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Comparative Study of Soil Tillage Practices Effects on Hydraulic Conductivity and Bulk Density of a Sandy Loam Soil in Tunisia

Roua Amami [1*], Khaled Ibrahimi [1], Khaoula Abrougui [1], Amira Hmila [1], Sayed Chehaibi [1]

[1] Higher Institute of Agricultural Sciences, Sousse University, 4042 Chott Meriem, TUNISIA
***Corresponding Author:** roua.amami1991@gmail.com

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ABSTRACT

The aim of this study was to investigate the effects of different tillage practices on bulk density, and the hydraulic properties of a sandy loam soil of eastern Tunisia. A replicated randomized complete block design with treatments consisting of (i) no-tillage (NT), (ii) tillage with moldboard plow at three level depths (SM=15cm, MM=20cm and DM=25cm), (iii) and tillage with disc plow at three level depths (SD=15cm, MD=20cm and DD=25cm) practices established at the Higher Institute of Agricultural Sciences of Sousse; Tunisia was used for the study. The soil bulk density and saturated hydraulic conductivity were determined for each of the treatments. The bulk density (BD) was determined at the depths of 5, 15 and 25 cm while the saturated hydraulic conductivity was determined on the surface (0-10 cm) soil. Experimental results showed that all the tillage practices were significantly different in their effects on soil density and was in the descending order of NT>SD> MD>DD>SM>MM>DM. The soil bulk density decreased with the degree of soil manipulation during tillage practices, with NT having the highest (1.76; 1.86 and 1.81g cm^{-3}) and DD having the least (1.60; 1.56 and 1.59g cm^{-3}) respectively for 5, 15 and 25cm depths. The greater mean value of Ksat was found in DD while the lowest was found in NT with 36% reduction than DD. The research concluded that the best Tillage Practices to be adopted in terms of improvement in physical and hydraulic properties is Shallow tillage practice.

Keywords: tillage, disc plow, moldboard plow, bulk density, hydraulic conductivity, beerkan test, Best Method

INTRODUCTION

Over the decades, reduction of tillage requirements has been the principal motivating force in agricultural mechanization (Osunbitan et al., 2005). Tillage is the most widely researched management practice affecting hydraulic conductivity and physical properties of the soil (Strudley et al., 2008). Many researchers examined the influence of tillage practices on soil bulk densities. According to Hammel et al. (1989) bulk density in the top 300 mm of silt loam soil were higher with zero tillage than with minimum or conventional tillage practices. Hoffman (1990) also observed that bulk densities of zero tillage and minimum tillage increased from the surface of the soil to a depth of 150 mm. Previous studies show that high BD, strong soil crust and low total porosity have a negative influence infiltration rates (Bhattacharyya et al., 2006; Gicheru et al., 2004). Bulk density is inversely related to total porosity (Carter & Ball,1993), which gives us an idea of the porous space left in the soil for air and water movement. Than when tillage is reduced, soil porosity tends to increase (Voorhees & Linstrom, 1984), and often, surface sealing occurs, reducing the infiltration rate (Lindstrom & Onstad, 1984).

Previous investigations Messing et Jarvis (1993) and Nicolas B, 2010, have found that K(h) showed a large intra-annual variability, decreasing shortly after tillage under tilled treatments, followed by an increase in the spring and a decrease in the summer for the three tillage treatments.

Kamemickova et al. (2012) mentioned that the tillage practices of the top layer of the soil plays a key role in the changes of the hydro-physical properties, mainly saturated hydraulic conductivity of the upper layer, soil perforation through tillage enhances soil water catchment and increases the infiltration of water into the soil surface, raising the hydraulic conductivity sorptivity values (Abrisqueta et al., 2006).

There are no recorded experiences on the influence of different tillage systems on the soil bulk densities and hydraulic conductivity in semi arid region of eastern Tunisia. On this background, the objectives of this study were to evaluate the effects of tillage implements, on soil Bulk density and hydraulic conductivity in sandy loam soil in eastern Tunisia.

