Soil physical properties, nitrogen uptake and grain quality of maize (*Zea mays* L.) as affected by tillage systems and nitrogen application

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Abstract

Soil compaction is a global issue pertaining to agricultural lands. The frequent use of farm machinery and field operations at the same depth are the major causes of soil compaction. The gradual increase in soil compaction deteriorates maize grain quality due to reduced nitrogen (N) uptake. Quality food production by reducing soil compaction is the need of time, which can be achieved through deep tillage and N management. In this study, three tillage systems viz. conventional tillage (using cultivator), tillage with mould board plough +2-cultivations (MBP), and tillage with chisel plough +2-cultivations (CP); and three nitrogen levels viz. 100, 150 and 200 kg ha^{-1} were used to evaluate their effect on soil properties, N uptake and grain quality in maize. Lower bulk density (1.41 Mg m^{-3}), higher total porosity (0.47 m^3 m^{-3}) and higher nitrogen uptake (96.01 kg ha^{-1}) was recorded under chisel plough (CP) compared with other tillage systems. Different N levels had significant effect on grain and total N uptake and grain quality, while soil properties remains unaffected. Higher N uptake was recorded with 200 kg ha^{-1} N application than other treatments. Similarly, 8.51% and 8.57% more grain protein contents were recorded with 200 kg ha^{-1} N during first and second year respectively. Unlike grain protein, starch and oil contents were negatively affected by N application being higher starch (71.7%) and oil contents (3.41%) with less N supply (100 kg ha^{-1}). However, interaction effect of tillage and nitrogen levels was found non-significant for all studied parameters except for oil contents. Higher oil contents were recorded with MBP along with 100 kg ha^{-1} N application. Overall study indicated that deep ploughing with CP is important for maize to explore more soil area for nutrient uptake and N is also important for improving grain quality especially protein contents an important food constituent.

Introduction

Continuous cultivation of agricultural soils with same implement and at same depth creates hard pan (Hamza and Anderson, 2005; Wasaya *et al.,* 2011). The existence of hard pan in soil has negative impact on soil bulk density and porosity leading to increased root penetration resistance and poor nutrient uptake, which directly or indirectly affects the crop yield (Ishaq *et al.,* 2003; Shahzad *et al.,* 2016a, 2016b). Moreover, different tillage operations also affect the soil compactness or looseness, as growing crops by no-tillage for many years adversely affects crop growth by limiting nutrients availability due to hard subsoil layer (Mead and Chan, 1988). Existence of soil compaction decreases uptake of N (11-15%), K (5-10%) and P (11-15%) and yield reduction of wheat (Ishaq *et al.,* 2003).

Deep tillage is the most effective practice to reduce compaction (Daniells, 2012) and has a significant impact on soil physical properties such as moisture contents, bulk density, penetration resistance, soil porosity and aeration (Liu *et al.,* 2016; Shahzad *et al.,* 2016b). Tilling the soil at more depth improves soil physical properties and hence leads to high crop yield (Ji *et al.,* 2013). Moreover, subsoiling also improves the soil porosity and enhances root proliferation at deeper depth for the uptake of nutrients and moisture (Ji *et al.,* 2013). Similarly, soil penetration resistance (Wang *et al.,* 2009) and soil cone index (Wang *et al.,* 2009) also decreased with increasing tillage intensity. Soil disturbance usually enhance N availability for plant use by improving soil aeration and mineralization of organic N (Dinnes *et al.,* 2002). Soil compaction can be removed by increasing porosity or decreasing bulk density of soil (Hamza and Anderson, 2005), which is possible through sub-soiling up to 30 cm depth. It may increase aeration and soil hydraulic conductivity more than double and enhances soil porosity up to 27% (Drewry *et al.,* 2000). Similarly, soil loosening by tilling also improves grain yield (Schmidt *et al.,* 1994; Wasaya *et al.,* 2017a) and biomass production (Wasaya *et al.,* 2012) by improving water infiltration rate and root proliferation

(Wang *et al.,* 2015). On the other hand, deep tillage also has some negative effects on soil structure. It lowers soil organic matter due to higher decomposition rate because soil inversion generates more soil aeration and favours microbial activity (Six *et al.,* 2000).

