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# EFFECT OF VARIOUS TILLAGE PRACTICES ON SOIL PROPERTIES AND MAIZE GROWTH

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**Abstract**

Appropriate tillage practices are vital for good tilth that is pre-requisite for aggregate formation, soil aeration, better root development and plant growth. A field experiment of maize was carried out at the experimental site of Sindh Agriculture University Tandojam during two consecutive growing seasons 2009 and 2010. A randomized complete block design with three treatment conventional tillage (CT), reduced tillage (RT) and no tillage (NT) was used in the study. Significant differences between tillage treatments were observed in the soil properties, growth and root development of plants. The NT treatment retained higher soil water contents (15.8 and 16.0%) measured at 0-20 cm depth during 2009 and 2010, respectively. Likewise, the soil bulk density (1.4 and 1.4 $cm^{-3}$) was higher at this depth consequently; it resulted in greater soil strength (81 N $m^{-2}$ and 79 N $m^{-2}$) during 2009 and 2010, respectively. The negative and significant correlations were recorded between root dry weight and soil strengths. On the other hand, positive and significant relationship of root dry weight with mean total dry matter production and LAI was observed. Moreover, the root development related observations were significantly enhanced under CT as compared to RT and NT treatments. The results indicate that conventional tillage improve maize growth and root development by improving soil properties.

**Key words:** Correlations; Dry matter; Root development; Soil strength.

## Introduction

Conventional tillage transforms the properties of soil that conserves soil water (Jin *et al*., 2011;Putte *et al*., 2010); enhances the carbon amount in soil as well as enhance the microbial biomass in the topsoil (Babujia *et al*., 2010); decreases the soil temperature in tropical regions and improves biodiversity of soil (Adl *et al*., 2005). With the increase of organic matter content in top layer of soil, the soil fertility and productive capability improves that in turn results in greater yields and plant health (Chandio *et al*., 2012).

Several types of conservation tillage such as minimum tillage, incomplete tillage, reduced tillage, and no tillage, etc. are practiced across the world. According to data gathered by the Conservation Technology Information Center (Anon., 2004) about 40.7% of total crop land on 45.44 million hectares was under conservation tillage system. Of that, no tillage was used on about 23.6% of land in the United States. However, the implementation of this practice is based on soil properties including type, compaction, water retention and other factors. Generally reduced or no tillage provides minimum disturbance of the soil and leaves the surface covered with crop residues. The crop residues are not absolutely mixed and most or all of them remain on the top of soil surface rather being plowed into the soil. They maintain a constant cover of organic material on the surface, which allows maximum infiltration of rainfall and irrigation, retains water and minimizes runoff, reduces erosion and sedimentation and improves water quality. The new crops are planted into these stubbles or small strips of tilled soil.

It is whispered that soil compaction, flooding and poor drainage conditions are formed under reduced tillage and zero tillage practices. Compaction increases water holding capacity of the soil, hence crops grown under reduced tillage and zero tillage use water more efficiently as compared to conventional tillage. Nevertheless, compaction and crusting prevent root penetration into the soil that results in poor plant growth and development finally crop yields are reduced.

Information on the impacts of tillage showed that root growth of the grain crop is least affected while, the effect of tillage practice on root growth and development under zero tillage is related to depth of tillage implement. The roots under no tillage system accumulate to a greater extent in the top 5 cm depth as compared under conventional tillage system where roots move toward deeper depths. Wulfsohn ***et al.*** (1996) observed a similar pattern. According to them, plant roots concentrated near the soil surface under conservation tillage due to improved moisture condition and surface mulch. The crops having fibrous or shallow root system such as wheat face the management challenges especially during periods of extreme drought when surface-water is limited.

Tillage effects on the soil nutrient status and root growth have been reported in the literature (Gregory, 1994; Crozier ***et al.***, 1999; Marwat ***et al.,*** 2007). Reduced tillage often affects the immoveable phosphorous, thus it induces higher root length distribution in the top-most layer. In general, the root length distribution is greater at the outer side of a row than at the mid-portion of the row (Rubino & Franchi, 1990). Due to contradictory findings there is needed to investigate the impacts of tillage on soil properties, root distribution and yield of maize crops. Hence, this study was designed to investigate the correlations studies among soil properties, growth, and root development under different tillage systems (conventional tillage, reduced tillage and no-tillage). The measurements on these parameters were taken at regular intervals to establish differences among three tillage treatments.

## Methodology

**Experimental site:** The experiments were conducted at the Latif Experimental Farm of Sindh Agriculture University Tandojam during 2009 and 2010. The experiment area is located at one km from the main campus of Sindh Agriculture University Tandojam. The experimental site lies at 25.42°N latitude and 68.53°E longitude while the elevation of land is about 12 m above the sea level.

**Crop husbandry:** Each plot measured 0.54 ha (5400 $m^2$). The main plot (60 × 90 m) was divided into three blocks each of size 60 × 30 m. Each block, separated by 2 m plot buffer, and was further divided into three sub-plots measuring 30 × 20 m. This combination resulted in a total of nine experimental units. Three treatments used in this study i.e. conventional tillage (CT) was performed using a combination of moldboard plow and cultivator, while the reduced tillage (RT) comprised a regular double action disc harrow operated twice, and no tillage (NT). The plots under conventional tillage were plowed to a depth of 25 cm and maize was sown using a mechanical drill. In the reduced tillage plots, two passed with a disc harrow were used to till to a depth of 15 cm. Under no tillage treatment, direct seeding was done during both study years. The weeds were controlled manually and all other agronomic treatments were kept uniform in each plot.

Experiment was sown at the end of July during 2009 and same experiment was repeated in following year. The recommended dose of N, P and K (250, 125 and 125 kg $ha^{-1}$, respectively) was applied. The 1/3rd dose of nitrogen was applied at the time of sowing and the remaining nitrogen was applied in two split doses. The phosphorus, in the form of triple super phosphate (TSP), and potassium in the form of sulphate of potassium (SOP) were applied as a single dose at the time of sowing. The maize variety locally known as Akbar was sown at a row spacing of 0.15 m with a seed rate of 75 kg $ha^{-1}$. This allowed 40 rows in each unit under each replication. Thinning was done at $3^{rd}$ to $4^{th}$ leaf stage to maintain the plant population. The outer 5 rows in each replication were used as buffer between plots. All other agronomic treatments were kept uniform in each plot. Harvesting was manually done during$1^{st}$ week of November, both in 2009 and 2010. Meteorological data were collected from the meteorological observatory of Drainage Research Centre, Sindh Agriculture University Tandojam. The meteorological station is situated at a distance of about two kilometers from the experimental site.

