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Full Length Article

Impact of Tillage Systems and Temporal Nitrogen Application on Soil Properties, Nitrogen Uptake and Net Returns in Maize

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Abstract

Nitrogen (N), being a mobile element, is often lost due to injudicious use, conventional soil and crop management practices; however, its losses can be reduced by temporal N application and optimal tillage practices. This 2-year experiment was conducted to evaluate the impact of different tillage systems i.e., conventional tillage (CT), mouldboard plough (MBP) + 2-cultivations and chisel plough (CP) + 2-cultivations and temporal N application i.e., whole at sowing, ½ at sowing+½ at V5 (5-leaf stage), ½ at sowing+½ at tasseling, ½ at V5+½ at tasseling, 1/3 at sowing+1/3 at V5+1/3 at tasseling on soil properties, grain yield, nitrogen uptake and net returns in maize. Tillage systems and N timings significantly affected leaf area index (LAI), leaf area duration (LAD), crop growth rate (CGR), soil properties, grain yield, N uptake and net returns. Chisel tilled plots observed less bulk density, more LAI, CGR and total N uptake compared with CT and MBP. Nitrogen application in three splits resulted higher LAI and duration, CGR and nitrogen uptake, compared with other treatments. Maximum net returns were recorded in chisel-tilled plots with N application in three splits. In conclusion, N uptake coupled with higher N use efficiency, and higher net returns were observed with chisel tillage system, and applying N in three splits under semi-arid irrigation conditions.

Keywords: Bulk density; Crop allometry; Economic yield; Split application; Tillage regimes

Introduction

Tillage practices are used as fundamental and important field operation to achieve higher crops yield (Sharma *et al.*, 2011; Shi *et al.*, 2016). It significantly affects different soil properties such as soil bulk density, water movement and storage in soil (D'Haene *et al.*, 2008; Jabro *et al.*, 2015). Repeated field ploughing with same tillage implement in semi-arid regions creates a hard or plough pan in the subsoil layer which adversely affects crop productivity (Wasaya *et al*., 2011; Shahzad *et al.*, 2016a), and may alter the structure and physicochemical properties of soil (Elcio *et al*., 2003; Huang *et al*., 2007). This condition may obstruct the development of root system and cause reduction in root length, seedling growth and seed yield of many crops (Coelho *et al*., 2000). The projection of plough pan may decrease roots proliferation (Whitmore *et al.,* 2011) and soil porosity which eventually disturb the crop growth (Ishaq *et al.,* 2003).

Rising of plough/hard pan may also cause reduction in soil porosity, enhances soil bulk density, and adversely affects soil penetration resistance and cone index (Wang *et al.,* 2009). This increase in penetration resistance limits root penetration and crop yield (Ishaq *et al.,* 2003). However, these compacted soil layers can be managed by mechanical loosening of the soil for improving crop yield (Lal, 1989). Deep tillage result in soil loosening as it may alter soil environment constituents, which are essential for crop growth and improve organic nitrogen mineralization and soil aeration (Dinnes *et al*., 2002; Halvorson *et al*., 2002). It may also increase root density as well as its distribution (Mosaddeghi *et al.*, 2009; Sun *et al.*, 2017), by decreasing penetration resistance (Jabro *et al.*, 2010) and soil bulk density, and improving hydraulic conductivity of saturated soils (Akinci *et al.*, 2004; Muqaddas *et al.*, 2005). Loosening and manipulating the deeper soil layer through deep tillage improves grain yield (Wasaya *et al.*, 2017a) and biomass production (Wasaya *et al.*, 2012) in maize.

