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Impact of tillage practices on soil physical properties, nitrate leaching and yield attributes of maize

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ABSTRACT

Tillage, undoubtedly, is one of the most crucial practice to ameliorate crop productivity and maintain soil health. A field experiment was conducted at research farms; Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan to examine how soil properties and maize crop respond to different tillage strategies (minimum, conventional and deep tillage). Randomized complete block design (RCBD) was finalized for the experiment with three repeats. Maximum total biomass production and grain yield were recorded in case of deep tillage practices. Conventional tillage not only improved leaf area index but also harvest. Minimum tillage minimized the leaching of nutrients especially nitrates. Soil bulk density (Mg m^{-3}), particle density, soil organic carbon (g kg^{-1}), infiltration rate (mm hr^{-1}), percent porosity (%) and soil saturated hydraulic conductivity (mm hr^{-1}) got affected by different tillage practices. To avoid leaching losses of nutrients, minimum tillage is suggested as this loss reduces the crop productivity.

Key Words: *Tillage, Maize, Leaching, Nitrates and Soil properties*

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I. Introduction

Maize, after wheat and rice, is 3rd most important cereal crop. It plays a decisive role in agriculture based economy of the country. It has vital nutritional value: maize seeds contain many by-products like glucose, fatty acid, amino acid etc. along with 72% starch, 10% protein, 4.8% oil and 8.5% fiber (Ministry of Food and Agriculture (MFA), 2009-10). Tillage, one of the most important practices in agriculture, is performed primarily to mix the soil with organic residues and fertilizer, to loose the upper layer of soil, to check weeds and to create a suitable seedbed for germination and plant growth (Rasmussen, 1999). Soil physical and biological characteristics are influenced by tillage practice which in turn lead to alter plant growth and yield (Wasaya *et al*., 2011; Rashidi and Keshavarzpour, 2007).

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Atkinson *et al.* (2007) reported that nitrogen, as a macro nutrient, has an essential role in plant nutrition and also acts as one of the most important yield limiting plant nutrient for crop production around the globe. The mineralization of soil organic matter releases nitrogen (N) that is readily available to the plant. The NH_4^+ and NO_3^- are two important N forms available to plants. Along with tillage, amount of irrigation, type of fertilizer and amount and time of application are also key factors that affect plant growth and soil environment. Some nitrogenous fertilizers such as ammonium nitrate and urea have a high mobility potential and may undergo leaching. Also, the excessive use of nitrogenous fertilizers in agriculture has resulted in losses in the form of their derivatives and leaching of fertilizers below the root zone that created problems by contaminating groundwater (Wierenga, 1977). Harmmel (1989) reported that the tillage practices influenced the sustainable use of the soil resources by altering soil physical properties. Nitrate, passing through macro pores which serve as flow passage for water, can move into the soil with the infiltrate water. The enhanced water movement through soil macro pores in the profile increases the potential of soluble nitrates movement under no tillage scenario (Ahmad *et al.*, 2009). Ground water pollution, due to nitrate (NO3-) leaching, causes serious problems concerning human health and the environment in many developing as well as developed countries (Benbi *et al.*, 1991; Carman, 1997; Wilson *et al.*, 1999). Nitrate leaching, a naturally occurring process, occurs when nitrates leave the soil in drainage water. Nitrate, being soluble and mobile, is not problematic when it is present in the root-zone, but when it goes beyond root zone or into the ground water and other fresh water bodies it causes environmental pollution. Drinking nitrate (NO_3^-) contaminated water can result in various diseases in the human and animals especially in infants like methemoglobinemia commonly known as blue baby syndrome (Ray, 2011). Aikins and Afuakwa (2010) searched the factors which affect nitrate movement in soil profile; it included soil physical properties (especially soil texture and structure) irrigation water, soil type, method and time of nitrogen fertilizer application and the management practices. They further reported, after the experimentation, that favorable soil conditions and higher amount of nutrients availability to the plant does happen due to conventionally tilled soil and it may also lead to vigorous crop growth which is the result of rapid decomposition of organic source of N in deep soil layer. Mehdi *et al*. (1999) and Sainju and Singh (2001) concluded that the application of tillage practice in crop production system is important for the plant growth as it affects soil environmental components. It can also have its influence on the N availability and N pool status for maintaining proper nutrient levels in the soil environment system. The effect of tillage practices particularly on N, for the crop production, is therefore critical for the production of sustainable crops. The integration practices including appropriate N management and tillage practices, for sustainable crop production, thus presents a significant challenge. Therefore, currently, different tillage techniques are being used without evaluating their effects on physical, chemical and mechanical properties of soil. So there is a substantial interest and emphasis on the shift to conservation and no-tillage methods. Thus, this study was conducted to determine the effect of different tillage strategies on the movement of nitrate in the soil profile and to check response of some selected physical and mechanical properties of soil (moisture content, bulk density and penetration resistance). Hence, the objectives of this study were to estimate the effect of minimum tillage, conventional tillage and deep tillage strategies on the movement of nitrate (NO_3^-) in the soil profile and how some selected physical properties of soil (bulk density, particle density, porosity, infiltration rate, and soil saturated hydraulic conductivity) respond towards tillage.