## Observations

**Soil properties:** Soil samples were collected from 0-21 and 22-42 depths before and after tillage treatments for the determination of soil water contents, soil bulk density and soil strength. The analytical procedures and methods used to determine various physical properties are described as under.

**Soil water content:** Soil water content on dry weight basis was determined at three randomly selected locations under each replication at 0-21 and 22-42 cm depths. Initially, the weight of wet samples was taken using an electrical balance then the samples were dried for 24 hours in an oven maintaining a temperature of 105°C. The dried soil samples were re-weighed in the electrical balance and the dry weight was recorded. The soil water content was calculated using the following formula, RNAM, (1995).

$$MC = \frac{Ww - Wd}{Wd} \times 100$$

where

MC = Moisture content (%)
Ww = Weight of wet soil (g)
Wd = Weight of dry soil (g)

**Bulk density of the soil:** Bulk density was determined at three randomly selected locations under each replication for 0-21 and 22-42 cm depths. Samples were collected using a core sampler at each depth. The diameter of core sampler was measured with a vernier caliper. The samples were placed for 24 hours in an oven that maintained a temperature of 105°C. The dried soil samples were weighed in the electrical balance and the dry weight was recorded. The bulk density of soil was then calculated using the following formula, RNAM, (1995).

$$\rho = \frac{M}{V}$$

$$V = \frac{\pi}{4} D^2 L$$

$$\rho = \frac{4M}{3.142\ D^2 L}$$

where,

ρ = Soil bulk density ($g/cm^3$)
M = Dry soil mass in a core sampler (g)
V = Volume of cylindrical core sampler ($cm^3$)
D = Diameter of cylindrical core sampler (cm)
L = Length of cylindrical core sampler (cm)

**Soil strength:** Soil strength (Penetration resistance) is the ability or capacity of a particular condition to resist or endure an applied force. Penetration resistance is a composite parameter that involves several independent properties of a soil but it is generally considered to reflect the strength of the soil. To measure penetration resistance, a simple instrumented probe known as a penetrometer is pushed into the soil and the force is observed in relation to penetration depth. Penetrometer consists of a T-handle, penetration rod, proving ring of 1-kN capacity with dial indicator, and a removable cone point. The penetrometer consists of a 30$^o$ cone having 3.23 cm$^2$ (1/2 in$^2$) base area, and 46 cm (18″) extension rod, a proving ring dial indicator and handle. When the cone was forced into the ground, the amount of force required for penetrating the cone slowly through the soil was as indicated on the dial. This force was considered an index of the shearing resistance of the soil and called the "cone index". The instrument was kept vertical during operation. The range of the dial is 150 pounds load and is marked 0-207 N cm$^{-2}$ (0-300 lb. In$^{-2}$).

The soil strength (Penetration resistance) was directly recorded prior and after tillage treatments. The data was collected from three randomly selected locations in each plot for the depths (0-21 cm) and (22-42 cm) (Busscher *et al.,* 1986). The cone index was calculated by using the following equation:

$$CI = F/A$$

where,

CI = Cone index, N cm$^{-2}$ or lb in$^{-2}$

F = Normal force, N or lb

A = Base area of the cone, cm$^2$ or in$^2$

**Root development:** Number of roots plant$^{-1}$, root length and root dry weight was measured at crop maturity stage at three locations for each replicated plot. A total of nine plants for root measurements in a treatment were used. The root length was measured from the base of stem to the tip of root. Number of roots and length of each were determined by digging hole to 120 and 180 cm depth in each plot. The soil block with plant was soaked in water for 24 hr. Roots were carefully separated from adhering organic matter and soil particles. After cleaning, the root length was measured and number of roots was counted. The dry weight of roots (g) was taken by separating the roots from the base of the stem. After oven drying, the roots of three plants taken from each plot were weighted and average was determined.

**Plant growth:** In each plot, 5 plants were randomly selected for harvest to ground level at the intervals of 20-days. The fresh and dry weights of the plants were determined separately by drying the subsamples in an oven (Model: WFO-600ND, Tokyo Rikakikai Co.) at 70 °C until a constant weight was reached. A subsample of 10 g of leaf lamina was taken at 20-day intervals to calculate leaf area with a leaf area meter (CI-202, CID Bio-Science). The leaf area index (LAI) was calculated using a standard formula (Watson, 1952).

$$LAI = \frac{LA}{GA}$$

where LA = Leaf area GA = Ground area

Similarly, the oven-dried samples were used for total dry matter calculations.

**Statistical analysis:** The effects of tillage treatments on the various parameters were evaluated by ANOVA using the SAS statistical software (Anon., 2004). When F-values were significant, the least significant difference (LSD) test was used for comparing treatment means. In all cases, differences were considered to be significant if $p<0.05$. Pearson's correlations were drawn between various parameters using Microsoft Excel Program.

## Results

The meteorological data on daily maximum and minimum temperature, daily sunshine and daily rainfall is plotted in Fig. 1. The data reveals that more rainfall was recorded during the 2010 as compared to 2009. While maximum temperature i.e., 45˚C was recorded during maize growing season of 2009. On the other hand, minimum temperature was noted during maize growing season of 2009 as compared to 2010. Moreover, maximum sunshine was recorded during the growing season of 2009.

