THE EFFECT OF TILLAGE TREATMENTS ON SOIL WATER HOLDING CAPACITY AND ON SOIL PHYSICAL PROPERTIES

N.H. Abu-Hamdeh
Department of Biosystems Engineering, Jordan University of Science and Technology, Irbid, Jordan.

Abstract

The effect of tillage treatments (moldboard plowing, chisel plowing, and disk plowing) on soil water holding capacity and on soil physical properties was investigated. Soil physical properties include soil bulk density and infiltration rate. Soil bulk density was measured on cores obtained by a manually operated tool. Infiltration rate of the soil in all treatments was measured using double ring infiltrometer. Soil response was measured to 40 cm soil depth. Soil water holding capacity was investigated by plotting soil water characteristic curves for different tillage treatments. These curves were constructed by measuring soil moisture potential and moisture content. Potential was measured using watermark sensor and moisture content was measured by gravimetric method. These measurements were replicated three times. The Statistical Analysis System (SAS) computer package was used to analyze the data. ANOVA procedure was used to evaluate the significance of each parameter and their interactions. Significant differences were reported for the 10% probability level. Data obtained from the experimental plots showed that infiltration rate was strongly affected by tillage treatments in the top soil. Dry bulk density from 0 to 20 cm was affected by tillage treatments and from 20 to 40 cm by axle load. Tillage systems generally affected the ability of the soils to hold moisture and the available water capacity.

Additional Keywords: soil, aggregation, conservation, density, infiltration,

Introduction

Soil compaction refers to the packing effect of a mechanical force on the soil. This packing effect decreases the volume occupied by pores and increases the density and strength of the soil mass. Bulk density and water infiltration are the indices of soil compaction. Carpenter *et al*. (1985) in discussing the effect of wheel loads on subsoil stresses say, “although soil compaction affects many important soil physical properties, perhaps the most detrimental effect is the drastic reduction in hydraulic conductivity, which ultimately results in soil erosion and reduced crop yields due to reduced infiltration, increased run-off and poor drainage”. Bailey *et al*. (1988) mentioned that excessive compaction may cause such undesirable effects as decreased infiltration of water, restriction of root growth, and increased runoff. These detrimental effects can increase erosion.

Tillage treatments are expected to affect soil response and crop yield. Erbach *et al*. (1992) evaluated the effect of four tillage treatments - no till, chisel plow, moldboard plow, and para plow systems - on three soils (poorly drained, medium, and fine textured) in Iowa. Results showed that all tillage tools reduced bulk density and penetration resistance to the depth of tillage. However, after planting, only the soil tilled with the para plow remained less dense than before tillage.

The soil-water properties of soils are of great importance to soil fertility and are the subject of interest to agricultural engineers and farmers. Soil water characteristics are required to describe the availability of water to plants, to predict root growth of plants and to model the movement of water in soils for irrigated and non-irrigated crop production. The effect of changes in bulk density due to compaction on water retention and hydraulic conductivity of soils has been studied by certain researchers. Jamison (1953) pointed out that compaction often increases total water storage, but decreases the amount of water available to plants. Douglas and McKyes (1978) showed that the decrease in porosity of a compacted soil decreased its unsaturated hydraulic conductivity. Jamison and Kroth (1958) observed the available water storage capacity of several Missouri soils to increase with the decrease in density. Soil water retention, expressed as percent water content by weight, was found by Stevenson (1973), to increase at each soil water suction as the peat content increased. The objectives of this research were to: (a) quantify the effect of tillage systems at different compaction levels of clay loam soil on its soil-water properties, and (b) measure changes in soil physical properties as affected by tillage system resulting from wheeled traffic on tilled soil in the field..

Materials and Methods

The experiment was initiated in the fall of 2002 on a clay loam soil on a farm located at the Northern part of Jordan. Compaction was carried out with a 2 axled 4-wheel drive off-road truck. Loading levels of 5, 10, and 15 t axle^{-1} were chosen as the compactive efforts. The 10 and 15 t axle^{-1} treatment were obtained by loading the truck with gravel until a load of 10 and 15 tons is exerted on each axle.