Nitrogen is a major nutrient for plants, which limits their growth if not applied in adequate amount. Higher rather than adequate N level in the soil negatively affects the crop growth (Oscar and Tollenaar, 2006). Maize (*Zea mays* L.) shows positive response to N application depending upon different climatic and edaphic factors such as nutrient status, soil characteristic and the nutrient response of the cultivated varieties (Nagy, 1997) and produce high dry matter (Greef *et al.,* 1999). Its application to maize resulted in increased grain yield (24%) and biomass production (22%) (Amanullah *et al.,* 2009) due to improvement in yield components (Sharifi and Taghizadeh, 2009). In addition to yield improvement, N increments also have positive impact on grain quality. Increasing N application in different cropping environments leads to increase in grain protein while decrease in grain oil and starch contents in maize (Singh *et al.,* 2004; Miao *et al.,* 2006). Interaction effect of tillage and nitrogen application on maize with different N sources (commercial N + liquid manure) found non-significant (Mensah and Al-Kaisi, 2006). Similarly, a non-significant interaction effect of tillage and split application of N was also observed for grain yield and related traits in maize (Wasaya *et al.,* 2017b). Contrary to this a wheat yield was strongly affected by the season, tillage and N rate interactions (Feng *et al.,* 2014). However, in another study it has a significant effect on improving soil N and grain yield (Ahmad *et al.,* 2009).

Framers of semi-arid irrigated regions usually grow maize fol-

lowing conventional tillage practices and apply under dose of N due to unavailability and high cost of fertilizers and tillage implements. Ploughing the field in a conventional way leads to creation of hard pan, which could be a possible cause of less N uptake due to poor root penetration. Although some researcher has studied the effect of tillage and N management as individual factor in maize but their interaction effect under semi-arid irrigated conditions is lacking. Therefore, a two-year field study was conducted to evaluate the effect of different tillage systems and N levels on soil physical properties, N uptake and grain quality in maize under semi-arid irrigated conditions.

Materials and methods

Experimental site description

This study was conducted during summer season of 2008 and 2009 at Agronomic Research Farm, University of Agriculture, Faisalabad (73° E, 31° N and 135 m above sea level), Pakistan. Soil of the experimental field was sandy clay loam, which contained 58, 20.2 and 21.8% sand, silt and clay respectively. The experimental soil was also analysed for its chemical properties including EC 1.46 ds m^{-1}, pH 7.9, organic matter 0.70%, organic carbon 0.41%, total N 0.038%, available P 6.4 ppm and available K 117 ppm. The crop was sown under semi-arid climatic conditions and irrigated with canal water. The weather data for both study years is given in Figure 1.
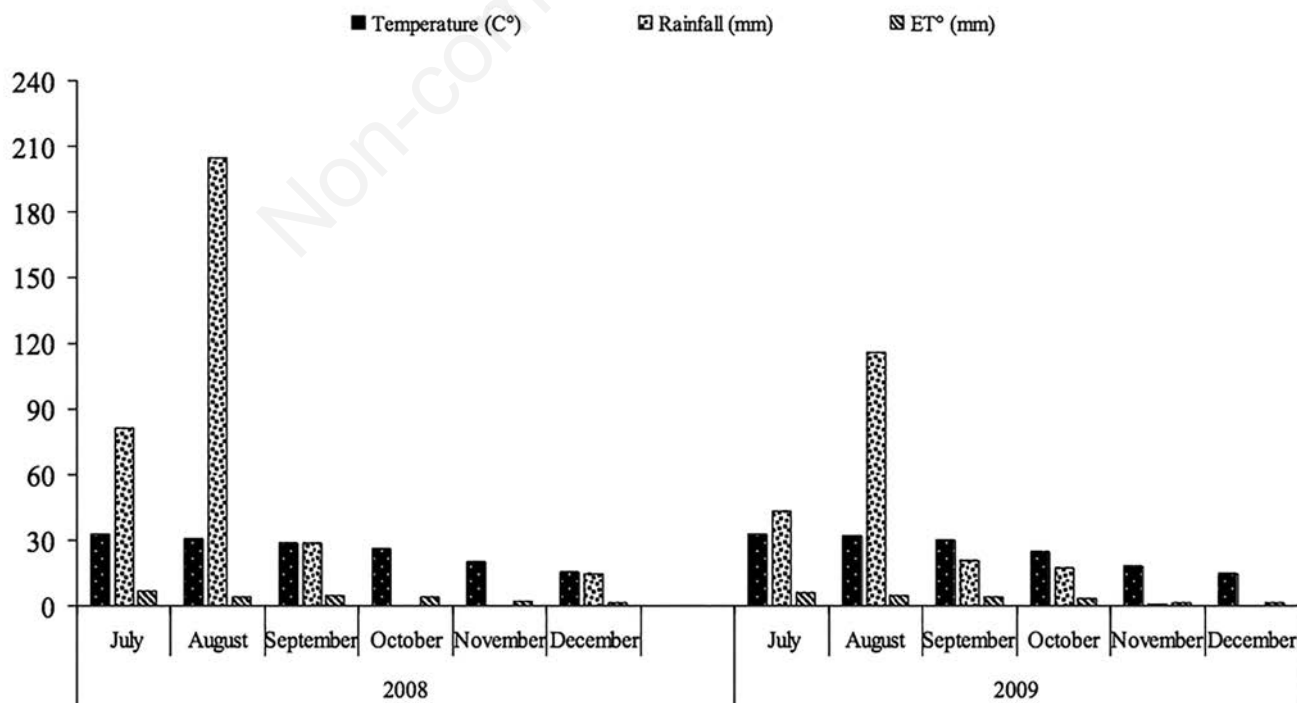