II. Materials and Methods

A field experiment was conducted at research farms; Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad (31.25°N, 73.09°E), Pakistan during the year 2011-12 to examine the effect of different tillage strategies (minimum, conventional and deep tillage) on soil properties and crop growth with treatment plan (table 01). The climate of Faisalabad region is subtropical with an average precipitation of about 200 mm. The experiment was laid out in randomized complete block design (RCBD) having three repeats with net plot size of 7.38 m × 8.53 m. The maize variety Pioneer 30Y87 was cultivated as a test crop, with hand drill, keeping row to row (R×R) and plant to plant (P×P) distances of 30" and 9" respectively having seed rate of 25 kg ha^{-1}. Recommended doses of N, P and K (195, 140 and 105 kg ha^{-1}) were applied. Doses of nitrogen, phosphorous and potassium were applied using urea, di-ammonium phosphate and sulphate of potash (SOP). All the doses of phosphorous and potassium were given at the time of sowing while nitrogen was applied in three splits. Six (6) irrigations of 4" each were applied to the maize crop. To avoid the competition by weeds and keep the

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crop free from insects, pests and diseases, plant protection measures were carried out uniformly. Prior to experimentation, soil samples were collected and analyzed for physical and chemical properties (EC, pH, organic carbon, soil bulk density, soil saturated hydraulic conductivity and infiltration rate) using standard methods and procedures (table 02). Data collected, for all the parameters, was analyzed statistically using fisher's analysis of variance technique and least significant (LSD) test, at 5% probability level, was applied to compare the treatments' means (Steel *et al.*, 1997). Grain yield (ton ha^{-1}), plant biomass (ton ha^{-1}) and harvest index (%) were measured at maturity after harvesting. Leaf area index (LAI) was also recorded. Plant samples were also collected from each plot according to standard procedure. Soil bulk density (Mg m^{-3}), particle density, soil organic carbon (g kg^{-1}), infiltration rate (mm hr^{-1}), percent porosity (%), soil saturated hydraulic conductivity (mm hr^{-1}) and nitrate concentration (mg kg^{-1}) were measured after harvesting of the crop. After harvesting of the crop, soil samples were also collected from each plot following standard procedures. Soil bulk density was determined by core method, while soil particle density was determined using pycnometer method. Soil organic carbon was determined up to 1 m depth. Infiltration rate was measured with a double ring infiltrometer (Klute, 1986). Soil porosity was calculated using the following formula;

$$\textbf{Percent porosity } (\phi) = 1 - (\textbf{Bulk density / particle density}) \times 100$$

Soil saturated hydraulic conductivity was measured by Guelph permeameter (Model 2800 KI), taking three steady-state readings. Nitrate-N was measured by a spectrophotometric method (using chromo tropic acid). Bouyoucos hydrometer method was applied to examine percentage of sand, silt, and clay. After obtaining the extract from saturated soil paste with the help of vacuum pump EC_e was measured using a digital Jenway electrical conductivity meter (Dellavalle, 1992). Soil pH was recorded with a digital pH meter, after making a standard soil saturated paste and standardizing pH meter with 4.0 and 9.2 pH buffer solutions (Dellavalle, 1992).