In addition to soil compaction, considerable N losses may occur due to denitrification, volatilization and leaching, when it is applied in the field. In order to minimize these losses, the management of N application works in a substantial way to increase N use efficiency (NUE) and yield of crops. In increasing NUE, split application of N plays a significant role as N required by crop differs within a field depending upon soil available N and variations in crop yield potential (Scharf *et al.*, 2005). Over dosage of applied N coupled with its application at improper time is a

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common practice in maize-wheat cropping system (Zhao *et al.*, 2006). Pre-silking N application is relatively critical than post-silking as insufficient supply of N has nocuous impact on crop yield and yield attributes. Similarly, limited supply of N from seedling to V8 (8-leaf) resulted in irrecoverable reduction in grain yield (up to 30%) and its related components (Subedi and Ma, 2005), while delayed application found to be non-effective or resulted in reduced N uptake and dry matter production (Jokela and Randall, 1989). Mitchell *et al.* (2000) observed that pre-sowing N application resulted in more NO_3^- leaching as compared to side dressing. Split application of N cuts NO_3^- leaching by 25% compared with pre-sowing and lead to 13% increment in maize yield (Bakhsh *et al.*, 2002). Split application of N into 3–4 doses resulted in higher crop growth rate (CGR), and relative growth rate (RGR) which leads to more crop agronomic efficiency and additional grain yield (Sitthaphanit *et al.*, 2010).

Judicious use of N by adjusting its time of application according to crop requirement improved fertilizer use efficiency and grain yield (Delin, 2004; Ul-Allah *et al.*, 2018). Timing of N application is also important in deciding NUE, as N application should match with peak crop requirements. Both tillage systems and N timing play a key role to get higher yield. The existence of plough/hard pan can be managed through subsoiling the field after every three years, to break the compacted or hard soil layer. It may enhance soil pore spaces and facilitate root proliferation to extract moisture and nutrient from deeper soil layers.

Role of tillage practices and N application in splits to improve soil properties and crop yield in independent studies is well reported (Bakhsh *et al*., 2002; Ishaq *et al.*, 2003; Shahzad *et al.*, 2016b) but little information is available about their interactive effects in this regard. In our earlier studies, we have evaluated the role of interactive effects of different tillage practices and temporal N application on biomass production, yield and yield related traits of maize (Wasaya *et al.*, 2012, 2017b) but information regarding crop allometry, N uptake and its use efficiency and economic returns is still lacking. Therefore, this 2-year field experiment was planned to evaluate the impact of tillage systems and temporal N application on soil properties, N uptake and NUE, and net return in maize under semi-arid regions of Pakistan.

Materials and Methods

Site Description

This field study was executed at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan during autumn season 2008 and 2009. The experimental site is located in semi-arid region (31.25° N, 73.09° E and 135 m asl) where crop was irrigated with canal water. The experimental site has sandy clay loam texture amounting 58, 20.2 and 21.8% of sand, silt and clay respectively, with 0.72% organic matter and 0.04% total N contents. The climatic data for both years of crop season is presented in Table 1.

Experimentation

Maize crop was sown under three tillage systems viz., conventional tillage (CT) (two cultivations using cultivator followed by planking); tillage with moldboard plough (MBP) up to 30 cm depth followed by 2-cultivations with cultivator and one planking; and tillage with chisel plough (CP) up to 40 cm depth followed by 2-cultivations with cultivator and one planking with five N-application timings *viz.* whole at sowing; ½ at sowing + ½ at 5-leaf stage (V5)/leaf development stage (30 DAS), ½ at sowing + ½ at tasseling (VT)/inflorescence emergence (50 DAS), ½ at V5)/leaf development + ½ at VT/inflorescence emergence and N_5: $^1/_3$ at sowing + $^1/_3$ at V5/leaf development + $^1/_3$ at VT/inflorescence emergence (Nielsen, 2010). The experiment was laid out following randomized complete block design (RCBD) with split plot arrangement by assigning tillage systems and N splits in main and sub plots, respectively. Whole experiment was replicated three times with net plot size of 4.5 m × 10 m.