Figure 1. Weather data for study period for 2008 and 2009.

Experimental details

The study was consisted of three tillage systems viz. conventional tillage (CT) (using cultivator), tillage with mould board plough (MBP), and tillage with chisel plough (CP) each followed by two cultivations and three nitrogen (N) levels viz. 100, 150 and 200 kg ha^{-1}. In CT, soil was cultivated twice with tractor mounted cultivator followed by planking. In MBP, soil was cultivated with mould board plough upto 30 cm depth followed by 2-cultivations with tractor mounted cultivator, and one planking. In CP soil was cultivated twice with chisel plough upto 40 cm depth followed by cultivator (2-cultivations) and one planking. Three different N levels 100, 150 and 200 kg ha^{-1} were applied to maize crop. Three different levels were chosen to investigate the impact of low (farmer practice), medium (recommended) and high rates of N levels on maize yield. The experiment was carried out in a split plot design keeping tillage systems in main and N levels in sub-plots. All the treatments were replicated thrice with net plot size of 4.5×10 m.

Crop husbandry

A pre-soaking irrigation of 10 cm was applied to experimental field before maize sowing and final seedbed was prepared after six days of irrigation when soil moisture reached at workable condition. Seedbed was prepared according to treatments and maize hybrid pioneer-31R88 was sown with the help of dibbler using 25 kg ha^{-1} seed rate, at line-line distance of 75 cm and plant-plant distance of 20 cm on August 07, 2008 and August 01, 2009. Two seeds per hill were planted manually and then thinning was done at 3-leaf stage by maintaining one plant per hill. Phosphorous (P) and potassium (K) were applied at 100 kg ha^{-1} each along with N as per treatments. Whole P and K were broadcasted and mixed with soil through ploughing at sowing time, while N was applied in three splits. Half of the total N according to each treatment was broadcasted and mixed with soil through ploughing at sowing time and remaining half was side-dressed in two splits *i.e.* at 5-leaf stage (V5) and at tasseling (VT). Nitrogen was applied using urea while P and K were applied using single super phosphate (SSP) and sulphate of potash, respectively. Crop was irrigated with canal water through surface irrigation method when needed. Overall five irrigations each of 7.5 cm depth were applied to mature the crop. All other agronomic practices except specific treatments were kept uniform for all experimental units. Appropriate plant protection measures were used to keep the crop free from diseases and insect attack. Crop was harvested at physiological maturity.