III. Results and Discussion

Total grain yield (ton ha^{-1})

Grain yield was significantly affected by different tillage practices and highest grain yield (7.25 ton ha^{-1}) was obtained from those plots where deep tillage practices were done followed by conventional tillage practices and minimum grain yield (6.45 ton ha^{-1}) was noted where minimum tillage was practiced. However, regarding deep tillage which is 10.99% more value for the total grain yield then minimum tillage (table 03).

Total plant biomass (ton ha^{-1})

Highest plant biomass (39.82 ton ha^{-1}) was obtained from those plots where the deep tillage practices were performed that was followed by conventional tillage practices in maize and lowest total plant biomass (35.30 ton ha^{-1}) was recorded from minimum tillage practiced plots (table 03). As regards deep tillage practice which is 11.35% more value for the total plant biomass then minimum tillage practice.

Harvest index (%)

In maize the highest harvest index (18.73%) was recorded from those plots where the conventional tillage practices were done followed by minimum tillage treatment in maize and lowest harvest index (18.18%) was recorded from deep tillage practiced plots (table 03). As regards conventional tillage practices which presented 2.93% more value for the harvest index than deep tillage.

Leaf area index (LAI)

During maize growth period the highest value for leaf area index (7.18) was obtained from those plots where the conventional tillage practices were exercised followed by deep tillage practices while lowest leaf area index (6.47) was recorded from minimum tillage practiced plots (table 03). As of conventional tillage treatment which has 9.89% more value for the leaf area index then minimum tillage.

Soil bulk density (Mg m^{-3}): After harvesting of maize crop soil bulk density was recorded and greatest values for bulk density (Mg m^{-3}) were recorded (1.48 Mg m^{-3}) from those plots where

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minimum tillage practices were done followed by deep tillage treatment and lowest bulk density (1.40 Mg m^{-3}) was recorded from conventional tillage practiced plots (table 04). So conventional tillage treatment represented the 5.40% more value for the bulk density than minimum tillage treatment.

Particle density
After harvesting of maize crop soil particle density was noted and highest value for particle density (Mg m^{-3}) was measured (2.64 Mg m^{-3}) from those plots where minimum tillage practices were done (table 04) while conventional tillage and deep tillage treatments in maize showed similar results (2.63 Mg m^{-3}). While minimum tillage has 0.37% more value for particle density than conventional and deep tillage treatments.

Soil organic carbon (g kg^{-1})
After harvesting of maize crop soil samples were analyzed for determination of soil organic carbon and highest values for soil organic carbon were (3.57) recorded from those plots where the minimum tillage and deep tillage treatment practices were done. While the lowest value of soil organic carbon were (3.56) recorded from plots where conventional tillage practices were done (table 04). As regards minimum and deep tillage treatments show similar results for soil organic carbon which is 0.28% more value of soil organic carbon then conventional tillage.

Infiltration rate (mm hr^{-1})
After harvesting of maize crop soil infiltration rate was noted and greatest values for infiltration rate were recorded (25.35 mm $hour^{-1}$) from those plots where the conventional tillage practices were exercised followed by deep tillage treatment and lowest infiltration rate (22.95 mm $hour^{-1}$) was recorded from minimum tillage practiced plots (table 04). So the conventional treatment showed 9.46% more values for infiltration rate than minimum treatment.

Percent porosity (%)
After harvesting of maize crop percent porosity was recorded and greatest values of percent porosity (ϕ) were recorded (46.77) from those plots where the conventional tillage practices were done followed by deep tillage and lowest percent porosity (ϕ) (43.94) was recorded from minimum tillage practiced plots (table 04). Conventional tillage treatment have 6.05% more value than the minimum.

Soil saturated hydraulic conductivity (mm hr^{-1})
After harvesting of maize crop soil saturated hydraulic conductivity was measured and greatest soil saturated hydraulic conductivity (mm $hour^{-1}$) was recorded (57.92) from those plots where the deep tillage practices were done followed by conventional tillage treatment and lowest soil saturated hydraulic conductivity (mm $hour^{-1}$) (48.95) was recorded from minimum tillage practiced plots (table 04). So the deep tillage treatment showed 15.48% more value for soil saturated hydraulic conductivity than minimum treatment.