**Soil water content at different depth:** The effect of tillage treatments on soil water content (SWC) was determined during maize growing seasons 2009 and 2010. The soil water content at 0-21 cm depth before tillage was measured during two maize growing seasons i.e. 2009 and 2010 and the data are given in Table 1. Results indicated non-significant effects of treatments on SWC before tillage. The CT, RT and NT gave similar SWC results during 2009 (16.0, 16.0 and 15.7%) and 2010 (16.1, 16.7 and 16.0%), respectively. While the SWC was measured at 0-21 cm soil depth after tillage treatments during 2009 and 2010 and the data given in Table 1 showed that different tillage treatment had significant effects on soil water content. The CT, RT and NT gave significantly different soil water content results during 2009 (14.8, 14.1 and 15.8%) as well as during 2010 (14.9, 14.6 and 16.0%). During both study years, the soil water content under the no tillage system was greater than conventional and reduced tillage treatments.

The soil water contents measured in the 22-42 cm soil depth after tillage treatments during growing seasons 2009 and 2010 are given in Table 1. Non-significant effects of tillage treatments on soil water content were observed. The CT, RT and NT gave similar soil moisture content results during 2009 (17.7, 17.0, and 17. 7%) as well as during 2010 (18.1, 17.4 and 18.0%), respectively. The soil water content was measured at 22-42 cm depth after tillage treatments during 2009 and 2010 and the data are presented in Table 1. Results showed that tillage treatments had significant effect on soil water content. The conventional tillage and reduced tillage treatments gave similar soil water content results during 2009 (15.4 and 14.8%) as well as during 2010 (15.3 and 14.9%), respectively. The water content under no tillage treatment was remarkably higher during 2009 (16.5%) and 2010 (16.9%) than conventional and reduced tillage treatments.

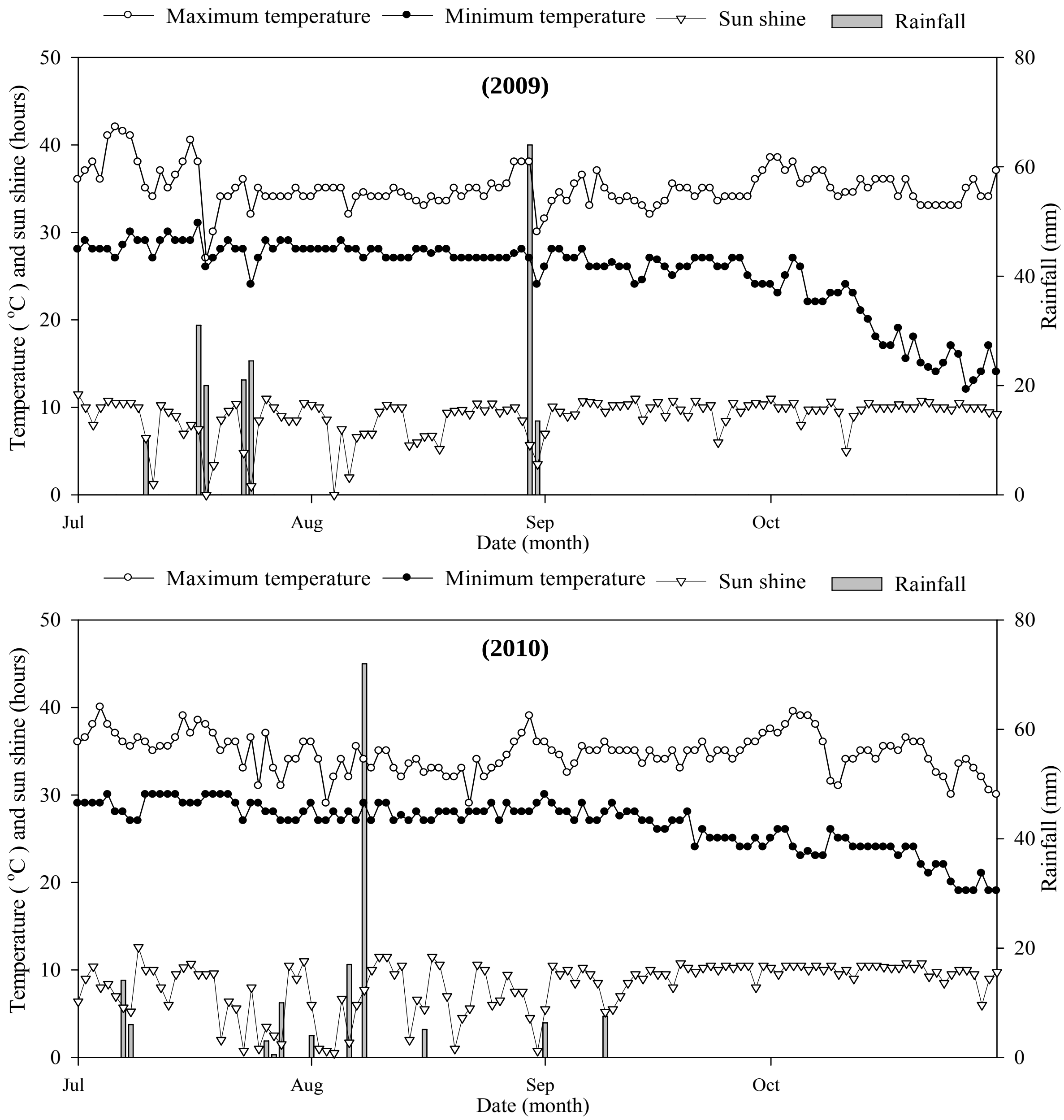


Fig. 1. Daily temperature, sunshine and rainfall data of experimental site during growing seasons 2009 and 2010

**Table 1. Impact of various tillage practices on soil water contents (%) during 2009 and 2010.**

| Tillage treatments | SWC before tillage at 0-21 cm | | SWC after tillage at 0-21 cm | | SWC before tillage at depth 22-42 cm | | SWC after tillage at depth 22-42 cm | |
|---|---|---|---|---|---|---|---|---|
| | Year | | Year | | Year | | Year | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 |
| $T_1$ (conventional tillage) | 16.0 | 16.1 | 14.8 b | 14.9 b | 17.7 | 18.5 | 15.4 b | 15.3 b |
| $T_2$ (reduced tillage) | 16.0 | 16.7 | 14.1 c | 14.6 c | 17.0 | 17.4 | 14.7 b | 14.9 b |
| $T_3$ (no-tillage) | 15.7 | 16.0 | 15.8 a | 16.0 a | 17.7 | 18.0 | 16.5 a | 16.9 a |
| LSD | - | - | 0.33 | 0.21 | - | - | 0.8 | 0.5 |
| Significance | NS | NS | ** | ** | NS | NS | ** | ** |

