Corn root length density as affected by soil physical properties due to different manure and short-term tillage systems

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Abstract. Soil physical properties and root attributes are affected by agricultural practices. This study was conducted to investigate short-term changes of soil bulk density (BD) and cone index (CI) and corn (Zea mays L.) root length density (RLD) under different management regimes. The interaction effects of tillage (no-till, NT; chisel plow, CP; and moldboard plow, MP) and composted cattle manure applications [0, 30, and 60 Mg (dry weight) ha⁻¹] on BD, CI, and RLD were assessed in a split-plot design under corn plants. The RLD was determined from 10 cm diameter soil core samples. The BD and CI were determined by core method and cone penetrometry, respectively.

Tillage methods and manure applications had significant effects on RLD, CI and BD. The MP system had higher values of RLD with lower values of both CI and BD. The NT system resulted in lower RLD, and higher CI and BD. The increased BD and CI of the topsoil in the NT treatment probably restricted root growth. Increasing manure to the soil significantly increased RLD in the order of 60>30>0 Mg, manure ha⁻¹. There were also significant differences in CI and BD among manure treatments. The positive effects on CI and BD of manure applications are attributable to manure incorporation in soil structural improvement. The significant overall relation between RLD and CI illustrated the dominant effect of soil mechanical impedance on root growth. Our results indicate short-term beneficial effects of manure application on corn root length density as well as soil physical properties while combined with the tillage systems.

Keywords. Tillage, Manure, Root length density, Bulk density, Cone index
Introduction

Soil physical properties and crop yield are affected by compaction and tillage systems. Although several studies which evaluated effect of tillage and soil amendments on root growth have been documented (Dwyer et al., 1995; Anderson, 1987.; Barber, 1971) but they are often combined only with inorganic fertilizers sources and little information exist on the combined effect of reduced tillage and manure applications. Organic amendments such as manure can reduce soil susceptibility to erosion and compaction, decrease soil bulk density, soil mechanical impedance and increase soil moisture content. Tillage operations such as plowing are known to influence soil physical characteristics. Lal et al. (1989) reported that elimination of tillage on poorly drained soils can adversely affect root growth of crops. On a sandy loam soil under rice-wheat rotation, no-tillage in the absence of residue restricted horizontal and vertical proliferation of wheat roots compared to surface tillage which disrupted the soil to 0.10 m depth (Gajri et al., 1992). Mechanical resistance in the surface soil can influence the distribution of roots in the profile. It slows the downward progression of roots, and the root system is restricted to the upper parts of the profile. On such soils, no-tillage may be inappropriate because of restricted root development at least for the short-term periods. Increased soil strength not only restricted root growth but also changed the morphology of the roots. Greater mechanical impedance can restrict the elongation of root main axes and stimulate branching of lateral roots (Russell et al., 1974). On a silt loam, corn roots grew more extensively and greater depths with a 0.20 m deep tillage compared to no tillage; also, roots in tilled soil were finer and longer than in no- tilled soil (Barber, 1971). Thicker roots having a less absorbing surface as a result of no till compared to plow till were also observed by Griffith et al. (1977).

In contrary to the mentioned results, Unger (1984) reported that soil condition with no-tillage were as good as better than conventional tillage. In arid and semiarid environments on well-drained soils, surface residue with no till becomes important for maintaining or achieving favorable soil conditions such as high aggregate stability, low crust strength, high infiltration rate, low runoff, and increased water storage. Merrill et al. (1996) observed that no-till in spring wheat significantly increased early vegetative root axes and tiller growth more than plow-till. Also, there was a 30 to 100 percent enhancement in root length growth with no-till as opposed to plow-till that resulted from superior water conservation and a more favorable soil thermal regime in the near surface zone of the soil. In a study on a clay loam soil, Sow et al. (1997) showed that root growth of sorghum was a function of moisture-mediated soil strength. The management practices, such as furrow diking of conventionally tilled and no-tilled soils conserved water by reducing runoff and/or evaporation, reduced soil strength, and increased depth and density of rooting compared to conventional tillage and no tillage without residue.

