) was due to compaction and greater immobilization of available N under relatively undisturbed agro-ecosystems.

Conclusions

Tillage and nitrogen fertilization had variable effect on bulk density and soil strength, total carbon and nitrogen accumulation, nitrate content, and corn yields. Transitional deep tillage (2 years) decreased bulk density and soil strength, however, increased water infiltration than in no-till and minimum till, respectively. The effect of nitrogen fertilization on soil physical properties was less consistent than the effect of tillage treatments. Total carbon and nitrogen contents increased and nitrate content decreased in no-till and minimum till, respectively. Nitrate content was higher with increasing rates of N fertilization. Deep tillage had taller plants with significantly higher corn yields than in no-till and minimum till, respectively. Similarly, nitrogen fertilization significantly increased corn yields and harvest index. Tillage and nitrogen interaction significantly influence total carbon and nitrogen, nitrate, and corn yields. While total carbon and nitrogen content increased by nitrogen fertilization under no-till and minimum till, nitrate content increased with nitrogen fertilization under deep tillage.

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