Within columns, means followed by the same letter are not significantly different

*, ** = Significant at 5% and 1%, respectively, NS= Non-significant, SWC = Soil water contents LSD = least significant difference

**Soil bulk density at different depth:** The soil bulk density before tillage operations during the 2009 and 2010 two maize growing seasons was determined at 0-21 cm soil depth and the data are given in Table 2. Results showed non-significant effects of tillage treatments on soil bulk density before tillage treatments but significantly affected by after tillage practices. The maximum soil moisture was recorded in no tillage which 10.4% over to conventional tillage. The CT, RT and NT gave similar soil bulk density results during 2009 (1.5, 1.5, and 1.5 g/cm$^3$) as well as during 2010 (1.5, 1.5 and 1.5 g/cm$^3$), respectively. The soil bulk density after tillage treatments was measured at 0-21 cm soil depth and the data are shown in Table 2. Significant impacts of tillage treatments on soil bulk density were observed after tillage for both study years. Under reduced tillage and no tillage, the soil bulk density showed similarity during 2009 (1.3 and 1.4 g/cm$^3$) being the greatest under no tillage, while under conventional tillage the soil bulk density was the lowest (1.3 g/cm$^3$). During 2010, the soil bulk density was markedly higher (1.4 g/cm$^3$) under no tillage, followed by reduced tillage (1.3 g/cm$^3$) and the lowest soil bulk density (1.3 g/cm$^3$) was observed under conventional tillage.

While the soil bulk density before tillage treatments during two maize growing seasons i.e. 2009 and 2010 was measured at 22-42 cm soil depth and the data are given in Table 2. Results demonstrated non-significant effects of tillage treatments on soil bulk density. The CT, RT and NT gave similar soil bulk density results during 2009 (1.6, 1.6, and 1.6 g/cm$^3$) as well as during 2010 (1.5, 1.5 and 1.6 g/cm$^3$), respectively. The soil bulk density after tillage treatments during 2009 and 2010 was determined at 22-42 cm soil depth and the data are presented in Table 2. The data indicated the significant impact of tillage treatments on soil bulk density during both the study years. Under reduced and no tillage, the soil bulk density showed similarity during 2009 (1.4 and 1.4 g/cm$^3$) being the highest under no tillage, while under conventional tillage the soil bulk density was the lowest (1.3 g/cm$^3$). During 2010, the soil bulk density was markedly higher (1.4 g/cm$^3$) under no tillage, followed by reduced tillage (1.4 g/cm$^3$) and the lowest soil bulk density (1.3 g/cm$^3$) was determined under conventional tillage.

**Soil strength at different depth:** The soil strength before tillage operations during 2009 and 2010 in maize fields was analyzed at 0-21 cm soil depth and the data are given in Table 3. Results showed non-significant effects of tillage treatments on soil strength. The maximum soil strength i.e. 97 N m$^{-2}$ and 96 N m$^{-2}$ was determined under reduced tillage during 2009 and 2010, followed by conventional tillage i.e. 91 N m$^{-2}$ and 90 N m$^{-2}$ and the lowest soil strength (85 N m$^{-2}$ and 83 N m$^{-2}$) was observed under no tillage.

The soil strength after tillage treatments for maize growing seasons 2009 and 2010 was analyzed at 0-21 cm soil depth and the data are given in Table 3. Results showed significant impact of tillage treatments on soil strength after tillage during both study years. Under no tillage and reduced tillage, the soil strength showed similarity during 2009 (81 N m$^{-2}$ and 73 N m$^{-2}$) the greatest being under no tillage, while under conventional tillage the soil strength was the lowest (59 N m$^{-2}$). During 2010, the soil shear strength was markedly higher (79 N m$^{-2}$) under no tillage, followed by reduced tillage (68 N m$^{-2}$) and the lowest soil strength (55 N m$^{-2}$) was recorded under conventional tillage. The soil strength before tillage treatments for maize sowing at 22-42 cm soil depth during 2009 and 2010 was examined and the data (Table 3) showed non-significant impacts of tillage treatments on soil strength. Relatively greater soil shear strength i.e. 138 N m$^{-2}$ was determined under both reduced tillage and no tillage treatments, while 136 N m$^{-2}$ was observed under conventional tillage during 2009. During 2010soil strength (143 N m$^{-2}$) was higher as compared to 2009 under reduced tillage and no tillage treatments, while it was 133 N m$^{-2}$ under conventional tillage. The soil strength was examined at 22-42 cm soil depth after tillage treatments during 2009 and 2010 and the data (Table 3) indicated significant impact of tillage treatments on soil strength during both the study years. Soil strength (137 N m$^{-2}$ and 133 N m$^{-2}$) was greater under no tillage, followed by reduced tillage (128 N m$^{-2}$ and 124 N m$^{-2}$); while the lowest soil strength (118 N m$^{-2}$ and 114 N m$^{-2}$) was determined under conventional tillage during 2009 and 2010, respectively.

**Leaf area index:** The crop growth was effected by the different tillage treatments during both study years. The increase in LAI of maize plant was significantly affected by different tillage treatments. Fig. 2 showed the development of LAI affected by the different tillage treatments. Maximum LAI was recorded under conventional tillage treatment 80 days after sowing during 2009 and 2010, respectively. While under reduce tillage treatment, the minimum LAI was recorded during growing season 2009 and 2010 under zero tillage treatment. After the 80 days of sowing, the LAI started decreasing gradually up to harvesting. The increase was greater during 2009 as compared to 2010.

