Soil hydraulic properties as affected by different management practices

Safadoust¹, A., A.A. Mahboubi¹, M.R. Mosaddeghi¹ and A. Nouroozi²

1. Department of Soil Science, College of Agriculture, Bu-Ali Sina University, Hamadan 65174, Iran
2. Agricultural Research Center, Hamadan, Iran

Introduction
Soil hydraulic properties are known as soil water content vs. matric suction relationships (i.e. soil water characteristic curve, SWCC) and hydraulic conductivity (K) as a function of soil water content or potential. Agricultural management practices can significantly affect soil hydraulic properties and transport processes. Several studies have shown that tillage practices alter soil pore size distribution and consequently affect soil water retention and transfer properties (Green et al., 2003). Soil volumetric water content was found to be consistently greater under conservation tillage than under conventional tillage systems due to the changes that occurred in the soil pore size distribution (Mahboubi et al., 1993). They indicated that conservational tillage had significantly higher soil saturated hydraulic conductivity (Kₕ) than convention tillage. Voorhees and Lindstorm (1984) reported that 3-4 years is required before continuous conservation tillage could have a favorable porosity in the 0-15 cm soil layer than continuous plowing. It was shown that the soil receiving moldboard plowing became less porous with time as compared with the soil under conservation tillage.

Organic amendments such as manure can increase soil water retention properties and transfer coefficients and consequently enhance soil physical qualities. These may be attributed to: (i) increase in total porosity of soil, (ii) change in the aggregate size distribution (which may change the pore size distribution), and (iii) imressed adsorptive capacity or increase in the specific surface area of the soil (Bouyoucos, 1939). With manure addition to soils ranging from sand to clay texture, Bouyoucos (1939) reported an increase in water holding capacity and available water content. A similar increase in soil water retention and hydraulic conductivity was reported due to application manure to soil over a 20 years period (Biswa and Khosla, 1971). Lunt (1959) reported that non-capillary pore space and field capacity increased and bulk density decreased by adding manure to a loam soil.
Little information exists on the combined effects of tillage and manure applications on soil hydraulic properties in Iran. The objective of this study was to determine the combined effects of short-term tillage and manure application on SWCC and $K_s$ of a sandy loam soil in west of Iran.

**Materials and Methods**

A field experiment was conducted in 2003 on a sandy loam soil at Hamadan Agricultural Research Center, west of Iran. The soil was classified as a fine loamy, mixed, mesic Calcixerollic Xerochrepts. The topsoil (0-30 cm) contains 62% sand, 26% silt, 12% clay and 0.34% organic carbon. From 1993 to 2003, the site was conventionally tilled for grain corn (*Zea mays* L.) production.

Treatments consisted of combinations of tillage and manure application, 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 tillage systems consisted of (i) No-till (NT), planting was accomplished directly in an undisturbed soil without any primary tillage operations; (ii) Chisel plowing (CP) involved plowing by chisel plow to a depth of about 15 cm; and (iii) Moldboard plowing (MP) involved complete soil and crop residue inversion 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$^{-1}$ applied on the soil surface before tillage treatments’ application. 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 employed for irrigation according to the local recommendation.

Hydraulic properties were measured in the laboratory on the undisturbed soil samples obtained from the field. The sampling was done by the core method using cores of 5 cm inner diameter and 7.5 cm height. The samples were taken from non-wheel track inter rows in three layers to a depth of 22.5 cm. Soil water characteristic curve (SWCC) was determined on the soil cores using a combination of a sandbox, for matric suctions of 0-100 cm (Clement, 1966) and pressure plate extractors, for matric suctions of 100-15000 cm (Klute, 1986). Water retention at matric suction of 15000 cm was determined on the sieved samples (<2 mm fraction). Available
water content (AWC) was considered as the difference between the amount of water retained at matric suctions of 100 cm and 15000 cm. Saturated hydraulic conductivity ($K_s$) of the cores was determined by using a constant-head permeameter (Klute and Dirksen, 1986). The analysis of variance for soil water retention at selected matric suctions, AWC and $K_s$ was performed independently for the sampling depths and subjected to the procedure of SAS (SAS Institute, 1990).