The short- and mid-term effects of tillage systems on soil and plant attributes were not significant in central Iran (Hajabbasi and Hemmat, 2000; Shirani, et al., 2002). The unstable structure of the soil due to low organic carbon content might be the reason of unique behavior concerning the effect of tillage systems. The soils are usually top-crusted and behave similar to hardsetting soils (Mosaddeghi, et al., 2003). The information on effect of management systems on soil and plant attributes is little in west part of Iran. Therefore, the objective of this study was to investigate the influence of tillage and manure application to a coarse-textured soil on corn root length density and soil physical properties in the west part of Iran.

Materials and methods

This research was initiated in April 2003 at the Agriculture Research Center located 5 km outside of the city of Hamadan, in West of Iran. The climate is of a semi-arid type, with long-term average annual precipitation of 328 mm. Most of the precipitation occurs during the winter
months. Monthly mean temperatures ranged from a high of 24.5°C observed in July to a low of –3 °C noted in January. The soil is classified as fine loamy, mixed, mesic Calciixerollic Xerochrepts. The top 30 cm of the sandy loam layer contained 620 g kg\(^{-1}\) of sand, 260 g kg\(^{-1}\) of silt, and 120 g kg\(^{-1}\) of clay with 3.4 g C kg\(^{-1}\), 0.3 g N kg\(^{-1}\), and pH of 8. From 1993 to 2003 (when this study began), the site was conventionally tilled for grain corn (Zea mays L.) production, and the nutrient required were generally supplied in urea and triple-super phosphate fertilizer.

Three tillage systems and three rates of manure were arranged in a split-plot design with tillage treatments as main plots and manure applications as subplots. Three replicates of the treatments were applied in a randomized block design. The three tillage systems consisted of: (i) No-tillage (NT) treatment, planting was accomplished directly in an undisturbed soil without any primary tillage operations; (ii) Chisel plow (CP) treatment involved chisel plowing to a depth of about 15 cm; and (iii) Moldboard plow (MP) treatment involved complete soil inversion and crop residue to a depth of 30 cm. In addition, in CP and MP plots implement operations were applied for seedbed preparation prior to sowing. Three rates of composted cattle manure were: 0, 30, and 60 Mg (dry weight) ha\(^{-1}\). Chemical fertilizer was also added to the plots supplying N, P and K based on soil test recommendations. The fertilizer rates applied with basal starter and dressing fertilization, which were based on local recommendation. Corn (cross 108) was planted at 66000 plants ha\(^{-1}\) in 0.75 m rows. The planting date was 10 June 2003. Plots were 10 m long and 5 m wide with the long dimension up and down the 1 to 1.5 % slope. A sprinkler system was used for irrigation according to the local recommendation.

Root sampling was done using the soil–core method (Böhm, 1979) when 100 % of the tassels appeared. The soil cores (11.29 cm inner diameter and 10 cm length) were taken to a depth of 0.5 m at two sampling locations per plot using a hand-held power sampler. At each sampling location, cores were taken at distances of 0.05 and 0.15 m from a plant on each side of the row. Only non-wheel track inter rows were sampled, because wheel traffic affects the growth and distribution of roots (Kaspar et al., 1991). Soil was rinsed from the samples by using 2 mm mesh screens under running tap water. The length of roots was determined by using the grid intersection method of Newman (1966). The total root length per sample, divided by the core volume, was used as the root length density, RLD (km roots per m\(^3\) of soil).

At the time of root sampling, soil physical properties were measured. Soil bulk density (BD) was determined by the core method using cores with diameter and length height of 5 and 7.5 cm, respectively. The samples were taken from 0-7.5, 7.5-15, and 15-22.5 cm depths. The cone index (CI) was measured by Rimik cone peneterometer (Model CP20) at 3 random locations next to the locations of root sampling in 2 cm increments up to 30 cm depth.

