THE EFFECT OF ORGANIC MATTER APPLICATIONS ON THE SATURATED HYDRAULIC CONDUCTIVITY AND AVAILABLE WATER-HOLDING CAPACITY OF SANDY SOILS

DEMİR, Y.[1*] – DOĞAN DEMİR, A.[2]

[1]*Department of Soil Science and Plant Nutrition, Bingol University Bingol, Turkey*

[2]*Biosystem Engineering, Bingol University, Bingol, Turkey*

**Corresponding author*
(e-mail: ydemir@bingol.edu.tr; phone: +90-426-216-0030)

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Abstract. Soils are natural resources that require preservation and good management due to their ever-changing structure. Among the soil management applications, organic material amendments are known to be the most practical soil management methods in the improvement of the chemical and physical properties of soils. Organic matter amendments are used to preserve water in coarse-textured soils and arid region soils. This study was carried out at Bingol University Research laboratory located in eastern Turkey. In the study, different doses of soil organic matter (SOM) including walnut sawdust (WS), earthworm manure (EM) and farmyard manure (FM) were applied to sandy soils to measure their effects on the saturated hydraulic conductivity (K*sat*) and available water-holding capacity (AWC) of the soils. Compared with the control application, the SOM amendments decreased the hydraulic conductivity of the sandy soils ($p < 0.01$). A comparison with the control application showed that the 8% WS application reduced the hydraulic conductivity of the soils by 51%, followed by the FM application with 35% and EM application with 39%. On the other hand, the SOM amendments increased the available water-holding capacity of the soils when compared with the control application ($p < 0.01$). The application with the most notable effect was determined to be the 1% WS application.
Keywords: *soil properties, soil management, vermicompost, agricultural wastes, soil water*

Introduction

In soil systems, saturated hydraulic conductivity (Ksat) is related to multiple soil properties and thus, is of great importance for engineers, scientists, and agriculturalists (Lal and Shukla, 2004; Gamie and De Smedt, 2018). Depending on the number and diameter of the pores in the soil, the hydraulic conductivity of a soil is a function of certain properties such as bulk density, porosity, pore size distribution and water-holding capacity (Kessler and Oosterbaan, 1974; Varallyay, 2002; Hillel, 2003).

Sandy soils are widespread around the world and have a sand content above 50%. According to the United States Department of Agriculture (USDA, 2010), they are classified as Entisols and cover 18% of the Earth’s land surface. Sandy soils are described as soils comprising rocks and mineral particles and containing rocks such as limestone, quartz and granite. The shape, size, degree of weathering and geological origin of the mineral soil components can strongly affect the hydrophysical properties of the soil, especially its water-holding capacity and hydraulic conductivity (Martens and Frankenberger, 1992; Brouwer and Anderson, 2000; Cousin et al., 2003). Due to their low water-holding capacity and high permeability, soil conditioners have attracted attention in recent years for their use in soil improvement (Al-Omran and Al-Harbi, 1997; Zibilske, 1998). Various studies carried out using soil conditioners have reported aggregate development, increased water-holding capacity and decreased infiltration and

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saturated hydraulic conductivity (Al-Omran et al., 1987; El-Shafei et al., 1994; Choudhary et al., 1995).

The organic soil materials used as conditioners contain an array of compounds such as proteins, fats and carbohydrates and high-molecular weight humic and fulvic acids. Today, many mineral and organic soil conditioners are used to improve the physical and chemical properties of problem soils. The increase in the water-holding capacity and decrease in the infiltration and saturated hydraulic conductivity are more evident in coarse-textured soils than in fine-textured soils.

Several studies have been carried out to determine the effect of mixing organic materials with soils on the physical properties. In their study, Unger and Stewart (1974) determined that organic matter amendment in clay soils increased the aggregate stability and soil permeability. In a similar study, Zebarth et al. (1999) reported that the most important effects of organic materials on soils were the decrease in the bulk density and increase in the water-holding capacity, aggregate stability, hydraulic conductivity and permeability. In their study, Nyamangara et al. (2001) investigated the effects of different doses of a chemical fertilizer and farmyard manure on the aggregate stability and water-holding capacity of soils. Their results showed that aggregate stability and water-holding capacity increased with the application of farmyard manure compared with the control and other applications. Asghari et al. (2009) applied 25 g/kg cattle manure to sandy loam soil and determined that, compared with the control, the application significantly increased the number of micropores and significantly decreased the number of macropores ($P \leq 0.05$) and correspondingly, led to an increase in the water holding-capacity. Eusufzai and Fujii (2012) reported that the application of compost, rice straw and sawdust to clay loam-textured soil increased the water-holding capacity, hydraulic conductivity and pore size of the soil.