**Results and Discussion**

The analysis of variance for the soil hydraulic properties is shown in Table 1. The effects of tillage and manure treatments on the water retention of the 0-7.5 cm soil layer at different matric suctions were significant, except at exception of 15000 cm suction which was not affected by tillage method. Water retention was not affected by tillage and manure interactions. Water retention of the 7.5-15 soil layer at different matric suctions was significantly affected by both tillage and manure treatments. Similar trends were observed for the 15-22.5 cm soil layer. The interaction of tillage and manure had significant effect on the water content at matric suctions of 0, 10 and 2000 cm for the 7.5-15 cm soil layer and at 10 and 15000 cm for the 15-22.5 cm soil layer.

There were significant effects of tillage and manure on AWC for the 7.5-15 cm soil layer and of manure on the same variable for the 15-22.5 cm soil layer. The AWC of all the soil layers was not affected by tillage and manure interactions. The $K_s$ was significantly affected by tillage, manure and their interaction in all soil layers.

**Soil Water Characteristic Curve**

The effects of tillage systems (averaged over manure treatments) on SWCC of the soil profile are shown for different soil layers in Fig. 1-a. The soil from MP plots retained more water than CP and NT at all matric suctions. Differences in water retention were moderately more apparent at lower than at higher matric suctions. At any given suction, the amount of retained water were in the order MP>CP>NT. Tillage–induced differences in size distribution of integrated pores, bio-channels, and structural properties are responsible for the differences in SWCC. At the 0-15 cm, soil water retention under NT was lower than those of CP and MP. This difference may be attributed to lack of tillage as well as manure maintenance on the surface of no-tilled soil. Lack of soil disturbance below the depth of 15 cm under CP caused its SWCC to
be similar to that of NT. At this depth, MP created higher water retention due to complete inversion and manure incorporation into the soil pore size distribution.

The effects of manure application (averaged over tillage systems) on SWCC are illustrated in Fig. 1-b. At any matric suction, the amount of water retained by the soil increased as the amount of added manure increased (i.e. 60>30>0 Mg ha\(^{-1}\)) at all the three layers. Similar to the tillage effects, at high suctions the differences of water retained due to manure application were less than that at low suctions. Differences in water retention were slightly more apparent at 0-7.5 and 7.5-15 cm soil layers than at 15-22.5 cm layer. This indicates that there was a difference in the amount of pore space available for soil water storage due to manure application. Significant effects of manure on SWCC could be due to its dilution effect on the soil packing state and total porosity increase, change in the aggregate size distribution (which might affect the pore size distribution), or increased adsorptive capacity of the soil (i.e. increase in the specific surface area of soil). These results are similar to those reported by Bouyoucos (1939), Mays et al. (1973) and Gupta et al. (1977).

Saturated Hydraulic Conductivity

The effects of tillage treatments on \(K_s\) at different soil layers are presented in Fig. 2-a. At the 0-15 cm soil layer, \(K_s\) values were in the order of CP>MP>NT. Higher \(K_s\) of the soil under CP may be attributed to less aggregate breakdown and more organic matter content of the upper layers. Shallower working depth and smearing effect of stresses induced by chisel plow on the soil beneath caused decrease of \(K_s\) of CP to be less than that of MP in the third soil layer. Results of Wahl et al. (2004) also indicated a greater continuity of the macropore system for silty soils with conservation tillage systems. Afyuni and Mosaddeghi (2001) reported a non-significant increase of \(K_s\) in accordance with the increase of macroporosity of a sandy loam soil. The long-term no-tillage system increased the soil macroporosity significantly as compared with the conventional tillage. The reverse effects were recorded for a heavier (sandy clay loam) soil. Ciollaro and Lamaddalena (1998) also reported an increase in \(K_s\) values after plowing, by one or two orders of magnitude as compared with the values measured before plowing. However, the effects of conventional tillage (MP) and reduced tillage (disk harrowing) on physical properties of a silty clay loam soil were not significant in central Iran (Shirani et al., 2002). Fuentes et al. (2004) reported that after 27 years of continuous no-till, \(K_s\) under no-till increased significantly as compared with conventional tillage. However, \(K_s\) values of the soil under natural prairie were
about one order of magnitude larger than conventional and long-term no-tillage systems. It seems that even 27 years of no-tillage system has slightly contributed to the recovery of the hydraulic conductivity that existed previous to cultivation.