Nitrate (NO_3^-) concentration (mg kg^{-1}) in soil at 0-25 cm soil depth
Soil samples were collected at the depth of 0-25 cm after application of tillage treatment and before sowing of the maize crop, nitrate (NO_3^-) concentration was statistically non-significant however 3.61, 3.63 and 3.65 mg kg^{-1} were recorded in minimum tillage, conventional tillage and deep tillage respectively (Figure 01). After harvesting of maize, nitrate (NO_3^-) concentration in soil at the depth of 0-25 cm had highest value (5.63 mg kg^{-1}) from plots where the conventional tillage practices were done as followed by deep tillage treatment (5.42 mg kg^{-1}) and lowest nitrate (NO_3^-) in soil (5.38 mg kg^{-1}) was recorded from those plots where minimum tillage practice was done (Figure 02). As regards conventional tillage treatment which is 4.44% more value of nitrate (NO_3^-) concentration then minimum tillage. Figure 02 shows that there is variation in the nitrate concentration at the depth of 0-25 cm but statistically results are non-significant.

Nitrate (NO_3^-) concentration (mg kg^{-1}) in soil at 25-50 cm soil depth
Before sowing of maize, nitrate (NO_3^-) concentration was statistically non-significant at the depth of 25-50 cm, however 3.92, 4.05 and 4.32 mg kg^{-1} were recorded in minimum tillage, conventional tillage and deep tillage respectively (Figure 01). After harvesting of crop, the highest value for the nitrate (NO_3^-) concentration was (7.09 mg kg^{-1}) recorded at the depth of 25-50 cm in soil from plots where

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minimum tillage was done followed by plots having conventional tillage practices, while deep tillage treatment plots showed lowest value (5.86 mg kg^{-1}) regarding nitrate (NO_3^-) concentration. As minimum tillage treatment which is 17.34% more value of nitrate (NO_3^-) concentration then deep tillage. Therefore figure 02 shows the results are significant.

Nitrate (NO_3^-) concentration (mg kg^{-1}) in soil at 50-75 cm soil depth

Before sowing of maize, nitrate (NO_3^-) concentration at the depth of 50-75 cm was recorded highest (7.37 mg kg^{-1}) in plots where minimum tillage practices were done followed by plots getting deep tillage practice (6.92 mg kg^{-1}) and the lowest value for the nitrate (NO_3^-) concentration was (6.76 mg kg^{-1}) recorded from plots where conventional tillage practice was done. Figure 01 shows that nitrate concentrations are statistically significant under different tillage practices. After harvesting the crop, at the depth of 50-75 cm in soil the highest value for nitrate (NO_3^-) concentration was (10.37 mg kg^{-1}) recorded in those plots where the minimum tillage practices (9.94 mg kg^{-1}) was done followed by deep tillage treatment practiced plots and the lowest value for the nitrate (NO_3^-) concentration was (9.13 mg kg^{-1}) recorded from plots where the conventional tillage practice was done in maize. As minimum treatment which is 11.95% more value of nitrate (NO_3^-) concentration then conventional tillage treatment. Therefore, figure 01 shows that nitrate concentrations are statistically significant under different tillage practices at the depth of 50-75 cm.

Nitrate (NO_3^-) concentration (mg kg^{-1}) in soil at 75-100 cm soil

Before sowing of maize, nitrate (NO_3^-) concentration at the depth of 75-100 cm was recorded highest (3.25 mg kg^{-1}) in plots where minimum tillage practices were done followed by deep tillage treatment practiced plots (2.95 mg kg^{-1}) and the lowest value for the nitrate (NO_3^-) concentration was (2.89 mg kg^{-1}) recorded from those plots where conventional tillage practices were done. Figure 01 shows that nitrate concentrations are statistically significant under different tillage practices. At the depth of 75-100 cm in soil the highest value for the nitrate (NO_3^-) concentration was (11.24 mg kg^{-1}) recorded in plots where deep tillage practices were done followed by conventional tillage treatment practiced (8.63 mg kg^{-1}) plots and the lowest value for the nitrate (NO_3^-) concentration was (6.21 mg kg^{-1}) recorded from plots where minimum tillage was done in maize. As deep tillage treatment which is 44.39% more value of nitrate (NO_3^-) concentration then minimum tillage treatment. As Figure 02 shows that nitrate concentrations are statistically significant under different tillage practices.