**Table 2. Impact of different tillage practices on soil bulk density (g/cm$^3$) during 2009 and 2010**

| Tillage treatments | SBD before tillage at depth 0-21 cm | | SBD after tillage at depth 0-21 cm | | SBD before tillage at depth 22-42 cm | | SBD after tillage at 22-42 cm depth | |
|---|---|---|---|---|---|---|---|---|
| | Year | | Year | | Year | | Year | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 |
| $T_1$ (conventional tillage) | 1.5 | 1.5 | 1.3 b | 1.3 c | 1.6 | 1.5 | 1.3 c | 1.3 c |
| $T_2$ (reduced tillage) | 1.5 | 1.5 | 1.3 b | 1.3 b | 1.6 | 1.5 | 1.4 b | 1.4 b |
| $T_3$ (no-tillage) | 1.5 | 1.5 | 1.4 a | 1.4 a | 1.6 | 1.6 | 1.4 a | 1.4 a |
| LSD | - | - | 0.04 | 0.03 | - | - | 0.01 | 0.02 |
| Significance | NS | NS | * | ** | NS | NS | ** | * |

Within columns, means followed by the same letter are not significantly differ

*, ** = Significant at 5% and 1%, respectively, NS= Non-significant, SBD = Soil bulk density, LSD = least significant difference

**Table 3. Impact of tillage different practices on soil strength (N $m^{-2}$) during 2009 and 2010**

| Tillage treatments | Soil strength before tillage at 0-21 cm depth | | Soil strength after tillage at 0-21 cm depth | | Soil strength before tillage at 22-42 cm depth | | Soil strength after tillage at 22-42 cm depth | |
|---|---|---|---|---|---|---|---|---|
| | Year | | Year | | Year | | Year | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 |
| $T_1$ (conventional tillage) | 91 | 90 | 59 b | 55 c | 136 | 133 | 118 c | 114 c |
| $T_2$ (reduced tillage) | 97 | 96 | 73 a | 68 b | 138 | 143 | 128 b | 124 b |
| $T_3$ (no-tillage) | 85 | 83 | 81 a | 79 a | 138 | 143 | 137 a | 133 a |
| LSD | - | - | 8.8 | 6.3 | - | - | 5.04 | 7.12 |
| Significance | NS | NS | ** | ** | NS | NS | ** | ** |

Within columns, means followed by the same letter are not significantly differ

*, ** = Significant at 5% and 1%, respectively, NS= Non-significant, LSD = least significant difference

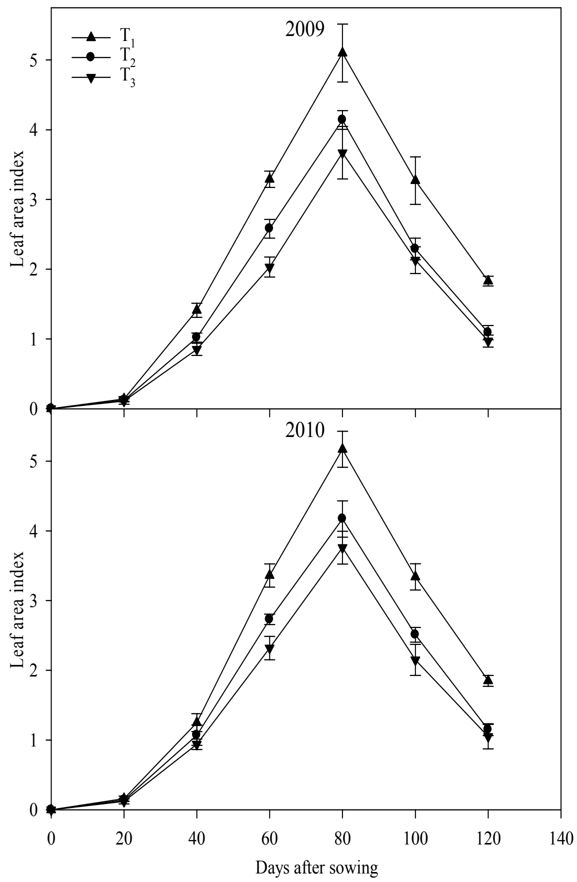


Fig. 2. Impact tillage practices on leaf area index of maize during 2009 and 2010.

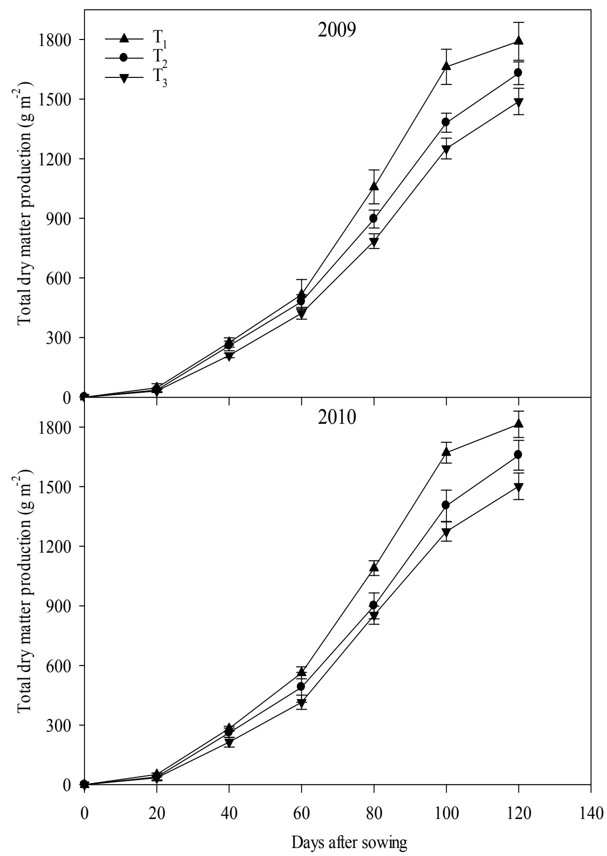


Fig. 3. Impact tillage practices on dry matter production of maize during 2009 and 2010.

**Total dry matter production:** The total dry matter production under different tillage treatments is shown in (Fig. 3). The total dry matter production was recorded at an interval of 20 days and it continued till harvest. The statistical analysis of results revealed that dry matter production was highly significant. The maximum total dry matter was recorded under conventional tillage treatment (Fig. 3) during 2009 and 2010 and it was followed by reduced tillage treatment. However, minimum total dry matter was recorded under zero tillage treatment during 2009 and 2010. Moreover the increase in total dry matter production was greater during the 2010 as compared to 2009 (Fig. 3).