The study aims to improve the physical properties of sandy soils and thus, the chemical properties of the soils were excluded from the study. There were many studies that aimed to determine the effects of worms on soil (Schrader and Zhang, 1997; Feng et al., 2001; Topoliantz et al., 2002; Panicker et al., 2007), but there is still a lack of information. The number of the studies investigating the relationship between earthworm manure and soil-water is limited. The studies have generally focused on the effects of earthworm population in manure on soil properties. On the other hand, it is not exactly known how food wastes (eg walnut shells) that are thrown or mixed after use have affected soil properties. This study investigates the effects of the application of different ratios of walnut sawdust (WS), earthworm manure (EM) and farmyard manure (FM) to sandy loam soil on the hydraulic conductivity (Ksat) and available water-holding capacity (AWC) of the soils.

Materials and method

The study was carried out under laboratory conditions to reduce the effects of environmental factors (climate, the effects of terrestrial and subterranean organisms, etc.) and prepare the conditions for the incubation of SOM. The study was conducted under laboratory conditions. During the study, mean humidity was 65 ± 5% and mean temperature was 25 ± 3 °C. The soils used in the study were collected from the Research and Application Farm of the Bingol University, Bingol, Turkey, from the depth of 0-30 cm. The general properties of the soil were determined by Demir (2016) and are given in *Table 1*. The organic matters (SOM) comprising walnut sawdust (WS),

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earthworm manure (EM) and farmyard manure (FM) were procured from a commercial agricultural company (https://www.ekosol.net.tr; http://www.kabukcu.com.tr). The general properties of the material were determined by the company and are given in *Table 1*.

Table 1. *The general properties of the materials*

Properties	Materials			
	Soil	**WS**	**EM**	**FM**
Clay (%)	17.4	-	-	-
Silt (%)	24.6	-	-	-
Sand (%)	58.0	-	-	-
Soil tekstural class	Sandy Loam	-	-	-
Great Soil Group	Xerorthent	-	-	-
pH	7.0	7.4*	6.7*	6.5*
EC (μS/cm)	176.4	-	-	-
$CaCO_3$ (%)	0.1	<0.1	<0.1	<0.1
Bulk density (g/cm^3)	1.49	0.57	0.38	0.32
Porosity (%)	42.7	68.0	72.0	77.0
Organic Matter (%)	2.3	77	46	69
CEC	31.6	33.4	48.2	47.1
C:N	9:1	78:1	15:1	22:1

*1:2 H_2O, WS: Walnut shell, EM: Earthworm manure, FM: Farm manure, EC: Electrical conductivity, CEC: Cation exchange capacity, C:N: Rate of carbon on nitrate

The soils were analyzed by Demir (2016) and the size distribution of the sand, silt and clay fractions of the soils was determined using the Bouyoucos hydrometer method (Gee and Bauder, 1986). The pH and electrical conductivity were measured in accordance with Mclean (1982) and Rhoades (1982) under saturated soil conditions. The organic matter content of the soil was determined following the Smith Weldon method (Nelson and Sommers, 1982). Soil lime content was determined using a Scheibler Calcimeter by following the method proposed by Nelson (1982). The cation exchange capacity was determined using sodium acetate in accordance with Chapman (1965). The bulk density values of the soils were determined by following the method proposed by Blake and Hartge (1986).

Preparation of the study materials

The SOMs were prepared by sieving with a 0.5-mm sieve and mixed with the soils at ratios of 1%, 2%, 4% and 8% on a weight/weight (w/w) basis. SOM application rates were determined according to the farmer practices (between 0 and 8% w/w) in Turkey. The mixtures were prepared in three replications and added to the test containers. In addition, a non-SOM-containing mixture was prepared to minimize the errors that may occur during the experiment. The test containers were made of plastic (pot volume: 22 L; top diameter: 420 mm; height: 310 mm). The mixtures in the test pots were irrigated under laboratory conditions at the level of field capacity and incubated for three months (*Fig. 1*). The pots were irrigated at 3-day intervals to maintain the soil moisture content at around field capacity. For this purpose, irrigation was carried out at a certain rate

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determined depending on the moisture hold by soils at field capacity (pF 2.54). The quality of the irrigation water was classified as C1S1 in accordance with the US Salinity Laboratory (USSL, 1954).