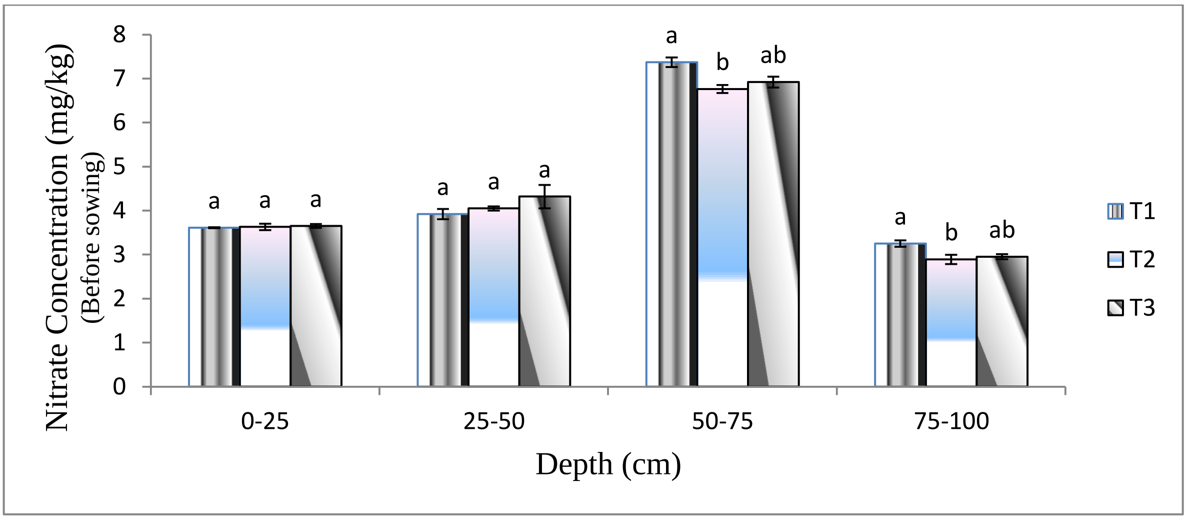

Figure 01. Effect of different tillage strategies on nitrate (NO_3^-) concentration in different depths of the soil before sowing of maize (*Zea mays* L.) crop.

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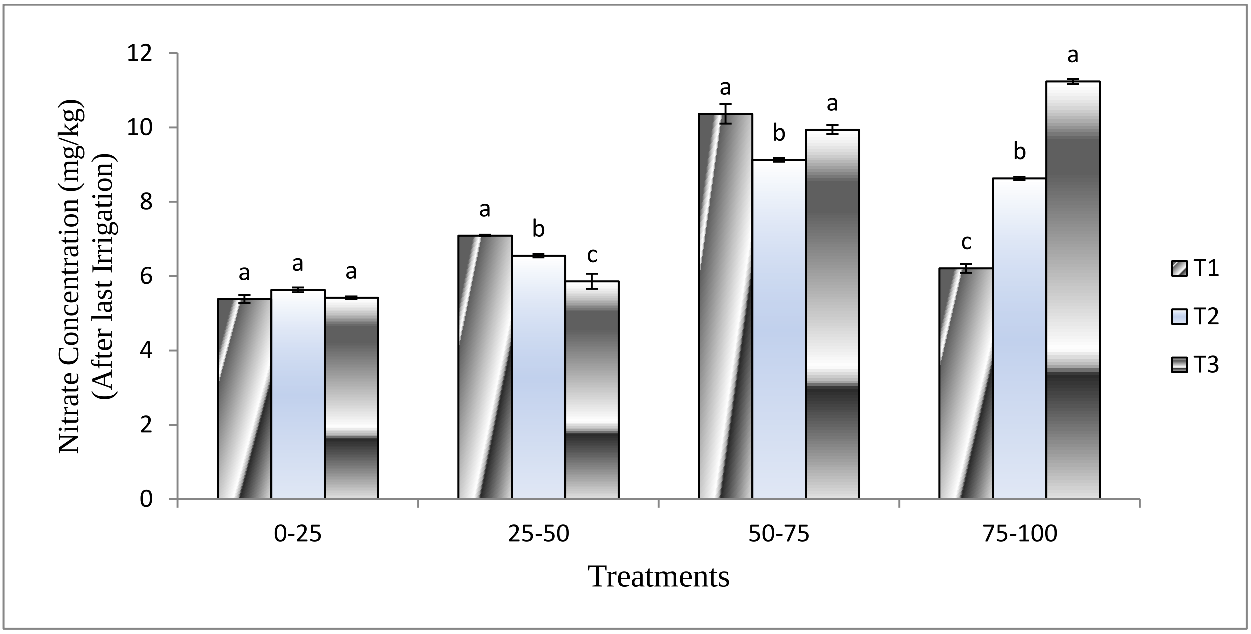