Crop Husbandry

A pre-soaking irrigation about 10 cm was given to experimental field before maize planting and final seedbed was prepared six days after irrigation when field reached at workable moisture condition. Seedbed was prepared according to treatments needs and maize hybrid pioneer-31R88 was sown with the help of dibbler on August 07, 2008 and August 01, 2009 by using 25 kg ha^{-1} seed rate, maintaining row-row distance of 0.75 m and a plant-plant distance of 0.2 m. Two seeds per hill were sown by hand and then one plant per hill was retained by thinning at 3-leaf stage. Nitrogen (N) was applied @150 kg ha^{-1} while phosphorous (P) and potassium (K) both were applied @100 kg ha^{-1} each. Whole P and K were applied at planting while N was applied according to the treatments by using single super phosphate (SSP), sulphate of potash (SOP) and urea as source. Overall five irrigations each of 7.5 cm depth were applied by observing the crop need to mature the crop.

Observations and Measurements

Soil properties: Three soil samples from each experimental unit were collected randomly by using soil core sampler immediately after maize harvesting to analyze the soil properties such as soil bulk density, soil porosity and soil organic matter. The samples were taken from 2 different depths, 0–15 cm and 15–30 cm, mixed and then dried in an oven at 105°C for 48 h. Bulk density was determined as a ratio of soil mass to soil volume. These samples were further used for determining particle density as a ratio of dry soil and volume of soil (Blake and Hartge, 1986). The total porosity of soil was calculated following Vomocil (1965).

Table 1: Mean monthly temperature, evapotranspiration (ET_o) and total monthly rainfall data at the experimental site for both study years (2008 and 2009)

Weather element	Years	July	August	September	October	November	December
Temperature (°C)	2008	32.9	30.9	29	26	19.7	15.5
	2009	32.9	32.1	30.3	24.9	18.2	14.5
Rainfall (mm)	2008	81.6	204.5	28.8	0	0	14.6
	2009	43.5	116	20.6	17.5	0.7	0
ET_o	2008	6.4	3.7	4.9	3.9	1.9	1.1
	2009	6	4.9	3.8	3.1	1.3	1.2

ET_o- Evapotranspiration
Source: Departement of Agronomy, University of Agriculture, Faisalabad, Pakistan

Crop Allometry

Ten plants were harvested from each experimental unit having an area of 1.5 m^2 with 15 days interval beginning from 40 days after sowing (DAS) up to 100 DAS. All leaves from all plants were detached manually from stem for measurement of leaf area with leaf area meter (DT Area Meter, Model MK2, Delta T Devices, Cambridge, UK). The leaf area index (LAI) was then calculated using a formula proposed by Watson (1947), leaf area duration (LAD) and crop growth rate (CGR) were calculated following Hunt (1978).

Nitrogen Indices

Different nitrogen indices like total N uptake (kg ha^{-1}), grain N uptake (kg ha^{-1}), Nitrogen utilization efficiency (NUtE) (kg kg^{-1}) and nitrogen harvest index (NHI) (%) was calculated using under given equations. For this purpose, grinded plant (grain as well as stover) samples were used to determine nitrogen contents by using the micro-Kjeldahl method (Anonymous, 1990), and then total N uptake was calculated using following formula. Data used for dry matter and grain yield was taken from same study published as Wasaya *et al.* (2012, 2017b).

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

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

$$\text{Grain N uptake} = \text{Grain yield} \times \frac{\text{Grain N}}{100} \quad (2)$$

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)

$$\text{NUtE} = \frac{\text{Grain yield}}{\text{Total uptake}} \quad (3)$$

Where NUtE represents nitrogen utilization efficiency in kg kg^{-1}

$$\text{NHI} = \frac{\text{Grain N uptake}}{\text{Total N uptake}} \times 100 \quad (4)$$

Where NHI represents N harvest index (%).