Observations recorded

Soil properties

Three soil samples were randomly collected from each experimental unit between the rows with the help of soil core sampler immediately after maize harvesting to analyse the soil properties such as soil bulk density, soil total porosity and soil organic matter. The samples were taken from 2 different depths, 0-15 cm and 15-30 cm, mixed and then oven dried at 105°C for 48 h. To collect the soil samples soil cores of 0.08 m height and 0.05m diameter were used (Blake and Hartge, 1986). Bulk density was estimated as a ratio of soil mass to soil volume. The same soil samples were then used for calculating particle density as a ratio of dry soil mass to volume (Blake and Hartge, 1986). The total porosity of soil was estimated following Vomocil (1965).

Nitrogen indices

Different N indices like total N uptake (kg ha^{-1}), grain N uptake (kg ha^{-1}), N utilization efficiency (NUtE) (kg kg^{-1}) and N harvest index (NHI) (%) were calculated using following equations.

$$\text{Total N uptake} = \text{DM (above ground)} \times \frac{\text{N (DM)}}{100} \tag{1}$$

where DM indicates above ground dry matter and N (DM) indicates the N concentration in the above ground dry matter.

$$\text{Grain N uptake} = \text{grain yield} \times \frac{\text{grain N}}{100} \tag{2}$$

where grain N indicates the N concentration in maize grain.

Nitrogen utilization efficiency was recorded using the formula as proposed by (Fiez *et al.,* 1995):

$$\text{NUtE} = \frac{\text{grain yield}}{\text{total N uptake}} \tag{3}$$

where NUtE represents N utilization efficiency in kg kg^{-1}:

$$\text{NHI} = \frac{\text{grain N uptake}}{\text{total N uptake}} \times 100 \tag{4}$$

where NHI represents N harvest index (%).

Grain quality

For estimation of protein contents the grain samples were oven dried at 70°C for 24 h. After drying, the samples were grinded with mechanical grinding machine and N content in maize grain was estimated using micro-Kjeldahl method (Anonymous, 1990). Then protein contents were computed using following formula:

$$\text{Protein content (\%)} = \text{N concentarion} \times 6.25 \tag{5}$$

Oil contents in maize grain were estimated by Soxhlet method as proposed by Low (1990) and starch contents were estimated by Gluco-amylase method (Anonymous, 1990).

Statistical analysis

Data collected through standard procedures were statistically analysed using statistical package MSTAT-C (Freed and Scott, 1986). Analysis of variance technique (ANOVA) and LSD test at 5% probability level was used to compare the differences among treatment's means (Steel *et al.,* 1997). Standard error was calculated using Microsoft excel software program while, figures were drawn using sigma plot software.

Results

The results indicated that bulk density and total porosity of soil were significantly affected by different tillage systems. Lower soil bulk density and higher total porosity were observed under chisel ploughed plots. Soil carbon remained unaffected with either of the tillage systems during both study years (Table 1). Different N levels had non-significant effect on all three soil properties during both study years (Table 1). Similarly, the interaction effect between tillage systems and N levels for aforementioned soil characters

were also found non-significant (Table 1).

Different tillage systems and N levels had significant effect on grain and total N and non-significant effect was found on stover N uptake during both study years. Nitrogen utilization efficiency (NUtE) and N harvest index (NHI) remained unaffected during first and significantly affected by tillage systems only during second year (Table 2). Higher grain and total N uptake was recorded in maize grown under chisel plough and was at par with conventional tillage systems while minimum was recorded in mould board ploughed plots during both years (Table 2). Among N levels, higher stover, grain and total N uptake was recorded in maize applied with 200 kg ha^{-1} N compared with other N levels during both years of study (Table 2). However, the interaction effect for all N indices remained unaffected during both study years (Tables 3-5).

Different tillage systems and N levels had also significant effect on oil contents and was non-significant effect on protein and starch contents during both years (Table 3). However, N application had significant effect on protein, oil and starch contents and their interaction effect was non-significant except for oil content which was found significant during both years (Table 3). The higher oil contents were recorded in maize grown under conventional tillage compared with other treatments. However, minimum oil contents were recorded in maize grown under chisel plough (Table 3). Regarding N levels, higher protein contents and lower oil and starch contents were recorded in maize grown with 200 kg ha^{-1} N application while lower protein and higher oil and starch contents were recorded in maize grown under 100 kg ha^{-1} N application (Table 3). Regarding interaction effect, higher oil contents were recorded in maize grown under mould board plough by applying 100 kg ha^{-1} N compared with all other treatment combinations during both years of study (Figure 2).