The effect of tillage systems was studied in this project. The effect of parameters and their interactions was identified. The settings for the main parameters were as follows:

Tillage treatment:
M = moldboard plowing,
C = chisel plowing, and
D = disk plowing.

Tire load
S = 5 t/axle,
L = 10 t/axle, and
B = 15 t/axle

The experiment was arranged in blocks consisting of 12 plots of randomized compaction treatments (50 m X 20 m). All treatments were replicated three times according to this type of design. All experimental areas received a primary tillage by chisel plowing in the fall to a depth of approximately 25 cm. Soil compaction was accomplished with a 2 axled 4-wheel drive off-road truck at three loading levels (5, 10, and 15 t axle^{-1}). The three tillage treatments (moldboard plowing, chisel plowing, and disk plowing) was then be applied. All tillage operations were done by a 60-kW two-wheel-drive KUBOTA M8030 tractor weighting 7.5 tons.

The texture of soil was determined by using the hydrometer test. First, 50 g of oven dry fine textured soil was added to the dispersing cup. Then a 125 mL of sodium hecta-metaphosphate was added to the cylinder which was filled by distilled water to reach the one liter marker. The first reading of the hydrometer was taken after 40 seconds and the second reading was taken after 2 hours. The percentages of sand, silt and clay were determined and the soil texture triangle was used to determine the texture of soil. It was found to be a loam soil.

Soil bulk density was measured on cores obtained by a manually operated tool. These cores were 5 cm in diameter, 10 cm deep and about 200 cm^3 in volume (Blake and Hartge, 1986). The collection of soil samples was made at three locations in each treatment. At each location, the collection was at four depths to a depth of 40 cm. Some of these samples were retained for moisture content measurements. Wet bulk density of soil sample was obtained by weighing the known volume of the core filled with soil and then subtracts the weight of the core itself. Since wet bulk density is a dynamic function, wet bulk density was converted to dry bulk density using the following equation:

$$\rho_d = \frac{\rho_w}{1+w} \tag{1}$$

where:
ρ_d = dry bulk density (g cm^{-3})
ρ_w = wet bulk density (g cm^{-3})
w = gravimetric moisture content

Infiltration rate of the soil in all treatments was measured using the double ring infiltrometer. The accumulated depth was plotted versus time on log-log paper to find the intercept and the slope of the straight line to get the accumulated depth equation. The intercept and the slope of the resulting straight line were determined and the accumulated depth equation was obtained as shown by equation (2). The infiltration rate equation was found as the derivative of the accumulated depth equation with respect to time as given by equation (3).

$$D = m\,T^{C} \tag{2}$$

$$i = dD / dT = cm\,T^{C-1} \tag{3}$$

where:
D = accumulated depth of infiltration (cm)
T = time (mins)
i = infiltration rate (cm/min)
m = intercept of the straight line in the log-log graph
c = slope of the straight line in the log-log graph

Water retention for the soils was determined at different pressures using watermark sensor. These matrix sensors have a range of 0-200 kPa. They are the appropriate devices when many replicates are required and are more durable in soil than gypsum block sensors. These devices measure soil matric potential by measuring changes in electrical resistance with changes in moisture content. The electrical resistance was inserted into the soil at a depth of 20 cm and then the block of soil was uniformly irrigated to saturation. After that the readings of the water mark were monitored. Water content will decrease as a result of evaporation and deep percolation of water and the reading of the water mark will change accordingly. At each value of electrical resistance, pressure and moisture content were recorded and the water retention curve was constructed in each plot.