The trends of change in RLD, BD and CI were drawn versus soil depth among different treatments by EXCEL. The RLD, BD and CI were averaged for sampling depths and subjected to analysis of variance (ANOVA) with the procedure of SAS (SAS Institute, 1990). Sources of variation included tillage practices and levels of manure as well as their interactions. Significant differences were separated by Fisher protected LSD tests and accepted at P=0.05.

Results and discussion

The F ratios obtained by analyses of variance for root length density (RLD), cone index (CI) and bulk density (BD) are shown in Table 1. Tillage methods and manure application had significant effects on RLD, CI and BD. Among the variables, only BD was significantly affected by the interaction between treatments.
Table 1. The F ratio from analysis of variance for root length density (RLD) of corn grown, soil bulk density (BD) and cone index (CI) under various tillage and manure treatments.

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>RLD</th>
<th>BD</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage (T)</td>
<td>2</td>
<td>20.69**</td>
<td>82.04**</td>
<td>54.33**</td>
</tr>
<tr>
<td>Manure (M)</td>
<td>2</td>
<td>27.04**</td>
<td>61.19**</td>
<td>27.81**</td>
</tr>
<tr>
<td>T × M</td>
<td>4</td>
<td>0.53</td>
<td>3.33*</td>
<td>1.76</td>
</tr>
</tbody>
</table>

*,* ** Significant at 0.05 and 0.01 levels of probability, respectively

Root length density (RLD)

Tillage and manure treatments significantly affected RLD (Table 1). Relative RLD for different tillage systems was 1.00 : 1.06 : 1.27 for NT : CP : MP. The means of RLD values did not differ (P=0.05) between NT and CP treatments. Lowest RLD on the NT - 0 manure.ha⁻¹ combination may have been a reflection of the manure maintained on the surface. High RLD in the MP treatment may attribute to the deeper rooting in conventional tillage than in conservation tillage (Table 2). Similar findings were noted by Raczkawski (1988) and Cox et al. (1990) who reported that surface soil water availability reduced root exploration on the deeper soil layers under conservation tillage. However, Lampurlanes et al. (2001) studied root growth of barley under different tillage systems on two soils in semiarid conditions and reported that RLD was significantly greater for no-tillage than for subsoiler or minimum tillage. They believed that no-tillage favored greater and deeper water accumulation in the soil profile and greater root growth.

Table 2. Corn root length density (km.m⁻³) as affected by tillage and manure treatments.

<table>
<thead>
<tr>
<th>Tillage (T)</th>
<th>Rate of manure application (Mg.ha⁻¹)</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>NT</td>
<td>2.30</td>
<td>2.82</td>
</tr>
<tr>
<td>CP</td>
<td>2.37</td>
<td>3.13</td>
</tr>
<tr>
<td>MP</td>
<td>2.94</td>
<td>3.46</td>
</tr>
<tr>
<td>X</td>
<td>2.54</td>
<td>3.14</td>
</tr>
</tbody>
</table>

LSD (0.05)

| Tillage (T) | 0.33 |
| Manure (M)  | 0.32 |
| T × M       | 0.55 |

\(^{\text{i}}\) NT= No-tillage, CP= Chisel plow, MP= Moldboard plow
Fig. 1: Tillage systems’ effects on root length density (a), soil cone index (b), and soil bulk density (c) at different soil depths.
In terms of tillage, there were not considerable difference in RLD between CP and MP to depth of 0.15 m (Fig. 1-a). Reduction of RLD under CP in comparison with NT and MP in 0.15-0.5 m layer may attribute to the plow pan effect. Manure effects on RLD were in the order of 60 > 30 > 0 Mg manure ha\(^{-1}\), with relative magnitude of 1.00 : 1.24 : 1.43. The favorable effects on RLD of 60 Mg manure ha\(^{-1}\) compared with 30 and 0 Mg manure ha\(^{-1}\) (Fig. 2-a) are attributable to manure incorporation in improvement of soil environment. The highest RLD was observed for MP-60 Mg manure ha\(^{-1}\) combination that may attribute to the lowest mechanical impedance encouraging root elongation.