Statistical Analysis

Data obtained using standard procedures were analyzed statistically with the help of MSTAT-C software (Freed and Scott, 1986). Analysis of variance (ANOVA) and Least Significant Difference (LSD) test were used to compare the differences among treatment's means at 5% probability level (Steel *et al.,* 1997). Moreover, Microsoft Excel Program was used for the graphical presentation of data using standard error (±S.E.).

Economic and Marginal Analysis

To find out the economic viability of tillage systems and N timings used for the experiment, an economic and marginal analysis was performed. Total expenditures incurred for maize production were included soil cultivation with different tillage implements, seedbed preparation, land rent, seed cost, sowing, irrigation, fertilizer, weeding, harvesting and shelling of crop. Gross income was assessed using current market price during study year for inputs at sowing and outputs at harvesting in the country. All the cost and profit were calculated in US dollar (US $) on per hectare basis. Moreover, net income/benefit was calculated through subtracting the total expenditure from gross income while benefit cost ratio (BCR) was calculated as the ratio of gross income to total expenditure. Marginal analysis was done based on net benefit and variable cost following the methodology as described by Perrin *et al.* (1979). Data for grain yield to calculate economic and marginal analysis was taken from Wasaya *et al.* (2017b).

Results

Different tillage systems (T) had a significant impact on soil bulk density, and total soil porosity, but non-significant effect on soil organic carbon (SOC) during both years of study (Table 2). Tillage with chisel plough reduced soil bulk density and increased total soil porosity compared with other tillage systems during both years (Table 2). However, time of N application (N) had no significant impact on all the soil properties. Similarly, T×N on soil properties was also found to be non-significant (Table 2).

Table 2: Effect of different tillage systems and time of nitrogen application on soil bulk density, total porosity and organic carbon

Year	Treatments		Soil bulk density (Mg m^{-3})	Total porosity (m^3 m^{-3})	Soil organic carbon (g kg^{-1})
2008	Tillage (T)	CT	1.47 a	0.45 b	2.71
		MBP	1.48a	0.44 b	2.68
		CP	1.41b	0.47 a	2.83
		LSD (0.05)	0.06	0.02	NS
	Nitrogen (N)	N_1	1.46	0.45	2.71
		N_2	1.46	0.45	2.80
		N_3	1.44	0.46	2.76
		N_4	1.45	0.45	2.71
		N_5	1.45	0.45	2.71
		LSD (0.05)	NS	NS	NS
		T×N	NS	NS	NS
2009	Tillage (T)	CT	1.46 ab	0.45 ab	2.87
		MBP	1.49 a	0.44 b	2.87
		CP	1.42 b	0.46 a	3.02
		LSD (0.05)	0.05	0.02	NS
	Nitrogen (N)	N_1	1.46	0.45	3.00
		N_2	1.46	0.45	2.99
		N_3	1.46	0.45	2.89
		N_4	1.45	0.45	2.79
		N_5	1.44	0.46	2.96
		LSD (0.05)	NS	NS	NS
		T×N	NS	NS	NS

Means not sharing the same letters in the column differ significantly at $p \leq 0.05$

Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

Different tillage practices and N application timings significantly affected crop allometric traits such as LAI, CGR and LAD (Fig. 1, 2 and 3). Seasonal data regarding LAI elaborates that tillage with chisel plough resulted in increased LAI while tillage with mouldboard plough caused reduction in LAI during both years (Fig. 1). In case of N application timings, higher LAI was obtained in plots where N was applied in 3 splits at varying growth stages. However, lower LAI obtained when N was applied in two splits i.e., ½ at leaf development stage and left over half split at tasseling (VT) (Fig. 1). Likewise, maximum LAD was attained in plots tilled with chisel plough and was at par with those under conventional tillage while, minimum LAD was attained in plots ploughed by mouldboard plough during both years (Fig. 2). Maize attained maximum LAD when N was applied in three splits ($^1/_3$ at sowing+ $^1/_3$ at leaf development + $^1/_3$ at tasseling) with less LAD in case of N_4 (i.e., ½ at leaf development + ½ at tasseling) during both years (Fig. 2). Chisel tilled plots observed more CGR but statistically it was at par with plots where conventional tillage was done, while less CGR was recorded in plots tilled with mouldboard plough during both years (Fig. 3). Similarly, higher CGR was recorded in plots where N was applied in three splits as compared to those where N was applied in two splits i.e., ½ at leaf development and ½ at tasseling stage (Fig. 3).