Specific gravity (G_s) of the experimental soil was measured in the soil mechanics lab according to the following procedure: a 100 mL of water (de-aired) of density 0.995 g cm^{-3} was poured into a 100 mL flask and the entrapped air was removed by using a vacuum pump. This took approximately 15 minutes during which the flask and water inside the flask should be in continuous movement. Then the weight of flask plus water, $W_{1,}$ was determined. Then 20 grams of an oven dry soil was carefully inserted into the flask, the flask was then filled with water. Next, the flask was connected to the vacuum pump where it remained for about one hour with continuous movement for a faster removal of the entrapped air. The combined weight of flask, soil, and water, W_2, was then determined. The soil and water was removed to an evaporating dish and then to an oven to dry the soil. The weight of the dry soil , W_3, was determined. Specific gravity (G_s) was calculated by knowing all the above weights and by using the following formula:

$$G_S\ (at\ T_1\ ) = W_3 / ((W_1 + W_3) – W_2) \qquad (4)$$

$$Gs\ (at\ 20\ C\ ) = Gs\ (at\ T_1\ ) * A \qquad (5)$$

where:

A = conversion factor
W_1 = weight of flask and water filled to 100 mL
W_2 = weight of flask plus soil plus water
W_3 = The weight of the dry soil in the evaporating dish

Results and Discussion

Measured soil physical properties were averaged within the depth ranges of 0 to 10 cm; 10 to 20 cm; 20 to 30 cm; and 30 to 40 cm for comparison of axle load and tillage effects. The statistical analysis software SAS was used to analyze the data. The ANOVA procedure was used to evaluate the significance of each parameter and the interactions between parameters on soil physical properties. Least-square mean values of dry bulk density at each treatment combination were statistically analyzed to determine soil response to the field operating parameters. Duncan's multiple range test was used for the statistical analysis.

Soil response to differences in axle load and tillage treatment are presented in Figure 1 for dry density and Figure 2 for infiltration rate. As shown in Figure 1, the vehicle significantly increased soil dry density to a depth of 40 cm for all treatments at 10 cm depth. The MB treatment caused the maximum percentage increase of dry bulk density at all depths. This indicated the significant effects of axle load on soil physical properties. The percentage difference for each treatment was less at the 10-20 cm depth than at the 0-10 cm depth. These results reflect a more compact soil layer at the 0-10 cm depth than at the 10-20 cm depth. The averages of percentage increase of dry density at the 0-20 cm depth show that the MB treatment had the highest effect while the CS treatment had the lowest effect. It appears that tillage obliterated the effect of the axle load on soil strength in the tilled layer. These results suggested that tire traffic followed by tillage might have a significant affect on the resulting soil physical properties. There is no significant difference ($P < 0.1$) between the ML and the CB at the 20-30 cm depth. The average values at the 20-40 cm depth show that the MB treatment had the greatest percentage increase of dry bulk density while the CS treatment had the lowest percentage increase of dry bulk density. Available information clearly demonstrates that the axle load are crucial factor for the depth of subsoil compaction. An increase in axle wheel loads resulted in greater soil compaction due to increased in both shear and vertical soil stresses.

Slopes and intercepts of straight-line curves of plots of accumulated depths versus time on log-log paper for the treatments were determined and used to get the accumulated depth equation. The infiltration rate was found from the derivative of the accumulated depth equation. Figure 2 shows the effect of each treatment on infiltration rate. All infiltration values between 10 minutes and 60 minutes for each treatment were averaged and compiled as one value. This value is the steady state infiltration rate for each treatment. Steady state values for all treatments were plotted and the results are shown in Figure 2. All treatments have the same trend. The CS treatment at the 0-10 cm depth gave a lower bulk density but gave a lower infiltration rate than the other treatments. This could be explained by knowing that the same soil samples were used to determine the bulk density while the infiltration data were obtained from different soil samples. The MB treatment caused the maximum decrease in infiltration rate and the CS treatment had the lowest effect.