However, Drost and Wilcox-Lee (2000) studied alteration of root distribution of mature asparagus planting as affected by tillage systems (till and no-till). Regardless of sample depth or harvest date, RLD was greater in no-till than till. RLD were greatest in the 0.3 and 0.45 m depths and tended to decrease as depth increased for both tillage systems. Abu-Hamdeh (2003) studied the combined effects of tillage and axle load treatments on okra root density. Plants in the no-tillage and moldboard-plowed treatments had a higher concentration of roots near the base of the plant compared to the plants in the chisel-plowed treatment.

**Soil cone Index**

Cone index (CI) was significantly lower under MP than under NT (P<0.001) from 0 to a depth of 0.30 m (Table 3). The mean CI values (average of all manure treatments) were 3.16, 2.52, and 1.79 MPa for NT, CP, and MP, respectively (Table 3). The lowest value of CI was observed for the MP-60 Mg manure ha\(^{-1}\) combination. There were also significant differences in CI among manure treatments. The mean CI values (average of all tillage systems) were 2.83, 2.43, and 2.22 MPa for 0, 30 and 60 Mg manure ha\(^{-1}\), respectively. The positive effects on CI of 60 Mg manure ha\(^{-1}\) compared with 30 and 0 Mg manure ha\(^{-1}\) are attributable to manure incorporation in soil structural improvement. The CI values over the soil depth due to manure application kept the order of 0 > 30 > 60 Mg manure ha\(^{-1}\).

Table 3. Soil cone index (CI) in MPa as affected by tillage and manure treatments.

<table>
<thead>
<tr>
<th>Tillage (T)</th>
<th>Rate of manure application (Mg.ha(^{-1}))</th>
<th>(\bar{X})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>NT</td>
<td>3.43</td>
<td>3.11</td>
</tr>
<tr>
<td>CP</td>
<td>2.76</td>
<td>2.51</td>
</tr>
<tr>
<td>MP</td>
<td>2.30</td>
<td>1.66</td>
</tr>
<tr>
<td>(\bar{X})</td>
<td>2.83</td>
<td>2.43</td>
</tr>
</tbody>
</table>

LSD (0.05)

| Tillage (T) | 0.37 |
|             |      |
| Manure (M)  | 0.18 |
| T x M       | 0.31 |

\(^{\circ}NT=\) No-tillage, CP= Chisel plow, MP= Moldboard plow
Fig. 2: Manure treatments’ effects on root length density (a), soil cone index (b), and soil bulk density (c) at different soil depths.
There was no difference in CI between MP and CP from the soil surface to a depth of 0.1 m. The overall increasing trend of soil strength with soil depth represents the overburden load effect on soil particles’ interlocking. The CI increased with depth in CP from 0.15 m to the depth of 0.30 m (Fig. 1-b) probably due to the stress induced by chisel plow at 0.15 m depth. As is showing on Fig. 1-b, the NT had the greatest percentage increase in CI over the soil depth. In agreement to this study, the results of Abu-Hamdeh (2003) showed that the no-tillage system intensified the effect of axle load on CI and BD. The manure applications decreased soil strength because of loose structure of amended soils (Fig. 2-b).