Table 1. Effect of different tillage systems and nitrogen levels on soil properties.

Year			Soil bulk density (Mg m^{-3})	Soil porosity (m^3 m^{-3})	Soil C (g kg^{-1})
2008	Tillage (T)	CT	1.46^{ab}±0.03	0.45^b±0.01	3.16±0.13
		MBP	1.49^a±0.03	0.44^b±0.01	2.96±0.18
		CP	1.41^b±0.02	0.47a±0.01	3.21±0.23
LSD (0.05)			0.06	0.02	NS
	Nitrogen (N)	N$_1$	1.45±0.03	0.45±0.01	3.00±0.18
		N$_2$	1.45±0.03	0.46±0.01	3.05±0.13
		N$_3$	1.46±0.03	0.45±0.01	3.28±0.22
LSD (0.05)			NS	NS	NS
	T×N		NS	NS	NS
2009	Tillage (T)	CT	1.44^{ab}±0.02	0.46^{ab}±0.01	2.81±0.12
		MBP	1.47^a±0.03	0.45^b±0.01	2.77±0.10
		CP	1.39^b±0.02	0.48^a±0.01	3.00±0.12
LSD (0.05)			0.05	0.03	NS
	Nitrogen (N)	N$_1$	1.43±0.03	0.46±0.01	2.82±0.12
		N$_2$	1.43±0.03	0.46±0.01	2.86±0.14
		N$_3$	1.44±0.03	0.46±0.01	2.91±0.13
LSD (0.05)			NS	NS	NS
	T×N		NS	NS	NS

Means not sharing the same letters in the column differ significantly at P≤0.05. NS, non-significant. Here CT, conventional tillage; MBP, Mouldboard plough; CP, Chisel plough; N$_1$=100 kg ha^{-1}; N$_2$=150 kg ha^{-1}; N$_3$=200 kg ha^{-1}.

Table 2. Effect of different tillage systems and nitrogen levels on nitrogen indices in maize.

Year			Stover N uptake (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	NUtE (kg kg^{-1})	NHI (%)
2008	Tillage (T)	CT	128.78±12.27	87.671^{ab}±7.51	216.45^{ab}±16.82	30.496±1.63	40.587±2.19
		MBP	126.62±11.44	77.800^b±5.88	204.42^b±15.11	29.086±1.92	38.223±2.22
		CP	125.73±6.82	96.017^a±6.49	221.74^a±11.57	32.772±1.22	43.264±1.63
LSD (0.05)			NS	12.59	12.903	NS	NS
	Nitrogen (N)	N$_1$	109.61^b±6.41	76.417^c±5.88	186.03^c±7.75	32.016±1.98	41.070±2.57
		N$_2$	129.18^a±4.05	87.110^b±5.73	216.29^b±5.22	30.382±1.55	40.210±2.03
		N$_3$	142.33^a±8.31	97.961^a±6.41	240.29^a±7.91	29.956±1.80	40.794±2.50
LSD (0.05)			13.637	7.479	10.788	NS	NS
	T×N		NS	NS	NS	NS	NS
2009	Tillage (T)	CT	132.47±7.09	97.71^a±8.21	230.18^a±13.08	31.547^{ab}±1.62	42.337^a±2.07
		MBP	132.49±5.11	82.42^b±7.35	214.91^b±11.28	28.709^b±1.12	38.176^b±1.75
		CP	129.40±3.79	101.44^a±6.79	230.84^a±9.08	32.840^a±1.05	43.840^a±1.49
LSD (0.05)			NS	10.248	7.4771	2.8522	3.3506
	Nitrogen (N)	N$_1$	122.53^c±3.81	82.07^c±7.61	204.59^c±7.01	30.736±2.07	39.936±2.70
		N$_2$	131.14^b±3.46	93.94^b±5.62	225.08^b±4.69	31.202±1.52	41.672±1.92
		N$_3$	140.69^a±2.16	105.56^a±7.13	246.25^a±6.72	31.158±1.30	42.744±1.88
LSD (0.05)			5.7339	10.343	8.8526	NS	NS
	T×N		NS	NS	NS	NS	NS

Means not sharing the same letters in the column differ significantly at P≤0.05; NS, non-significant. CT, conventional tillage; MBP, Mouldboard plough; CP, Chisel plough; N$_1$, 100 kg ha^{-1}; N$_2$, 150 kg ha^{-1}; N$_3$, 200 kg ha^{-1}.