Figure 02. Effect of different tillage strategies on nitrate (NO_3^-) concentration in different depths of the soil after 6th irrigation during maize (*Zea mays* L.) crop.

Table 01. Treatments

	Treatment	Description
T_1	Minimum Tillage (MT)	(2 ploughing + 2 planking)
T_2	Conventional Tillage (CT)	(1 disc + 2 planking + 2 ploughing)
T_3	Deep Tillage (DT)	(1 MBP + 2 planking + 2 ploughing)

Table 02. Physico-chemical properties of experimental soil

Determination	Values
Chemical analysis	
pH	7.83
EC (dS m^{-1})	1.73
Soil bulk density (Mg m^{-3})	1.43
Total Porosity (%)	45.40
Soil Infiltration Rate (mm hr^{-1})	25.40
Soil Hydraulic Conductivity (mm hr^{-1})	53.07
Total Nitrogen (mg kg^{-1})	0.52
Available phosphorus (mg kg^{-1})	9.46
Available Potassium (mg kg^{-1})	114.08
Soil Organic Carbon (g kg^{-1})	2.54
Physical analysis	
Sand (%)	46
Silt (%)	30
Clay (%)	25
Textural Class	Sandy clay loam

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Table 03. Effect of different tillage strategies on agronomic parameters of maize

Treatment	Grain yield (ton ha^{-1})	Plant biomass (ton ha^{-1})	Harvest index (%)	Leaf area index (LAI)
Minimum Tillage	6444.8 B	35300 C	18.256 B	6.4667 C
Conventional Tillage	7224.8 A	38566 B	18.732 A	7.1767 A
Deep Tillage	7241.2 A	39822 A	18.183 B	6.8767 B
LSD (0.05)	*164.74*	*180.96*	*0.3497*	*0.1739*

Table 04. Effect of different tillage strategies on soil properties

Treatment	Soil bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Soil organic carbon (g kg^{-1})	Infiltration rate (mm hr^{-1})	Percent porosity (%)	Soil saturated hydraulic conductivity (mm hr^{-1})
Minimum Tillage	1.28 a	2.64	3.57	22.95	43.943 b	48.95 B
Conventional Tillage	1.40 b	2.63	3.56	25.35	46.773 a	57.71 A
Deep Tillage	1.41 b	2.63	3.57	25.27	46.39 a	57.92 A
LSD (0.05)	*0.0507*	*NS*	*NS*	*NS*	*1.3531*	*4.4836*

Table 05. Effect of different tillage strategies Nitrate (NO_3^-) concentration (mg kg^{-1}) in soil at different soil depth after harvesting of maize crop

Treatment	0-25 (cm)	25-50 (cm)	50-75 (cm)	75-100 (cm)
Minimum Tillage	5.38	7.09 A	10.37 A	6.21 C
Conventional Tillage	5.42	6.55 B	9.13 B	8.63 B
Deep Tillage	5.42	5.86 C	9.94 A	11.24 A
LSD (0.05)	*NS*	*0.3909*	*0.7996*	*0.2585*