**Root development:** The root length of maize plants as influenced by various tillage treatments for the 2009 and 2010 two maize cropping seasons is presented in Table 4. Tillage treatments affected the root length of maize plants significantly during both the seasons. During 2009 and 2010 seasons, the maximum root length (25.7 and 26.7 cm) was recorded under conventional tillage, and a reduction in root length was recorded in reduced tillage

(22.3 and 23.0 cm) and no tillage treatments (21.0 and 21.0 cm), respectively. The seasonal comparison indicated that during 2010 the root length was relatively greater than the root length in different tillage treatments during year 2009. The number of roots plant$^{-1}$ of maize at 0-10 cm soil depth as affected by different tillage treatments was examined for 2009 and 2010 and the results (Table 4) indicated that the number of roots plant$^{-1}$ was significantly affected by the tillage treatments during both the years. During 2009 and 2010 maize growing seasons, the maximum number of roots (88 and 95 plant$^{-1}$) was observed under conventional tillage, and a consecutive reduction in the number of roots plant$^{-1}$ was recorded in reduced tillage (72 and 81 plant$^{-1}$) and no tillage treatments (70 and 75 plant$^{-1}$), respectively. The seasonal comparison indicated that during 2010 the number of roots plant$^{-1}$ was relatively greater than the number of roots plant$^{-1}$ during year 2009. The number of roots plant$^{-1}$ 11-20 cm soil depth under different tillage treatments was recorded and the results (Table 4) showed that the number of roots plant$^{-1}$ was significantly affected by the tillage treatments during both the years. During 2009 and 2010 seasons, the maximum number of roots (23 and 27 plant$^{-1}$) was observed under conventional tillage, and number of roots plant$^{-1}$ decreased considerably under reduced tillage (19 and 21 plant$^{-1}$) and no tillage treatments (15 and 18 plant$^{-1}$), respectively. The seasonal comparison indicated that during 2010 the number of roots plant$^{-1}$ was relatively greater than the number of roots plant$^{-1}$ during year 2009.

Similarly, the roots plant$^{-1}$ at 21-30 cm soil depth under various tillage operations was recorded and the results (Table 4) indicated that the number of roots plant$^{-1}$ was significantly affected by the tillage treatments during 2009 and 2010. During 2009 and 2010 seasons, the maximum number of roots (7 and 8 plant$^{-1}$) was observed under conventional tillage, and number of roots plant$^{-1}$ decreased under reduced tillage (6 and 7 plant$^{-1}$) and no tillage treatments (5 and 6 plant$^{-1}$), respectively at 21-30 cm soil depth. The seasonal comparison indicated that during 2010 the number of roots plant$^{-1}$ was relatively greater than the number of roots plant$^{-1}$ during year 2009. The root dry weight of maize plant under various tillage treatments was examined for 2009 and 2010 growing seasons and the results (Table 4) indicated that the root dry weight was significantly affected by the tillage treatments. During 2009 and 2010 maize growing seasons, the maximum root dry weight (20 and 24 g) plant$^{-1}$ was observed under conventional tillage, and the root dry weight plant$^{-1}$ was considerably reduced under reduced tillage (15 and 17 g) and no tillage treatments (12 and 13 g), respectively. The seasonal comparison suggested higher root dry weight during 2010 as compared to 2009.

**Relationship between root dry weight and soil strength at 0-21, 22-42 cm depths:** The Fig. 4 showed relationship between root dry weight and soil strength. Results on coefficient of determination (i.e. $R^2 = 0.99$) revealed that the root dry weight plant$^{-1}$ was negatively associated with the change in soil strength during 2009. Similarly, for the year 2010, the coefficient of determination ($R^2 = 0.97$) suggested that 97% change in the root dry weight is associated with the change in soil shear. While, relationship between root dry weight and soil strength measured at 22-42 cm soil depth and the data are plotted in Fig. 4. The coefficient of determination (i.e. $R^2 = 0.98$) revealed that the root dry weight plant$^{-1}$ was negatively associated with the change in soil strength for the year 2009. Similarly, for the year 2010, the coefficient of determination (i.e. $R^2 = 0.98$) indicated 98% change in the root dry weight was echoed by the change in soil strength.

**Relationship between root dry weight TDM and LAI:** The Fig. 5 indicated relationship between root dry weight, TDM and LAI. Results on coefficient of determination (i.e. $R^2 = 0.99$) showed that 99% variation in the root dry weight plant$^{-1}$was associated which change the TDM during 2009. Similarly, for the year 2010, the same trend was recorded. On the other hand, the relationship between root dry weight and LAI was plotted in Fig. 5. The coefficient of determination (i.e. $R^2 = 0.99$) revealed 99% variation in the root dry weight plant$^{-1}$ was associated which change in LAI for the year 2009. Similarly, for the year 2010, the coefficient of determination (i.e. $R^2 = 0.95$) indicated 95% change in the root dry weight was echoed by the change in LAI. Conclusively positive and highly significant correlation (i.e. $R^2 = 0.99$) was observed between mean total dry matter production and mean root dry weight.