Different tillage systems significantly affected total N as well as grain N uptake, while non-significant effect on NUtE and nitrogen harvest index (NHI) during both experimental years (Table 3). Maximum total N and grain N uptake was noted in chisel plough tilled plots while,

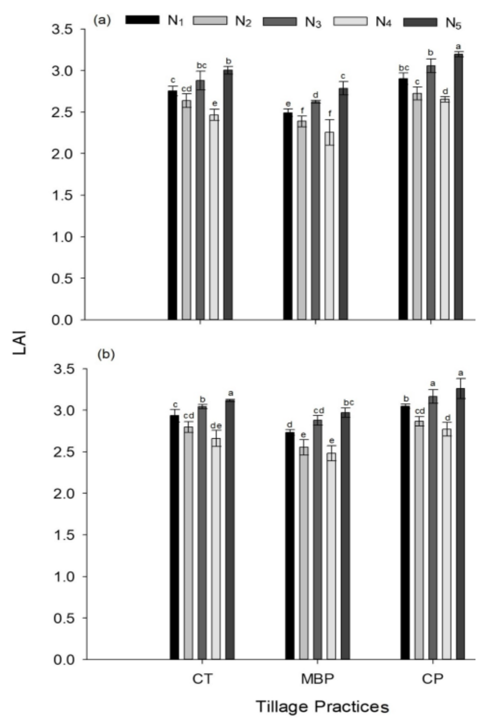

Fig. 1: Leaf area index as affected by different tillage systems and time of nitrogen application in a) 2008 and b) 2009. Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

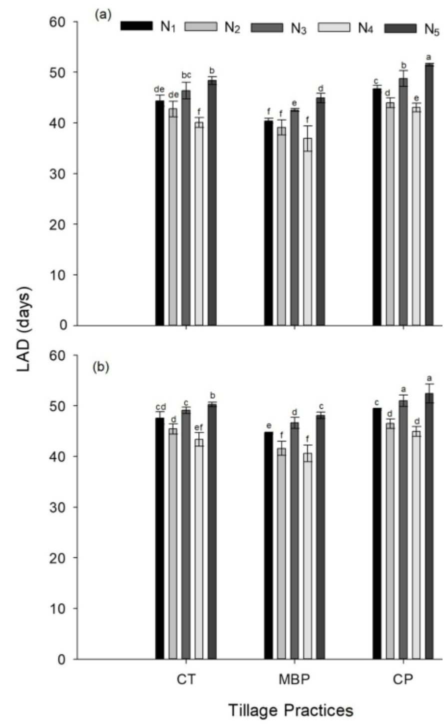

Fig. 2: Leaf area duration (days) as affected by different tillage systems and time of nitrogen application a) 2008 and b) 2009; Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