Table 1. Coordinates of the experimental site and Soil properties in the horizon (0±30 cm) of the experimental site before the commencement of the tillage treatments (clay, silt and sand content (US Department of Agriculture classification system)

Variable	Value
Coordinates	35°54’5.82”N - 10°33’46.84”E
Clay (%)	11.12
Silt (%)	6.28
Sand (%)	77.96
Textural triangle	Sandy-loam
Bulk density ρb (gcm^{-3})	1.93
Particle density (gcm^{-3})	2.49
Soil-water content $\theta 0$ (cm^3cm^{-3})	10.53%

MATERIALS AND METHOD

Location and Climate

The experimental site was located in Sousse region in the Center East of Tunisia and belongs to the Higher Institute of Agronomic Science of Chott Mariem (35°54’5.82”N-10°33’46.84”E). The climate of the area is semi-arid Mediterranean; with a mean annual air temperature vary from 16 to 19 °C and a rainfall close to 400 mm. A brief description of the soil properties at the start of the experiment is shown in **Table 1**.

The area, is rectangular and fairly flat and extends for approximately 0.126 ha (63 × 20 m^2). It was divided into 21 subplots (3m*15m) marked by iron stakes consisting of the following treatments: shallow (SM), medium (MM), deep (DM) moldboard plowing at depths of 10, 15 and 25 cm, respectively and shallow (SD), medium (MD), deep (DD) plowing with a disk plow at depths of 10, 15 and 25 cm, respectively (**Figure 1**). No-tillage (NT) was considered as control. Three replicates were laid out in randomized complete block design.

Soil Sampling and Analyses

Bulk density

The bulk density (BD) of the core sample was estimated from the ratio of dry weight to fresh volume taken with cylinder densimeter of 98.17cm^3 volume (5 cm diameter and 5cm height) in all treatments from three soil cores taken by subplot from the upper 30 cm soil layer in 10 cm interval with three replications per treatment. We obtained the dry weight of the core sample after drying it in an oven at temperature of 105°C for 24 hours (Yoro and Godo,1990). The bulk density (BD) and the Water content can be calculated with the formula as follow:

$$Bulk\ density\ (BD)\left(\frac{g}{cm^3}\right) = \frac{weight\ of\ oven\ dried\ soil\ sample\ at\ 105)C}{total\ volume\ of\ fresh\ soil\ sample} \quad (1)$$

$$Moisture\ content\ (\theta)(cm/cm) = \frac{weight\ fresh\ soil\ sample - weight\ of\ oven\ dried\ soil\ sample}{weight\ of\ oven\ dried\ soil\ sample} \quad (2)$$

A total of 63 disturbed soil samples were collected at 0-0.3 m depth to determine the soil textural characteristics. Three textural fractions according to the USDA standards, i.e., clay (0-2 µm), loam (2-50 µm) and sand (50-2000 µm), were used in the study to characterize the soil.

The Beerkan Infiltration Method

A simplified method based on a Beerkan infiltration run to determine the saturated soil hydraulic conductivity by only a transient infiltration process was developed.

The Beerkan method used in this study is a simple three-dimensional infiltration test under positive head conditions, using a cylinder having an inner diameter of 0.30 m. In the field, a BEST infiltration test was carried out at each sampling point (N = 21) in April 2018. The procedure was carried out in consecutive steps as follows. The surface vegetation was removed over an area slightly larger than the cylinder diameter, while the roots remained in situ (**Figure 2**). Then, the cylinder is positioned at the soil surface and inserted to a depth of about 1 cm to avoid lateral loss of the pouded water at the soil surface. A fixed volume of water (250 ml) was poured into the cylinder at time zero, and the time required for infiltration of the known volume of water was measured. As soon as the first volume had completely infiltrated, another equal volume of water was added to the cylinder and the time for this volume to infiltrate (cumulative time) was recorded. The procedure was repeated until the test reached nearly steady-state conditions, three identical consecutive infiltration times. In this way, each cumulative infiltration was treated using the three BEST methods (Slope, Intercept and Steady- state), which were developed respectively by

Figure 1. Various tillage implements: Tillage with moldboard plow tillage with disc plow

Figure 2. Beerkan infiltration. Known volumes of water prepared in the bottles are successively poured through the ring and time is measured

Table 2. Soil bulk density (BD) under tillage treatments. Within columns, letters denote statistical significance at $p < 0.05$ for the compari son of tillage treatments for each soil layer separately (Standard deviations are indicated in parentheses