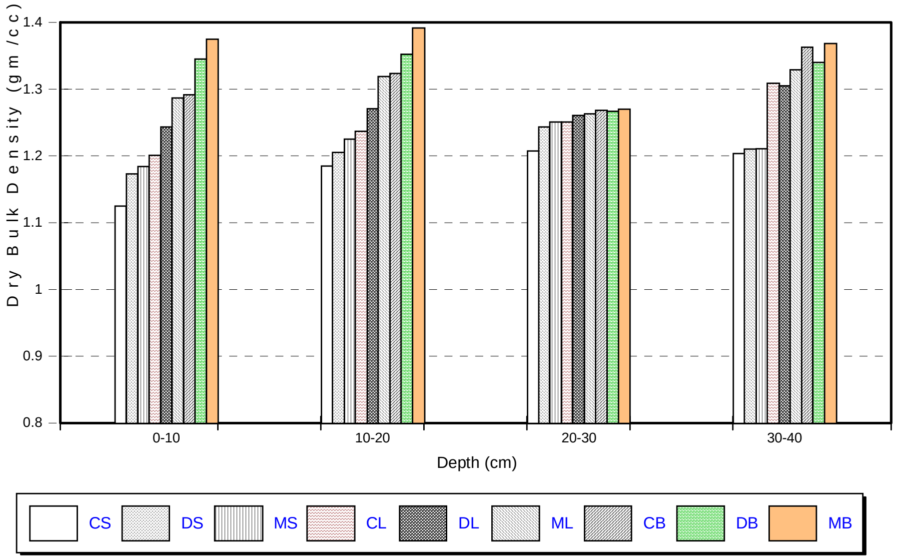

Figure 1. Soil dry bulk density for the different treatments in this study.

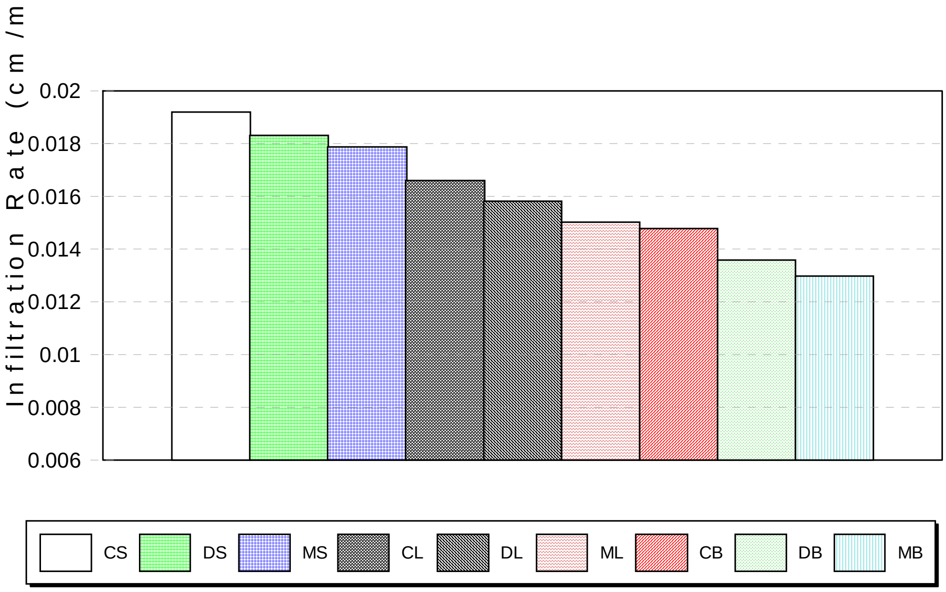

Figure 2. Steady state infiltration rate for the different treatments in this study.

Figure 3 shows that tillage system has significantly affected the water retention at each suction and the plant available water capacity of the soil at all soil densities. Chisel plowing resulted in finer soil particles which increased the soil pore space, hence increased the water retained by the soil. Also, the increase in pore space will increase the amount of water released to the plants. The increase in plant available water capacity of the soil for the different tillage treatments was found to decrease with an increase in the level of compaction. Because compaction results in the breaking down of larger soil particle aggregates to smaller ones, it is it is difficult for water to drain out of the soils because of the greater force of adhesion between the micropores and soil water. For the same tillage treatment, the effect of increasing the axle load upon a soil is to decrease the total porosity, and to increase the percentage of smaller pores as some of the originally larger pores have been squeezed into smaller ones by compaction (Figure 3).