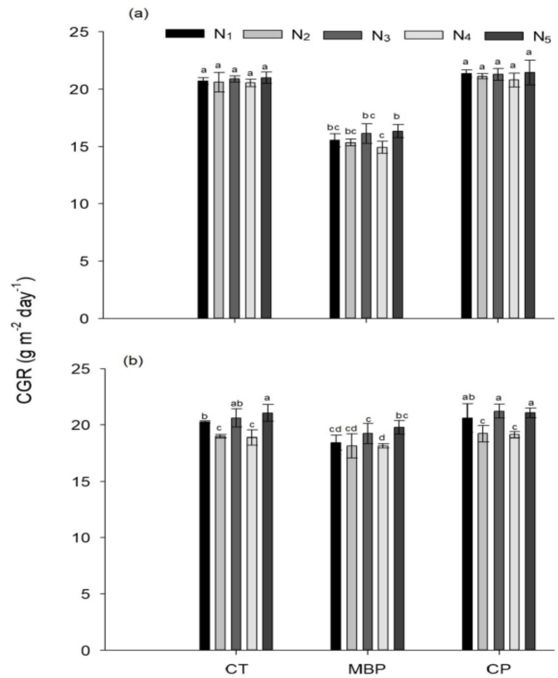

Fig. 3: Crop growth rate (gm^{-2} day^{-1}) as affected by different tillage systems and time of nitrogen application a) 2008 and b) 2009; Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

minimum of these components was noted under mouldborad plough tilled plots (Table 3). Similarly, time of nitrogen application had significant effect on all nitrogen indices such as total N and grain N uptake, NUtE and NHI in both years (Table 3). Highest total as well grain N uptake were observed in maize grown with nitrogen application in three splits while minimum values of all these factors were noticed in plots given N in two splits i.e., ½ at leaf development and half at tasseling during 2008 and 2009 (Table 3). However, higher values of NUtE and NHI were recorded where whole N was applied at sowing time whereas; lower values were obtained where N was applied in three splits (Table 3). Interaction among tillage systems and temporal N application had non-significant effect on total N uptake and NHI during both years of study and on grain N uptake during 2009 only (Table 4). However, interactive effects were found significant for grain N uptake during 2008 and for NUtE during 2009 (Table 4).

The economic analysis of this 2-year study disclosed that overall chisel plough had more benefit cost ratio (BCR) during both years (Table 5). Among N application timings, N application in three splits (1/3 at sowing + 1/3 at leaf development + 1/3 at tasseling) observed higher net income and BCR compared with other treatment followed by N application in 2-splits (½ at sowing + ½ at tasseling) during both study years (Table 5). However, maximum net return (980.48 US \$ ha^{-1}) and BCR of maize was recorded from chisel ploughed plots by applying N in 3-splits (Table 5). Similarly, marginal analysis showed the superiority of chisel plough along with N application in three splits with maximum (11683%) marginal rate of return (Table 6).

Discussion

Different tillage systems and N application timings had a variable effect on soil physical properties, crop allometric traits and net returns in maize. Results of this study disclosed that tillage with chisel plough and N application in 3-splits improved soil properties, CGR, LAI, N uptake, NUtE and net returns of maize (Fig. 1 and 2; Tables 2, 3, 4 and 5).

In general, the chisel plough favored N uptake and improved crop allometric traits by reducing soil bulk density and increasing porosity of soil (Osunbitan *et al*., 2005). Low soil bulk density with chisel plough might be attributed to breaking up of hard pans at greater depth (Gangwar *et al*., 2004) and reducing mechanical hindrance (Chatterjee and Lal, 2009) which in turn improved the soil porosity (Rashidi and Keshavarzpour, 2011).

Table 3: Effect of different tillage systems and time of nitrogen application on total N uptake and nitrogen harvest index (NHI) in maize

Year	Treatments		Total N uptake (kg ha^{-1})	NHI (%)
2008	Tillage (T)	CT	154.25 b	48.19
		MBP	135.86 c	49.67
		CP	168.65 a	49.21
		LSD (0.05)	9.27	NS
	Nitrogen (N)	N_1	138.25 c	52.95 a
		N_2	141.72 c	49.19 b
		N_3	169.63 b	46.01 c
		N_4	128.28 d	53.69 a
		N_5	186.72 a	43.28 d
		LSD (0.05)	7.17	2.53
		T×N	NS	NS
2009	Tillage (T)	CT	165.57 b	51.90
		MBP	142.88 c	52.22
		CP	181.75 a	50.40
		LSD (0.05)	9.34	NS
	Nitrogen (N)	N_1	147.61 c	55.67 a
		N_2	155.18 c	52.12 b
		N_3	176.41 b	48.56 c
		N_4	138.10 d	55.55 a
		N_5	199.70 a	45.64 d
		LSD (0.05)	8.06	2.20
		T×N	NS	NS