Discussion

Gomma *et al.* (2002) also found similar results. They conducted field experiments and studied maize grain yield under different tillage systems and highest grain yield was obtained by conventional tillage treatment. Tillage practice improved the availability of nutrients and water for efficient uptake that ultimately resulted in high grain yield. The results are in line with the findings of Gul *et al.* (2009). They conducted an experiment and their results were similar with the present study that significantly highest biological yield was obtained by practicing conventional tillage as compared to no tillage or reduced tillage and minimum tillage practices. This may be due to availability of nutrients and more production of root hairs because of well tilth soil favorable for root proliferation and it may also have facilitated nutrient uptake. Habtegebrial *et al.* (2007) also found similar results. They reported that various nitrogen sources and different tillage practices have significant influence on grain yield of maize. Higher yields can be achieved by conventional and deep tillage practices as compared to reduced tillage. Establishment of crop is better and conventional tillage might have contributed to higher grain yield and higher leaf area in these plots as compared to reduced tillage plots. It is also reported that tillage practices are also involved in retention of moisture in the soil and residues management on the soil surface which ultimately cause increase in maize yield. Habtegebrial *et al.* (2007) reported that various nitrogen sources and different tillage practices have significant influence on biological yield of maize and ultimately affect leaf area of crop. Conventional tillage might have contributed to higher grain yield, higher leaf area and better establishment of crop in these plots. The results are similar to the findings of Khan *et al.* (1999). They studied the effect of different tillage practices on soil physical properties and concluded that conventional tillage affected soil bulk density and also caused decrease in soil penetration resistance which resulted in increased drainage and

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nitrate leaching. Jabro *et al.* (2010) also found similar results; they studied that deep tillage resulted in lowering soil penetration resistance by manipulating and loosening of the deeper soil layer and ultimately resulted in more absorption of mobile nutrients from deeper soil depth. Bulk density and soil strength were relatively lower in ridge sowing plots as compared to seed drill and seed broadcasting plots. The results are similar to the findings of Bahadar *et al.* (2007) who studied the effect of tillage on soil organic carbon and reported after an experiment that generally it is believed that tillage practices are the primary cause of losing soil organic matter owing to soil disturbance. This problem can be solved by changing preferences as tillage known as reduced and minimum tillage having less destructive effects as compared to the conventional one. Basamba *et al.* (2006) found similar results who concluded after an experiment that soil organic soil and total C, N and P were generally better under no-till as compared to minimum-tilled soils. While P fractions were also generally higher under no-till treatments. Results from this study indicated that rotational systems (maize–soybean green manure and maize-pastures) improved the soil conditions to implement no-till or minimum tillage systems. Aulakh and Malhi (2005) also studied same results that soluble nutrients move into the soil profile through infiltered water into the macro pores and in case of no tillage practice there is a little disturbance in soil structure and macro pores come in contact with soil surface. Rashidi and Keshavarzpour (2007) also studied same results; they reported that conventional tillage also has impact by producing loose and finer soil structure as compared to no-tillage and conservation tillage systems and results in decreased water movement into the soil profile thus decreased nitrate leaching. According to the Aulakh and Malhi (2005) soluble nutrients move into soil profile through infiltration water into the macro pores. In case of no tillage practice there is a little disturbance in soil structure and macro pores come in contact with soil surface. Thus, these macro pores provide a path for water flow to full depth into the soil profile so nitrate leaching is more in case of no tillage as compared to other tillage practices which disturb the soil structure and ultimately water flow is hindered. Kanwar *et al.* (1985) concluded that there is 100% more water movement into the soil profile in no tillage as compared to conventional tillage which resulted in slightly greater concentration of nitrate leached beyond root zone in no tillage as compared with conventional tillage. Bahadar *et al.* (2007) reported after an experiment that generally it is believed that tillage practices are the primary cause of losing soil organic matter which is due to soil disturbance. This problem can be solved by changing preferences as tillage known as reduced and minimum tillage having less destructive effects as compared to conventional tillage. Halvorson *et al.* (2001) also studied same results that soil tillage practice is one of the most important factors which has its influence on crop yield, soil physical properties and ultimately on NO_3^- movement into the soil profile and nitrogen uptake. Benbi *et al.* (1991) studied that tillage systems can affect many soil properties, which ultimately alter the soil environment and consequently impact on root growth and distribution and crop yield also.

IV. Conclusion

Tillage is an important factor which plays a decisive role in crop productivity, availability of nutrients and water. It affects soil physical and, up to some extent, chemical properties also. Minimum tillage enhances the availability of nutrients to the plants. It, not only, affects different soil properties like soil bulk density, particle density, soil organic carbon, infiltration rate, percent porosity and soil saturated hydraulic conductivity but also is considered a phenomenon more appropriate to minimize leaching of nutrients along with water. Leachates are tantamount to be pollutants of underground water because they deteriorate the quality of underground water which ultimately affects the plant as well as human life.

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