Figure 2-b shows the effect of manure application on \( K_s \) in the soil profile. The \( K_s \) increased as the rate of manure application increased, due to the increase in the pore size. The \( K_s \) values were in the order 60>30>0 Mg manure ha\(^{-1}\) due to the increase in the pore sizes. Based on a 2 years experiment, Shirani et al. (2002) reported that manure application significantly increased log [\( K_s \)] of a silty clay loam soil in central Iran. However, the hydraulic properties of a sandy loam soil were significantly affected by the short-term tillage and manure combinations in our study.

References


Table 1. The analysis of variance for soil water retention characteristics and saturated hydraulic conductivity ($K_s$)

<table>
<thead>
<tr>
<th>source</th>
<th>df</th>
<th>0 cm</th>
<th>10 cm</th>
<th>100 cm</th>
<th>2000 cm</th>
<th>15000 cm</th>
<th>AWC (%)</th>
<th>$K_s$ (cm hr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage (T)</td>
<td>2</td>
<td>19.4**</td>
<td>22.46**</td>
<td>21.19**</td>
<td>50.33**</td>
<td>4.72</td>
<td>6.51</td>
<td>63.3**</td>
</tr>
<tr>
<td>Manure (M)</td>
<td>2</td>
<td>67.5**</td>
<td>80.77**</td>
<td>36.83**</td>
<td>69.01**</td>
<td>51.99**</td>
<td>3.83</td>
<td>242.0**</td>
</tr>
<tr>
<td>T×M</td>
<td>4</td>
<td>0.2</td>
<td>0.32</td>
<td>0.39</td>
<td>2.53</td>
<td>0.67</td>
<td>0.54</td>
<td>6.9**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>source</th>
<th>df</th>
<th>0 cm</th>
<th>10 cm</th>
<th>100 cm</th>
<th>2000 cm</th>
<th>15000 cm</th>
<th>AWC (%)</th>
<th>$K_s$ (cm hr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage (T)</td>
<td>2</td>
<td>57.8**</td>
<td>96.08**</td>
<td>44.61**</td>
<td>261.50**</td>
<td>44.14**</td>
<td>29.41**</td>
<td>123.8**</td>
</tr>
<tr>
<td>Manure (M)</td>
<td>2</td>
<td>70.6**</td>
<td>48.29**</td>
<td>51.46**</td>
<td>108.23**</td>
<td>108.50**</td>
<td>11.29**</td>
<td>163.2**</td>
</tr>
<tr>
<td>T×M</td>
<td>4</td>
<td>3.7*</td>
<td>3.68*</td>
<td>2.29</td>
<td>4.96*</td>
<td>1.00</td>
<td>2.71</td>
<td>27.1**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>source</th>
<th>df</th>
<th>0 cm</th>
<th>10 cm</th>
<th>100 cm</th>
<th>2000 cm</th>
<th>15000 cm</th>
<th>AWC (%)</th>
<th>$K_s$ (cm hr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage (T)</td>
<td>2</td>
<td>63.4**</td>
<td>95.84**</td>
<td>31.43**</td>
<td>31.45*</td>
<td>28.96**</td>
<td>6.73</td>
<td>112.6**</td>
</tr>
<tr>
<td>Manure (M)</td>
<td>2</td>
<td>26.1**</td>
<td>19.34**</td>
<td>6.04*</td>
<td>7.69**</td>
<td>42.58**</td>
<td>5.74*</td>
<td>20.9**</td>
</tr>
<tr>
<td>T×M</td>
<td>4</td>
<td>2.2</td>
<td>4.16*</td>
<td>1.31</td>
<td>1.35</td>
<td>6.83**</td>
<td>1.99</td>
<td>7.9**</td>
</tr>
</tbody>
</table>

*and ** mean significant effects at 0.05 and 0.01 levels of probability, respectively.

Figure 2. Soil saturated hydraulic conductivity ($K_s$) as affected by tillage systems (a) and manure application rate (b)
Figure 1. Soil water characteristic curve at different layers as affected by tillage systems (a) and manure application rates (b)