Discussion

Tillage systems play a significant role to affect the soil bulk density and total porosity, which greatly impact on grain and total N uptake as well as grain quality in crop plants. In present study, lower soil bulk density and higher total porosity in chisel ploughed plots were recorded which improved the grain and total N uptake compared with other treatments. Similarly, N application at 200 kg ha^{-1} resulted in higher N uptake as well as maize grain quality compared with other treatments (Tables 1-5 and Figure 2).

Lower bulk density and higher total porosity of soil under chisel plough might be due to ploughing the soil at more depth. As chisel plough disturbed the soil upto 40 cm depth and helped to reduce bulk density by breaking hard pan. Therefore, deep tilling lowered the soil bulk density by loosening the soil compared with conventional-tillage (Jabro *et al.,* 2010). Higher soil porosity under deep tillage might be due to more pore spaces compared with other tillage systems (Rashidi and Keshavarzpour, 2011). Non-significant effect of tillage systems on soil organic carbon might be due to least difference in organic matter in the soil (Ishaq *et al.,* 2002), as well as due to shorter time period as the effects of tillage system may become clear when studied for longer period. Non-significant but lower soil carbon value might be due to accelerated decomposition of organic matter favoured by strong microbial activities achieved through vigorous soil inversion (Six *et al.,* 2000).

Higher grain and total N uptake under chisel tilled plots of maize could be due to lower bulk density and higher total porosity of soil (Table 1). Lower bulk density and higher total porosity might have improved root growth and nutrient uptake in maize and also improved soil moisture conservation by loosening the soil through deep tillage (Wang *et al.,* 2015). Another reason may be higher root density and depth for higher N uptake in maize under chisel plough. In contrast compacted soil with higher soil bulk density reduces root growth (Croser *et al.,* 2000; Lecompte *et al.,* 2003), limits the roots in upper soil layer (Shierlaw and Alston, 1984), and resulted in decreased nutrient and moisture uptake (Watson and Kelsey, 2006) as observed with other tillage systems of present study. Lower oil contents in chisel ploughed treatments
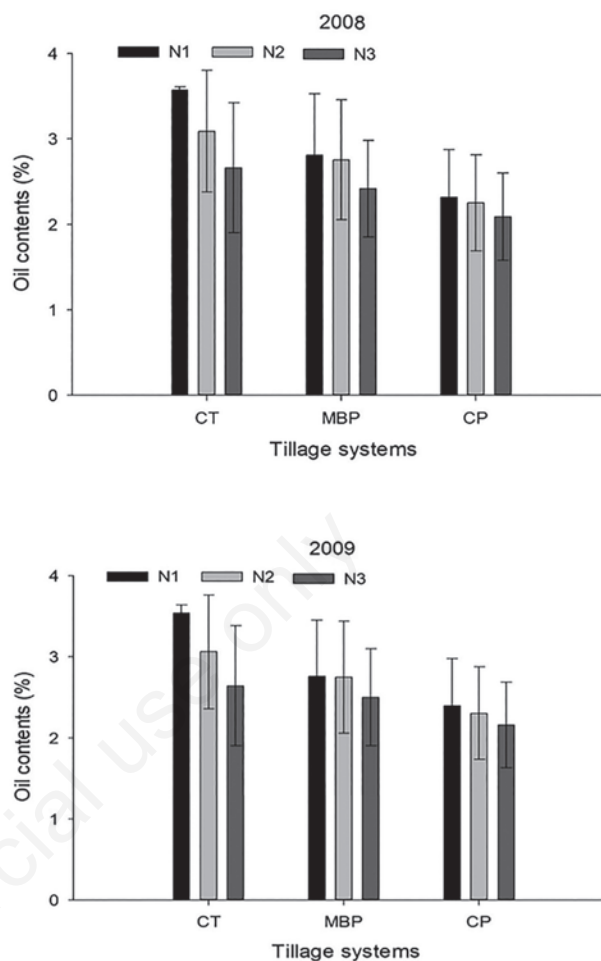

Figure 2. Interaction effect of different tillage systems and nitrogen levels on oil contents (%) in maize during both study years.