	Depths (cm)	NT	SD	MD	DD	SM	MM	DM
Soil bulk densities	0.10	1.76 a ± (0.05)	1.68 bc ± (0.09)	1.64 bc ± (0.06)	1.60 c ± (0.05)	1.69 ab ± (0.05)	1.66 bc ± (0.08)	1.65 bc ± (0.03)
	10-20	1.86 a ± (0.08)	1.66 b ± (0.06)	1.63 bc ± (0.06)	1.56 c ± (0.09)	1.67 b ± (0.04)	1.65 b ± (0.09)	1.63 bc ± (0.05)
	20-30	1.81 a ± (0.08)	1.67 b ± (0.03)	1.64 bc ± (0.03)	1.59 c ± (0.07)	1.70 bc ± (0.11)	1.63 bc ± (0.04)	1.61 bc ± (0.05)

Lassabatere et al. (2006), Yilmaz et al. (2010) and Bagarello et al. (2014). At the end of the experiment, the saturated soil is sampled to determine the saturated gravimetric water content and thus the saturated volumetric water content from the bulk density (BD) and the gravimetric water content, considering that water density is 1 g/cm^3.

RESULTS AND DISCUSSION

Effect of Tillage on Soil Bulk Density

Data related to soil bulk density after tillage operations are given in **Table 2**. Soil bulk densities are affected by tillage practices and become lower in line with more intensive tillage. This is mainly because small air spaces are formed between soil particles (clumps) of different structures during tillage (Šarauskis et al., 2018).

Statistical analysis indicated that both the tillage treatment had a significant effect on bulk density of soil (Osunbitan et al., 2005). A comparison of soil bulk density at 10 cm, 20 cm and 30 cm depths revealed the highest density to be found in No-tillage research plots (1.76; 1.86 and 1.81g/cm^3) respectively, and the lowest mean value to be found using disc plow at the different tillage depth (SD; MD; DD). There was no significant ($p<0.05$) differences were found between moldboard plow and disk plow treatments when operating at the same tillage depth (i.e. SD/SM; MD/MM; DD/DM) (Alvarez et al., 2009).

In the upper soil layer (0-10 cm), in average bulk density increases under shallow tillage represent a densification of only 4.7% related to deep tillage density mean using disk plow and 3.5% using moldboard plow. The results are in similarity with that (Dam et al., 2005) who reported that the bulk density reduced more profoundly by conventional tillage as compared to reduced tillage.

Hydraulic Conductivity Changes using BEST Methods

Each cumulative infiltration was treated using the 3 best methods (slope; intercept and steady-state); which were developed respectively by Lassabtère et al. (2006), Yilmaz et al. (2010) and bagarello et al (2014). The hydraulic conductivity varied due to tillage practices, the result presented in **Figure 3** showed significant difference ($p<0.05$) between No tillage and tillage managements (disc plow and moldboard plow) for both BEST algorithms.

In this investigation, the BEST steady was considered because according to Alagna et al. (2016) it allows a simple calculation of Ks. Saturated hydraulic conductivity (Ks) after tillage practices is presented in **Figure 3**, revealed that both the tillage methods significantly increased the hydraulic conductivity of soil as compared to No-tillage treatment, whereas their interactive effect was statistically non-significant. As regard tillage method practices, the maximum mean value of saturated hydraulic conductivity (36 x10-4 cm s^{-1}; 31 x10-4 cm s^{-1}) was observed in case of deep tillage with disc plow (DD) and moldboard plow (DM) respectively while the mean values for the other tillage methods were 23, 27, 29, 27 and 30 x10-4 cm s-1 for NT, SM, MM, SD and MD which were statistically similar. The average Mean increase in saturated hydraulic conductivity observed was 17.4%, (26/30.4%) and (34.8/56.5%) in the shallow (SM/SD), medium (MM/MD) and deep tillage treatments (DM/DD), respectively compared to No tillage, indicating that deep tillage (DD, DM) increases the saturated hydraulic conductivity when compared to other tillage practices. These findings are in agreement with those Ikbal et al. (2005) who reported that tillage practices increased soil hydraulic conductivity.