Means not sharing the same letters in the column differ significantly at $p \leq 0.05$; Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

Table 4: Interactive effect different tillage systems and time of nitrogen application on grain N uptake and nitrogen utilization efficiency (NUtE) in maize

Tillage	Nitrogen	Grain N uptake (kg ha^{-1}) 2008	NUtE (kg kg^{-1}) 2009
CT	N_1	74.02 de	42.28 bc
	N_2	68.20 fg	42.35 bc
	N_3	79.74 bc	36.98 d-g
	N_4	66.57 gh	38.52 c-g
	N_5	77.56 cd	35.06 fg
MBP	N_1	66.02 gh	44.89 ab
	N_2	63.29 hi	39.02 c-f
	N_3	71.43 ef	39.30 c-f
	N_4	61.60 i	41.21 b-d
	N_5	71.41 ef	35.45 e-g
CP	N_1	79.15 bc	41.83 bc
	N_2	77.64 cd	40.14 c-e
	N_3	81.95 b	36.23 e-g
	N_4	78.17 bc	48.71 a
	N_5	93.12 a	34.09 g
	LSD (0.05)	4.29	4.30

Means not sharing the same letters in the column differ significantly at $p \leq 0.05$; Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

Increase in LAI with chisel-tilled plots was linked with lower soil bulk density (Chatterjee and Lal, 2009; Wang *et al*., 2015) and higher soil porosity (Dıaz-Zorita, 2000; Hao *et al*., 2001). Low soil bulk density tied with more porosity created more favorable soil environment for root proliferation with better nutrient and moisture uptake

Table 5: Economic analysis for the impact of temporal nitrogen application on maize performance under different tillage systems

Treatments	Total Expenditure (US $ ha^{-1})	Gross Income (US $ ha^{-1})	Net Income (US $ ha^{-1})	Benefit-Cost Ratio
CTN_1	663.46	1422.18	758.72	2.15
CTN_2	665.31	1416.32	751.01	2.13
CTN_3	665.31	1456.53	791.22	2.19
CTN_4	665.31	1190.22	524.91	1.79
CTN_5	667.17	1497.14	829.97	2.25
$MBPN_1$	680.68	1241.72	561.04	1.82
$MBPN_2$	682.54	1196.57	514.03	1.75
$MBPN_3$	682.54	1316.58	634.04	1.93
$MBPN_4$	682.54	1134.30	451.77	1.66
$MBPN_5$	684.39	1365.64	681.25	2.00
CPN_1	696.72	1490.97	794.26	2.14
CPN_2	698.57	1454.90	756.32	2.08
CPN_3	698.57	1584.88	886.31	2.27
CPN_4	698.57	1607.55	908.98	2.30
CPN_5	700.43	1680.91	980.48	2.40

Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

Table 6: Marginal analysis for the impact of temporal nitrogen application on maize performance under different tillage systems

Treatments	Variable cost (US $ ha^{-1})	Net benefit (US $ ha^{-1})	Change in variable cost (US $ ha^{-1})	Change in net benefit (US $ ha^{-1})	Marginal rate of return (%)
CTN_1	-	616.02	-	-	-
CTN_2	1.93	524.00	1.93	-	-
CTN_3	-	704.18	-	180.18	-
CTN_4	-	496.98	-	-	-
CTN_5	1.93	650.45	1.93	153.47	7950.00
$MBPN_1$	11.58	467.70	9.65	-	D
$MBPN_2$	1.93	422.97	-	-	D
$MBPN_3$	-	551.35	-	128.38	D
$MBPN_4$	-	398.20	-	-	D
$MBPN_5$	1.93	535.91	1.93	137.71	7133.33
CPN_1	11.58	675.23	9.65	139.32	1443.33
CPN_2	1.93	646.27	-	-	D
CPN_3	-	713.84	-	67.57	D
CPN_4	-	666.54	-	-	D
CPN_5	1.93	892.08	1.93	225.55	11683.33