**Soil bulk density**

Bulk density (BD) followed a pattern similar to that of CI. The interaction between tillage and manure was significant (P<0.04). From 0 to 0.30 m depth, the MP showed a significantly reduced BD when compared with NT (Fig. 1-c). There was no difference in BD between MP and CP for the soil layer of 0-0.1 m depth. The BD increased linearly with depth in CP from 0.1 m to the depth of 0.2 m. This trend might be the result of plow pan created by implement forces. The data in Tables 1 and 4 show that BD was significantly affected by tillage and manure treatments and their interaction effects. The mean BD values (average of all manure treatments) were 1.43, 1.37 and 1.26 Mg.m$^{-3}$ for NT, CP and MP, respectively. The lowest BD was observed for the MP-60 Mg manure ha$^{-1}$ combination and the highest was for NT-0 Mg manure ha$^{-1}$ combination. There were also significant differences in BD among manure treatments (Table 4). The mean BD values (average of all tillage treatments) were 1.30, 1.36 and 1.41 Mg.m$^{-3}$ for 60, 30, and 0 Mg manure ha$^{-1}$, respectively. The dilution effect of organic manure on BD was persistent with soil depth (Fig. 2-c). The BD increases with soil depth keeping the same order as that of CI (Figs. 1-c and 2-c).

**Table 4. Soil bulk density (BD) in Mg.m$^{-3}$ as affected by tillage and manure treatments.**

<table>
<thead>
<tr>
<th>Tillage (T)$^\dagger$</th>
<th>Rate of manure application (Mg.ha$^{-1}$)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>30</td>
<td>60</td>
<td>$\bar{x}$</td>
</tr>
<tr>
<td>NT</td>
<td>1.47</td>
<td>1.45</td>
<td>1.37</td>
<td>1.43</td>
</tr>
<tr>
<td>CP</td>
<td>1.42</td>
<td>1.36</td>
<td>1.34</td>
<td>1.37</td>
</tr>
<tr>
<td>MP</td>
<td>1.33</td>
<td>1.28</td>
<td>1.18</td>
<td>1.26</td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>1.41</td>
<td>1.36</td>
<td>1.30</td>
<td></td>
</tr>
</tbody>
</table>

LSD (0.05)

| Tillage (T) | 0.04 |
| Manure (M)  | 0.02 |
| T × M       | 0.04 |

$^\dagger$ NT= No-tillage, CP= Chisel plow, MP= Moldboard plow
Root length density versus soil strength

Soil strength is an important property affecting root growth. The overall relationship between RLD and CI among all the treatments was assessed. A significant non-linear relation was found between RLD and CI (Fig. 3). The graph showed the higher effect of soil strength increase on root growth at lower values of CI when compared with the higher values of CI. The well-known critical CI value of 2000 kPa for root growth corresponds to major decrease in RLD when compared with the lower values of CI (Fig. 3). The close relation between RLD and CI implies that the soil mechanical impedance has dominant effect on root growth.

![Graph showing the relationship between root length density (RLD) and soil cone index (CI)](image)

\[ \text{RLD} = 76.352 \times \text{CI}^{-0.416} \]

\[ R^2 = 0.43 \]

Fig. 3: The overall relationship between root length density (RLD) and soil cone index (CI)

Conclusions

The moldboard plow system could have had higher values of root length density with lower values of both cone index and bulk density as a result of the moldboard plow mixing topsoil, residue, manure and nutrients into the plow depth. The no-tillage system resulted in lower root length density, and higher cone index and bulk density as a result of less favorable soil physical and nutritional properties. Chisel implement forces may caused plow pan from 0.15 m depth over soil profile showing an increase in the soil mechanical impedance and bulk density and consequently decreased root length density. The no-tillage had the greatest percentage increase in cone index over the soil depth. The lowest cone index was observed for the MP-60 Mg manure ha\(^{-1}\) combination due to manure incorporation in soil structural improvement. Bulk density followed a pattern similar to that of cone index. Bulk density was significantly affected by
tillage, manure treatments and their interaction effects. The increased bulk density of the top soil in the no-tillage treatment probably restricted root length density. The significant relation between root length density and cone index illustrated the dominant effect of soil mechanical impedance on root growth. Our findings indicate short-term beneficial effects of manure application on corn root length density while combined with the tillage systems. Drastically effects of manure on root length density, cone index and bulk density may attribute to the weakly soil structure due to especially very low soil organic carbon content. However, it is worth to continue the experiments for mid- and long-terms effects of tillage and manure combinations on crop root characteristics and soil physical properties.

References