**Table 4. Impact of tillage practices on number of roots plant$^{-1}$, root length and root dry weight.**

| Tillage treatments | Roots plant$^{-1}$ at 0-10 cm depth | | Roots plant$^{-1}$at 11-20 cm depth | | Roots plant$^{-1}$ at 21-30 cm depth | | Root length (cm) | | Root dry weight plant$^{-1}$ (g) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Year | | Year | | Year | | Year | | Year | |
| | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 | n = 9 |
| $T_1$ (conventional tillage) | 88 a | 95 a | 23 a | 27 a | 7 a | 8 a | 25.7 a | 26.7 a | 20 a | 24 a |
| $T_2$ (reduced tillage) | 72 b | 81 b | 19 b | 21 b | 6 ab | 7 ab | 22.3 ab | 23.0 b | 15 b | 17 b |
| $T_3$ (no-tillage) | 70 b | 75 b | 15 c | 18 b | 5 b | 6 b | 21.0 b | 21.0 c | 12 c | 13 c |
| LSD | 6.3 | 10. | 3.3 | 3.5 | 1.8 | 1.2 | 3.7 | 1.8 | 2.9 | 4.7 |
| Significance | ** | ** | ** | ** | * | ** | * | ** | ** | ** |

Within columns, means followed by the same letter are not significantly differ
*, ** = Significant at 5% and 1%, respectively, LSD = least significant difference

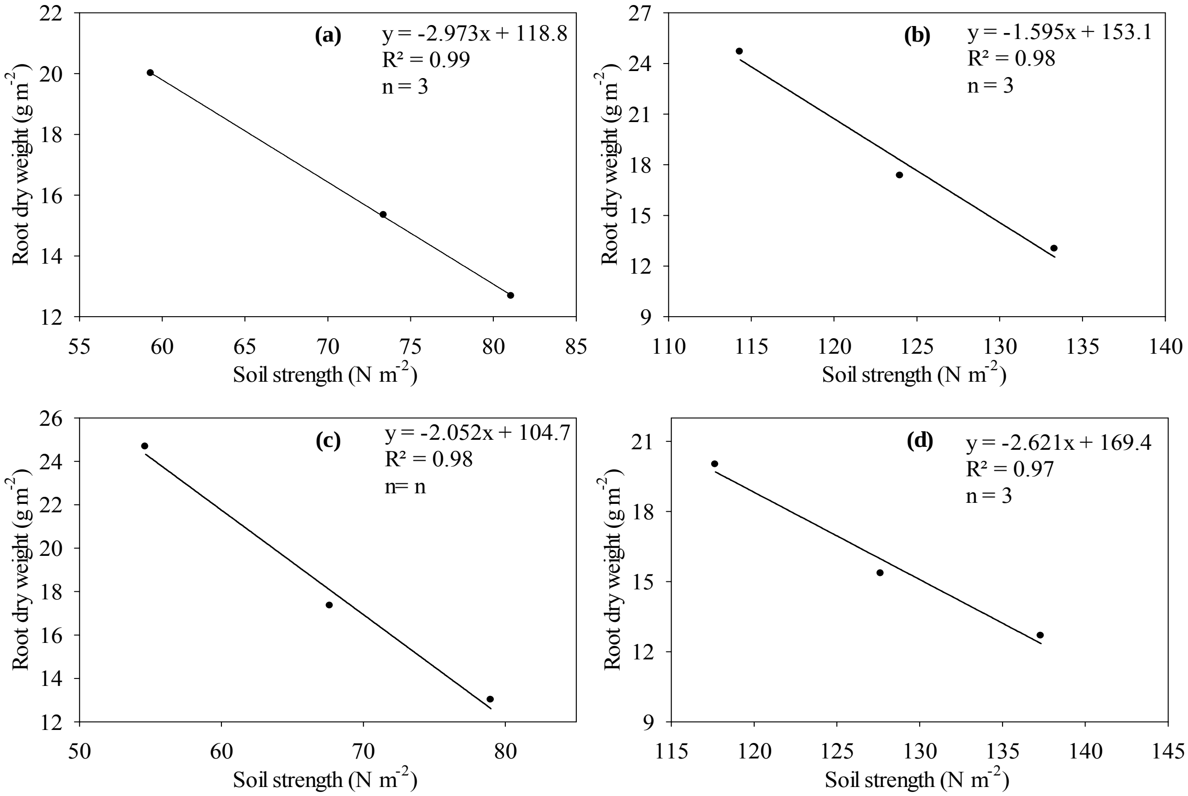


Fig. 4. Correlations of root dry weight with soil strength during growing season 2009 at the depth of 0-21 cm (a) and 22-42 cm (b) and during growing season 2010 at the depth of 0-21 cm (c) and 22-42 cm (d).