Table 3. Effect of different tillage systems and nitrogen levels on grain quality traits in maize.

Year			Protein content (%)	Oil content (%)	Starch content (%)
2008	Tillage (T)	CT	8.32±0.15	3.42[a]±0.09	70.63±0.78
		MBP	8.23±0.13	3.23[b]±0.27	70.67±0.76
		CP	8.25±0.12	2.68[c]±0.13	70.23±0.56
LSD (0.05)			NS	0.11	NS
	Nitrogen (N)	N$_1$	8.02[c]±0.04	3.42[a]±0.25	71.36[a]±0.59
		N$_2$	8.27[b]±0.04	3.07[b]±0.19	70.63[a]±0.54
		N$_3$	8.51[a]±0.06	2.83[c]±0.21	69.55[b]±0.53
LSD (0.05)			0.07	0.12	0.90
2009	Tillage (T)	CT	8.39±0.14	3.39a±0.11	71.19±0.81
		MBP	8.31±0.12	3.27[b]±0.19	70.78±1.00
		CP	8.34±0.11	2.76[c]±0.10	70.56±0.95
LSD (0.05)			NS	0.11	NS
	Nitrogen (N)	N$_1$	8.12[c]±0.06	3.39[a]±0.21	72.03[a]±0.59
		N$_2$	8.35[b]±0.05	3.11[b]±0.17	71.18[a]±0.54
		N$_3$	8.57[a]±0.05	2.92[c]±0.17	69.32[b]±0.74
LSD (0.05)			0.09	0.11	1.05
	T×N		NS	*	NS

Means not sharing the same letters in the column differ significantly at P≤0.05; NS, non-significant, *significant. CT, conventional tillage; MBP, Mouldboard plough; CP, Chisel plough; N$_1$, 100 kg ha^{-1}; N$_2$, 150 kg ha^{-1}; N$_3$, 200 kg ha^{-1}.

might be due to higher N uptake that reduces oil contents in crop plants including maize (Miao *et al.,* 2006) and brassica species (Gupta *et al.,* 2011). The non-significant effect of tillage systems on grain protein contents was also reported by Sabo *et al.* (2007). A non-significant interaction effect of tillage and nitrogen fertilizer for sugar beet production and quality was also observed by Palumbo *et al.* (2014).

Different N levels had non-significant effect on soil properties such as bulk density, total porosity and organic carbon in this study (Table 1). Non-significant effect of N levels on soil properties such as bulk density; total porosity and organic carbon had been also reported by Hossain *et al.* (2004). However, higher stover, grain and total N uptake during both years of study at higher N level might be due to more availability of N for plant uptake (Hussaini *et al.,* 2008).

Nitrogen plays significant role in improving protein contents due to presence of amino group, the building blocks for proteins. Higher protein contents at higher N level of present study might be due to more N uptake by maize grain compared with other N levels (Thomison *et al.,* 2004; Rafiq *et al.,* 2010). It is well established that increasing N supply improves protein contents in cereals grain (Spiertz and Ellen, 1978). With increase in N rate, the grain protein

contents increased, while the starch content decreased (Miao *et al.,* 2006; Zhang *et al.,* 2010). Different N application rates had negative impact on oil contents and increase in N rate resulted in reduction of oil contents in maize grain. An adverse effect of N application on grain starch contents was recorded and increase in N rate resulted in decline of grain starch contents of present study (Table 3; Miao *et al.,* 2006). Likewise, reduction in maize starch contents by applying more N was also observed by several researchers (Singh *et al.,* 2004; Zhang *et al.,* 2010).