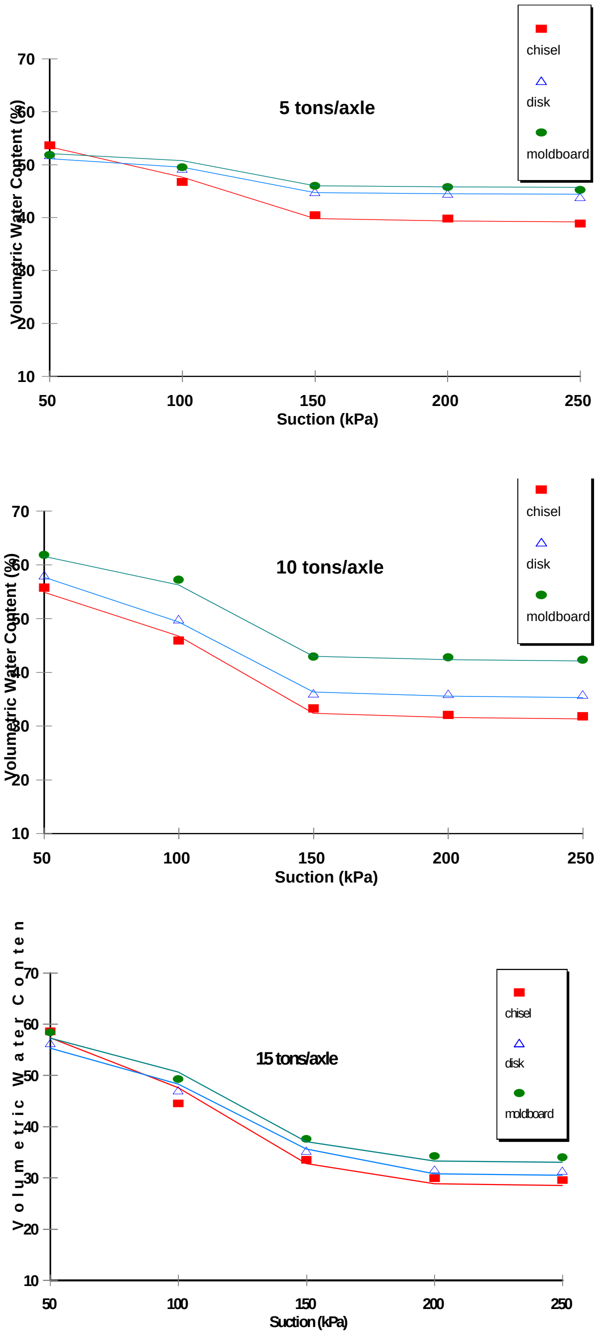

Figure 3. Experimentally obtained water retention curves for different axle load levels and different tillage systems.

Conclusions

The effect of tillage systems was studied in this project. The effect of these parameters and their interactions was evaluated through measuring the changes in soil physical properties (bulk density and infiltration rate) and by measuring changes in soil water holding capacity in comparison with controlled plots. Since crop yield is highly affected by soil density and soil-water hydraulic properties, the results will help on the decision of the type of tillage treatment that should be used to reduce yield loss due to soil compaction on some Jordanian soils under field conditions. Based on the laboratory and field results of this study, the following conclusions were drawn:

- Soil retention curve and water holding capacity were affected by the type of tillage treatment used.
- Infiltration rate decreased with increasing the axle load. At the same axle load, infiltration rate was higher in the chisel-plowed plots than in the disk-plowed and moldboard-plowed plots.

- Soil bulk density was lower in the chisel-plowed plots than in the disk-plowed and moldboard-plowed plots in the tilled layer. Also, it increased with increasing the axle load in the tillage zone.

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