Here CT = Conventional tillage; MBP = Mouldboard plough; CP = Chisel plough; N_1= Whole N application at sowing, N_2= ½ at sowing + ½ at V5 (5-leaf stage), N_3= ½ at sowing + ½ at tasseling, N_4= ½ at V5 + ½ at tasseling, N_5= 1/3 at sowing + 1/3 at V5 + 1/3 at tasseling

(Patil and Sheelavantar, 2006; Wang *et al*., 2015) which results in better plant growth (Ahadiyat and Ranamukhaarachchi, 2007; Gurumurthy *et al*., 2008). As leaves are the units of plant assimilatory system to intercept solar radiation. Therefore, higher LAI in chisel-tilled plots resulted in higher CGR due to more accumulation of photo-assimilates (Fig. 1 and 3). However, the soil organic carbon remained unaffected in all treatments because no extra organic matter was applied in any treatment (Ishaq *et al*., 2002). Nonetheless, the results were more prominent for 2nd year as compared to1styear of study, which reflects the continuous improvement of aforementioned treatment, if adopted, on long-term basis. The gradual improvement in the soil and plant growth properties might be due to deep tillage by using chisel plough (Halvorson *et al*., 2002; Blanco-Canqui *et al.,* 2017).

Due to volatile nature of N and its solubility in water, its efficiency reduced due to leaching and volatilization and it became unavailable to the latter stages of crop growth. Nitrogen fertilization management plays a vital role in enhancing crop productivity. Moreover, N is an important component of chlorophyll and optimum N supply is pre-requisite to improve photosynthetic efficiency of crops (Amanullah *et al.,* 2007; Khan *et al*., 2008; Islam *et al.*, 2009; Sitthaphanit *et al*., 2010) which lead to improved crop growth. Nitrogen application in three splits ($^1/_3$ at sowing + $^1/_3$ at leaf development + $^1/_3$ at tasseling) had improved the crop allometry, N uptake and its use efficiency. Its split application might reduce its losses and improved the N supply on continual basis, which in turn improved the total N uptake and N use efficiency (ViswaKumar *et al.,* 2008; Jan *et al.,* 2010; Reddy and Bhanumurthy, 2010; Sitthaphanit *et al.*, 2010; Sharma and Bali, 2017).

Therefore, better crop allometery coupled with improved N use efficiency in chisel-tilled plots with N application in three splits was linked with lesser soil bulk density and more porosity (created favorable environment for root growth to improve nutrient and water uptake) and continuous N supply throughout the crop life cycle (Fig. 1, 2, 3 and Table 2, 3, 4).

Farmer's main concern is to increase their profit hence; they adopt any new technology by considering its economic feasibility (Khan *et al.,* 2012). Economic analysis of this study revealed that the maximum net return in terms of benefit: cost ratio (BCR) was obtained by growing maize through applying N in 3-splits in chisel tilled plots during both study years compared with other treatments (Table 5). Although the cost of production was high in this treatment combination; however, increase in yield compensated the extra expenses hence improved the net income, BCR and marginal rate of return. Thus, adaptation of chisel plough may improve soil health and split in nitrogen application improve NtUE, combination of both lead to sustainable improvement in wheat yield and profitability of the farmers.

Conclusion

Deep tillage with chisel plough improved crop allometry by minimizing soil bulk density, and improving total soil porosity, and N uptake in maize. Moreover, N application in three splits improved the NUtE coupled with higher net benefit (980.48 US \$ ha^{-1}) and marginal rate of return (11683%). Therefore, deep tillage with chisel plough along with N application in three splits seemed highly profitable for maize cultivation under semi-arid conditions of Punjab, Pakistan.

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