Conclusions

Tillage methods had significant impact on soil bulk density, soil porosity, and grain and total N uptake while non-significant impact on soil organic carbon and grain quality. Lesser soil bulk density and higher soil porosity was achieved through chiseling which resulted in higher N uptake. Similarly, N application resulted in enhanced N uptake and had significant impact on grain quality. Grain protein contents increased with increasing N levels while grain oil and starch contents were adversely affected by increasing N levels. Interaction effect of tillage and nitrogen levels was found

Table 4. Interaction effect of different tillage systems and nitrogen levels on soil properties, nitrogen indices and grain quality in maize during 2008.

Treatments		Soil bulk density (Mg m^{-3})	Soil porosity (m^3 m^{-3})	Soil C uptake (g kg^{-1})	Stover N uptake (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	NUtE (kg kg^{-1})	NHI (%)	Protein content (%)	Starch content (%)
Tillage systems	Nitrogen levels										
CT	N$_1$	1.47	0.44	3.13	106.21	72.51	178.72	32.00	40.81	8.036	71.49
	N$_2$	1.45	0.45	3.093	125.99	93.50	219.50	32.187	42.55	8.33	70.647
	N$_3$	1.45	0.45	3.25	137.25	101.44	238.69	31.307	42.517	8.59	69.767
MBP	N$_1$	1.466	0.446	2.80	108.75	79.84	188.60	32.797	42.15	7.97	71.58
	N$_2$	1.49	0.44	2.92	126.51	83.84	210.35	30.04	39.737	8.256	71.04
	N$_3$	1.506	0.43	3.17	151.23	92.67	243.91	28.010	37.95	8.45	69.397
CP	N$_1$	1.406	0.47	3.07	113.88	76.89	190.77	31.247	40.247	8.04	71.017
	N$_2$	1.396	0.47	3.15	135.05	83.99	219.04	28.92	38.34	8.226	70.19
	N$_3$	1.42	0.46	3.42	138.50	99.77	238.27	30.55	41.91	8.486	69.477
LSD		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, non-significant; CT, conventional tillage; MBP, Mouldboard plough; CP, Chisel plough; N$_1$, 100 kg ha^{-1}; N$_2$, 150 kg ha^{-1}; N$_3$, 200 kg ha^{-1}.

Table 5. Interaction effect of different tillage systems and nitrogen levels on soil properties, nitrogen indices and grain quality in maize during 2009.

Treatments		Soil bulk density (Mg m^{-3})	Soil porosity (m^3 m^{-3})	Soil C uptake (g kg^{-1})	Stover N uptake (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})	NUtE (kg kg^{-1})	NHI (%)	Protein content (%)	Starch content (%)
Tillage systems	Nitrogen levels										
CT	N$_1$	1.46	0.45	2.88	120.25	84.77	205.02	31.777	41.277	8.126	72.157
	N$_2$	1.43	0.46	2.72	133.03	96.94	229.97	31.40	42.147	8.39	71.31
	N$_3$	1.436	0.46	2.84	144.12	111.41	255.53	31.46	43.587	8.66	70.10
MBP	N$_1$	1.436	0.46	2.65	122.16	70.96	193.11	28.387	36.61	8.0567	72.25
	N$_2$	1.47	0.44	2.84	133.94	83.76	217.70	28.74	38.44	8.356	71.37
	N$_3$	1.48	0.44	2.82	141.38	92.53	233.91	28.997	39.47	8.506	68.73
CP	N$_1$	1.38	0.48	2.92	125.17	90.47	215.64	32.04	41.92	8.176	71.683
	N$_2$	1.37	0.48	3.016	126.46	101.12	227.58	33.46	44.427	8.30	70.86
	N$_3$	1.41	0.47	3.076	136.58	112.73	249.31	33.01	45.173	8.55	69.14
LSD		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, non-significant; CT, conventional tillage; MBP, Mouldboard plough; CP, Chisel plough; N$_1$, 100 kg ha^{-1}; N$_2$, 150 kg ha^{-1}; N$_3$, 200 kg ha^{-1}.

significant only for oil contents, while remained unaffected for all other studied traits. It is therefore, concluded that maize should be grown by ploughing soil with chisel plough to increase soil porosity which increases crop root proliferation and ultimately enhances N uptake.

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