Figure 1. *Incubation of organic matter-soil mixture under laboratory conditions*

Hydraulic conductivity and water-holding capacity

The hydraulic conductivity (Ksat) of the soils under saturated conditions was determined using a permeameter by following Klute (1965). The Ksat was calculated using *Equation 1:*

$$Ksat = \frac{aL}{At}\ln\left(\frac{h0}{h1}\right) \quad \text{(Eq.1)}$$

Here, Ksat represents the hydraulic conductivity (cm/s), a represents the cross-sectional area of the burette (cm^2), A represents the cross-sectional area of the soil sample (cm^2), L represents the column length of the soil sample (cm), h0 represents the initial water height (cm), h1 represents the final water height (cm), and t represents the time between the start and end (s).

The available water-holding capacity and the moisture content at the field capacity (FC) and wilting point (WP) of the soils were measured using a pressure plate apparatus Cassel and Nıelsen (1986). Using a pressure membrane device, the field capacity of the undisturbed soil samples was determined using their moisture content at 1/3 atm and the permanent wilting point of the disturbed soil samples was determined using their moisture content at 15 atm.

The available water-holding capacity of the soils was calculated using *Equation 2:*

$$AWC = FC - WP \quad \text{(Eq.2)}$$

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Here, AWC represents the available water-holding capacity (%), FC represents the moisture content at field capacity (%) and WP represents the moisture content at wilting point (%).

The variance analysis of the results was performed using the SPSS software program (SPSS, 2015).

Results and discussion

The WS, FM and EM applications were determined to affect the hydraulic capacity of the sandy soils (*Table 2*). Compared with the control application, the SOM amendments reduced the hydraulic conductivity of the sandy soils ($p < 0.01$). The lowest mean hydraulic conductivity values were obtained with the WS and EM applications. The 8% dose of the SOM applications was more effective than the other doses. Compared with the control application, the 8% WS application decreased the hydraulic conductivity by 51%, followed by the FM application with 35% and EM application with 39%. Considering the average manure application dose, hydraulic conductivity was determined to decrease with increasing doses.

Table 2. *The effect of the organic materials on the saturated hydraulic conductivity of the soils*

Treatments	**Ksat (x 10^{-4} cm/s)**			
	WS	**FM**	**EM**	**Means**
%1	2.26bcd	2.69bc	2.60bc	2.51BC
%2	2.11cd	3.53a	2.17cd	2.61B
%4	2.43bcd	2.13cd	2.47bcd	2.34C
%8	1.89**d**	2.12cd	2.06cd	2.02**D**
Control	2.87ab	2.87ab	2.87ab	2.87A
Means	2.31B	2.67A	2.43B	
	Df	**Sum of squares**	**F**	**P**
Dose	2	9.8289567E-9	9.51	<0.01
SOM	4	3.5693963E-8	17.27	<0.01
Dose*SOM	8	3.5026754E-8	8.47	<0.01
Error	30	1.5498863E-8		
General	44	9.6048537E-8		

AWC: Available water content, WS: Walnut shell, EM: Earthworm manure, FM: Farm manure, SOM: Soil organic matter

The hydraulic conductivity of the sandy soil was also affected by the interaction between SOM and dose ($p < 0.01$). Within this context, the lowest K*sat* value was obtained with the 8% WS application. In other words, the 8% dose of the WS application was determined to decrease the hydraulic conductivity by 51%. The negative correlation between K*sat* and soil pore size results in increased water flow rate. The filling of large soil pores with fine organic materials leads to reduced K*sat* (Esmaeelnejad et al., 2017). Pulat et al. (2018) reported that the application of 1% biopolymer solution to a 70% sand-containing soil sample resulted in a 25-fold decrease in the hydraulic conductivity. In the same vein, Zhang et al. (2016) determined that the

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application of ground biochar particles to sandy soil decreased the hydraulic conductivity and attributed the decrease to the destruction of the pore structure of the sandy soil by the materials added to the soil.

Addition of organic matters to soils is one of the most commonly used methods to increase the water-holding capacity of soils in soil management applications. Water-holding capacity is defined as the amount of water retained by soils for the use of plants. This amount is largely determined by the texture of the soil and to a certain degree, by the structure and organic material content (Soıl Management Guıde, 2008). *Table 3* shows the effects of WS, FM and EM applications to sandy loam soil on the water-holding capacity. The SOM amendments resulted in increased water-holding capacity in comparison with the control application ($p < 0.01$). The results of the study showed that the 1% WS application was the most effective application, while the 1% FM application had the lowest effect. In the study, both the differences between the averages of the SOM varieties and the averages of the treatment doses were statistically significant. *Table 3* shows that the averages of the application doses were in the same significance group, while the differences between the averages of the SOM varieties were in different statistical significance groups. The data indicated that the WS application resulted in a higher increase in the AWC of the soils than other SOM applications.