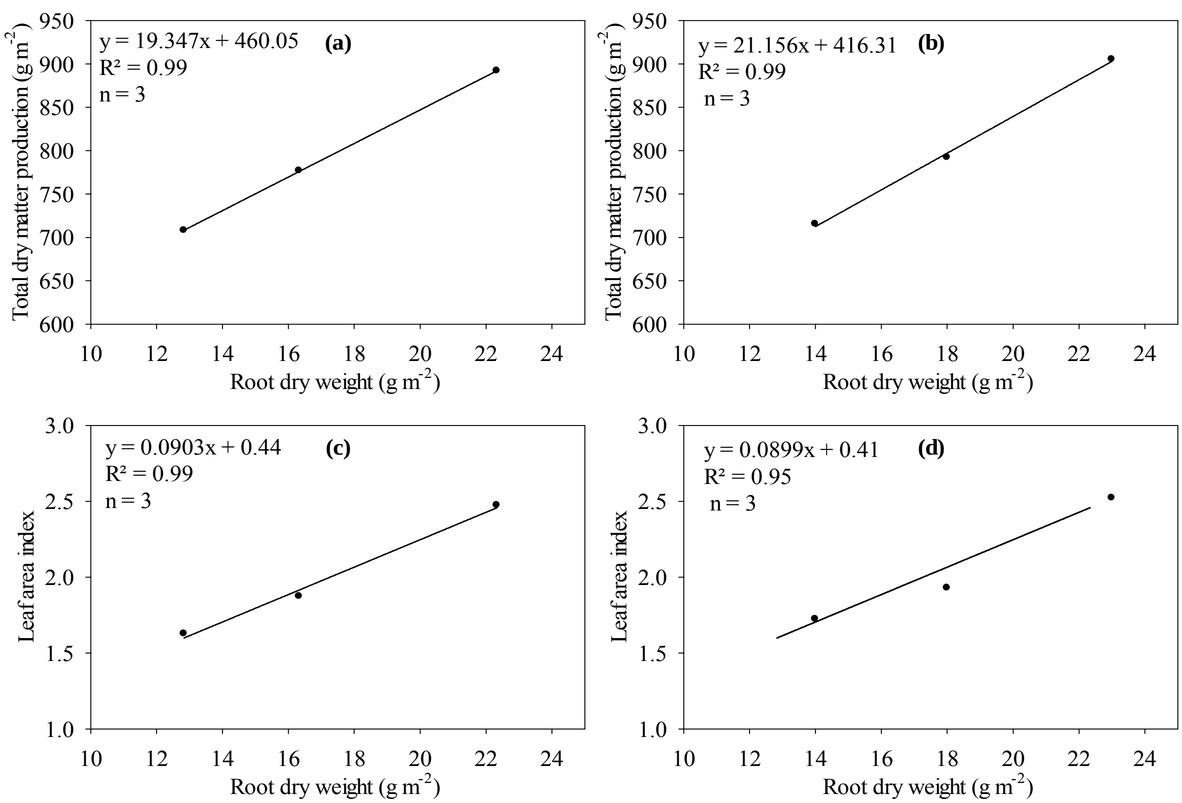


Fig. 5. Correlations of mean dry matter with mean root dry weight during growing season 2009 (a) and 2010 (b) and relationship of mean leaf area index with mean root dry weight during growing season 2009 (c) and 2010 (d).

## Discussion

The tillage treatments had significant effect on soil water content. These results have been supported by Alvarez & Steinbach (2009), who found that CT improved the soil water content in the cropped field. Similarly, Putte *et al*. (2010) and Jin *et al*. (2011) observed that conventional tillage transforms the soil physical properties that ensure better soil water conservation. Similarly, Feng *et al*. (2010) determined that tillage systems significantly influenced the soil water in fields. While the soil bulk density in experiment field was essentially increased with increasing soil depth and great bulk density was observed under NT system, followed by RT and CT systems. This trend was expected, because the soil remains compact under zero tillage, consequently bulk density increases. Whereas reduced and conventional tillage loosens the soil, hence it decreases bulk density. The findings of the present research are in line with those of Osunbitana *et al*. (2004) who reported that different tillage operations affect soil physical properties such as bulk density and tillage operations are significantly different in their effects on soil bulk density; while soil bulk density decreased with the degree of soil manipulation during tillage treatments, and reported that with no tillage highest values of 1.28 g $cm^{-3}$ was observed, while soil bulk density decreased under conventional tillage. Similarly, the soil strength at 0-21 cm depth under NT treatments was higher as compared to RT and CT treatments during 2009. Almost similar trends were observed during 2010, soil strength was higher (79 N $m^{-2}$) under NT than RT (68 N $m^{-2}$) and CT (55 N $m^{-2}$). This suggests that deep tillage can decrease soil penetration resistance below 20 cm depth, although the penetration resistance at 0–10 cm increased. Regardless the year of study, the values of soil strength were higher for sub-surface layers. Similar results have been also reported by other workers including Gajri ***et al.*** (1991) who testified that the tillage operations decreased soil strength and early post-seeding irrigation which also decreased the soil strength and under conventional tillage the soil strength was substantially decreased as compared to zero tillage. Similarly, Feng *et al*. (2010) determined that tillage systems significantly influenced the soil strength in wheat fields.

Tillage is one of the most effective ways to reduce soil strength Daniells, (2012). Soil physical properties as well as crop growth are affected by tillage systems Mosaddeghi *et al*. (2009). However, the effects on root between different tillage systems have not been consistent. Some researchers found that deep tillage reduced soil strength and soil bulk density Laddha & Totawat (1997), improved water storage in the soil, enhanced the root growth, increased the LAI and total dry matter production Holloway & Dexter (1991) and increased crop production Ghosh *et al*. (2006). In contrast to the above reports, we also found that soil conditions under a conventional tillage system were better than those under reduce tillage system and zero tillage system. The present study further showed that the roots of maize developed during 2009 and 2010 were lengthy enough (25.07 and 26.7 cm) under CT, which reduced in RT (22.3 and 23.0 cm) and NT treatments (21.0 and 21.0 cm), respectively. These results are in line with those of Feng *et al*. (2010) who determined that tillage systems significantly influenced the crop root development and plant growth. Similarly, the roots $plant^{-1}$ (0-10 cm depth) during 2009 and 2010 under CT system were greater (88 and 95 $plant^{-1}$) than RT (72 and 81 $plant^{-1}$) and NT treatments (70 and 75 $plant^{-1}$), respectively; while at 11-20 cm depth, maximum roots (23 and 27 $plant^{-1}$) $plant^{-1}$ were developed under CT, which decreased under RT (19 and 21 $plant^{-1}$) and NT treatments (15 and 18 $plant^{-1}$), respectively. These findings are further confirmed by those of Feng *et al*. (2010) who reported that tillage systems significantly influenced the number of roots $plant^{-1}$ of maize. Chan & Mead (1992); Rasmussen (1991), and Wulfsohn *et al*. (1996) observed that plant roots concentrated near the soil surface under conservation tillage due to improved moisture condition, as a result growth of plant increased rapidly. Shallow rooted crops experiences management challenges, especially during periods of extreme droughts when surface-level moisture is limited. Also, the root growth of was similar at later growth stages under conventional, reduced and no tillage systems in temperate regions (Ellis and Barnes, 1980; Dzienia & Wereszczaka, 1999). Sidiras *et al*. (2001) reported thicker maize roots under conventional than under no tillage, in contrast Pearson *et al*. (1991) found no effect of tillage on the diameter and number of roots. Similarly, tillage-induced differences in the soil nutrient status and root growth have been reported in the literature (Logan *et al*., 1991; Gregory, 1994; Cannell & Hawes, 1994; Holanda *et al*., 1998; Crozier *et al.*, 1999).

## Conclusion

It is concluded that conventional tillage provided better seed bed for root penetration, and root development as compared to reduced tillage and no tillage treatments. Soil physical properties particularly bulk density, soil strength decreased under conventional tillage which provided better environment for roots to penetrate to deeper depths. Contrary, bulk density, soil strength and water content were higher under no tillage. At the depth, compaction is common making long term impacts on rooting depth. While according to correlation studies soil strength significantly decreased the total dry matter production, root dry weight and LAI. Therefore, conventional tillage practices can increase maize growth and root development by improving of soil properties.

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