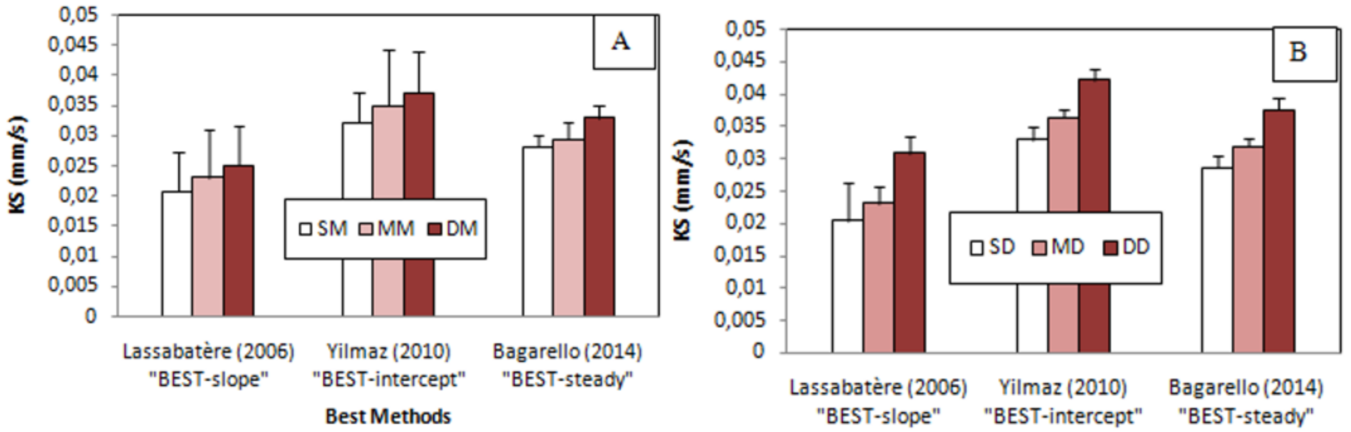

Figure 3. Soil hydraulic conductivity obtained with three BEST algorithms for the different treatments. A: Moldboard plow (SM, MM, DM); B: Disc plow (SD, MD, DD)

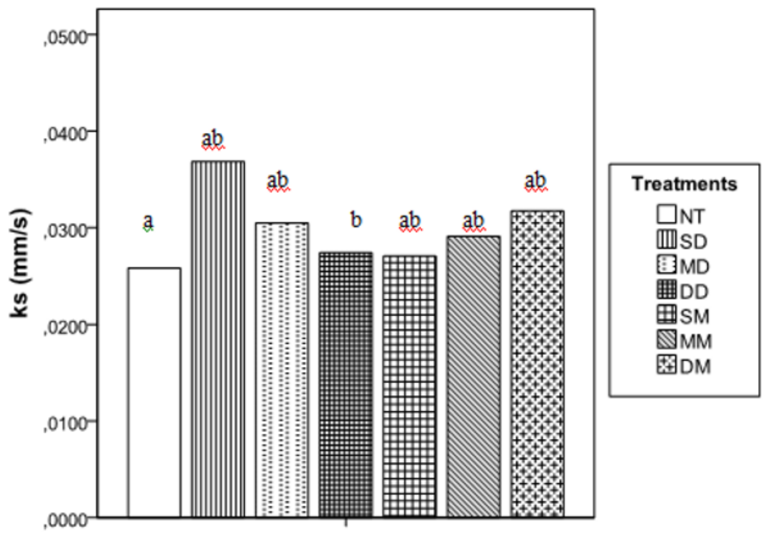

Figure 4. Mean saturated hydraulic conductivity (mm s^{-1}) of the surface (0–10 cm) soil under different tillage systems at weeks after tillage obtained with the procedure by Bagarello et al. (2014)

CONCLUSION

In this study the effects of tillage practices on the soil physical properties and hydraulic conductivity were evaluated. We conclude that the effect of till with disc plow, compared to Moldboard plow, was more pronounced with changes in bulk density and hydraulic conductivity. The NT system resulted higher bulk density and lower hydraulic conductivity than disc and moldboard plow. Our results demonstrate that SD tillage is a more sustainable soil management practice than the other tillage practices with respect to soil structural stability and the higher mean value of hydraulique conductivity which can enhances better penetration of water into the plant root zone, enabling root absorption of soil moisture for better plant growth and development.

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