Table 3. *The effect of the organic materials on the available water-holding capacity of the soils*

Treatments	**AWC (%)**			
	WS	**FM**	**EM**	**Means**
%1	11.96[a]	8.50[e]	10.17[abcde]	10.21**A**
%2	11.31[ab]	10.28[abcde]	10.83[abcd]	10.80**A**
%4	10.84[abcd]	10.06[bcde]	9.66[bcde]	10.18**A**
%8	11.26[abc]	9.40[cde]	11.33[ab]	10.66**A**
Control	9.27[de]	8.47[e]	9.60[bcde]	9.11**B**
Means	10.92**A**	9.34**C**	10.32**B**	
	Df	**Sum of squares**	**F**	**P**
Dose	2	15.91	25.06	<0.01
SOM	4	19.15	10.41	<0.01
Dose*SOM	8	11.70	3.83	<0.05
Error	30	11.46		
General	44	58.23		

AWC: Available water content, WS: Walnut shell, EM: Earthworm manure, FM: Farm manure, SOM: Soil organic matter

Considering the effect of the different doses of SOMs on the water-holding capacity, the highest effect was obtained with the 1% dose of the WS application, 2% dose of the FM application and 8% dose of the EM application. Thus, the effect of the dose varied depending on the characteristics of the SOM. Here, the most important issue is the effect of the organic matter on the moisture content both at field capacity (pF:2.54) and permanent wilting point (pF:4.2). When organic matters have the same effect at both levels, they do not have a significant effect on the water-holding capacity. However, when they have a higher effect at the field capacity than at the wilting point, they

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positively affect the water-holding capacity. Whether organic matter increases the water-holding capacity is an ongoing debate among many researchers. According to Hudson (1994), there is a positive correlation between the organic matter content and water-holding capacity of sandy soils (r = 0.79). Furthermore, Karhu et al. (2011) reported an 11% increase in the water holding capacity after biochar application to soil. Mınasny and Mcbratney (2018) analyzed the results of a total of 60 studies and reported increasing water-holding capacity with increasing amounts of organic carbon in soils and determined that this effect was more evident in sandy soils. The organic matters' retention of higher amounts of water than sandy soils is an expected outcome. This is attributable to the higher pore number of organic materials than that of sandy soils. In addition, the capillarity of organic materials is much higher than the capillarity of sandy soils. Indeed, the results of several studies agree with this theory. In various studies investigating the improvement of the water-holding capacity of soils, organic materials of different origins were used (farmyard manure, legume leaves, rice stalk, biochar) and the results have revealed that the use of organic materials led to increased available water-holding capacity (Yılmaz and Alagöz, 2008). Agreeing with previous studies, in the study, walnut sawdust was determined to increase the water-holding capacity of sandy soils.

Conclusions

The sustainable use of soils depends on knowing and preserving their properties. Soil organic matters, which have positive effects on various physical and chemical properties of soils, are also among the soil properties that require preservation and improvement. In the study, the application of walnut sawdust, earthworm manure and farmyard manure to sandy soil reduced the hydraulic conductivity of the soil. Moreover, the application of the materials to the soil increased the available water-holding capacity. In conclusion, the outcomes of the study can be summarized as follows:

1. The experiments showed that the application of the increasing doses of walnut shell, earthworm manure and farmyard manure to sandy-textured soil decreased the hydraulic conductivity.
2. Among the three organic waste types, the highest decrease in hydraulic conductivity was obtained with farmyard manure. In addition, in all applications, the highest decrease in hydraulic conductivity was obtained with the dose of 8%. This is of significance in terms of water conservation in sandy soils and especially in arid-region soils.
3. Another outcome of the study was the increased water-holding capacity due to organic matter application to soil. Furthermore, walnut sawdust increased the water-holding capacity more than other materials.
4. In this study, it is concluded that walnut shell waste decreases hydraulic conductivity in sandy soils and increases water holding capacity.
5. The use of the organic wastes that we use in our daily lives, such as walnut shell, in the improvement of the physical properties of problem soils should be investigated. If these materials are deemed suitable for this purpose, they should be used in soil management applications. They can especially be used effectively in combating erosion, which is the greatest soil problem worldwide.
6. The results of the study showed that earthworm manure improved the hydraulic conductivity and water-holding capacity of soils. However, its production in

limited amounts and high-cost restrict its use in large agricultural areas. In these areas, solely increasing the earthworm population in the soil layer will prove more beneficial. In the current circumstances, earthworm manures can be used in ornamental plant breeding and greenhouses.

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