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Improving Soil Physical Indicators by Soil Amendment to a Saline-Sodic Soil

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Abstract

The application of organic amendments can be an appropriate solution to reclaim and improve physical properties of saline-sodic soils. In this research, an experiment was performed under greenhouse conditions to study the effect of amendments to the physical properties of loamy saline-sodic soil. The five treatments were control (without amendment), municipal solid waste compost (MC), vermicomposting (VC), poultry manure (PM), and gypsum powder (G). They were carried out in a completely randomized design with three replications. Each treatment comprised 10 ton/ha of the specified soil added to the soil. The results showed that soil amendments decreased bulk density ($p<0.05$) and increased mean weight diameter of aggregates (MWD) ($p<0.05$) over the control. The saturated hydraulic conductivity (Ks) for the G treatment was significantly higher than other treatments ($p<0.05$). The addition of amendments significantly increased the S_{gi} index, which is defined as the slope of the retention curve at its inflection point, but the S_{gi} index between the G and MC treatments was not significant ($p<0.05$). In addition, plant available water content (PAWC) increased significantly ($p<0.05$) for organic amendments over the G and control treatments, and a maximum value was observed for the PM treatment. The positive effects of the amendments showed that the application of organic and/or inorganic amendments can be recommended for saline-sodic soil to improve soil physical quality.

Keywords: Amendments; Sodicity; Soil quality; Soil water content

1. Introduction

Soil is essential to a nation's food supply, so an understanding of the physical, chemical, biological, and mineralogical of soil is necessary. Suitable management practices and land use should be conducted for soil quality conservation (Lal *et al*., 1999). The physical quality of soil is characterized by different features. Soils with poor physical quality may have one or several of the following characteristics: low infiltration rate, surface run-off, hard-setting, low aeration, poor rooting, and poor workability (Dexter, 2004). Some important physical quality indicators in agricultural soils are relative field capacity, plant available water content (PAWC), aeration porosity, bulk density, organic carbon content, and the structural stability index (SI) (Reynolds and Topp, 2008).

Denef *et al*. (2001) suggested mean weight diameter (MWD) of wet stable aggregates as an effective parameter to measure soil quality. This parameter directly or indirectly affects retaining and providing water, air, and nutrients for crop production (Reynolds *et al*, 2009). Dexter (2004) introduced the slope of the retention curve (S_{gi} index) as an index of physical soil quality for physical properties, such as hydraulic conductivity, soil compaction, optimum moisture for tillage, soil resistance against root penetration, PAWC, and structural stability. Soil structure is also an important property that affects crop production. Qualitative soil

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parameters such as bulk density, porosity, permeability of air and water, and water retention are strongly related to soil structure (Hao *et al*., 2008; Pagliai *et al*., 2004).

The application of organic amendments to saline-sodic soils is a suitable remedy for reclaiming and improving soil productivity (Melero *et al*., 2007). In recent years, the application of municipal solid waste compost to agricultural lands has increased. Compost as a source of organic carbon improves soil physical properties. The helpful effects of compost on soil properties depend on soil texture, moisture conditions, and the source of organic matter (Drozd, 2003). Studies on municipal solid waste compost shows that it increases the soil organic carbon, and as a result, soil structure improves and water infiltration rate increases (Aggelides and Londra, 2000; Caravaca *et al*., 2003; Khandan and Astaraei, 2005). The addition of G to soil leads to sodium replacement by calcium ions at exchange sites, decreasing clay dispersion and improving soil physical properties (Mann *et al.*, 1982).

Khandan and Astaraei (2005) reported that bulk density in compost and manure treated soils decreased significantly compared to inorganic treatments. The values for water holding capacity, porosity, and micro-pores were highest for the compost treatment and for macro-pores were the highest for the compost and manure treatments. An increase in PAWC by the addition of municipal solid waste compost was reported by Emami and Astaraei (2012).

Tejada and Gonzalez (2006) found that increasing the electrical conductivity of saline soils, decreased the structural stability and bulk density. High amounts of exchangeable sodium ions and pH resulted in the swelling and dispersion of clay particles, aggregate degradation, and a reduction in the infiltration rate and PAWC (Lauchli, 1990).

The positive effect of organic matter and calcium compounds on soil physical properties has been reported in the literature. Aggelides and Londra (2000) concluded that the chemical properties of the loamy and clay soils were affected by the addition of compost. Similarly, the physical properties of the amended soils (saturated and unsaturated hydraulic conductivity, water retention capacity, bulk density, total porosity, pore size distribution, soil resistance to penetration, aggregation and aggregate stability) improved (Aggelides and Londra, 2000). Increasing the S_{gi} index, PAWC, MWD of the aggregates, and decreasing bulk density by the application of G and municipal solid waste compost was also reported by Emami and Astaraei (2012).

The unfortunate increase in land degradation in Iran requires different management practices. It appears that soil amendments on soil physical properties of saline–sodic soils is necessary. This research studied the effect of soil amendments (organic matter and gypsum powder) on the soil physical indicators in saline-sodic soil.

2. Materials and methods

This research was carried out as a completely randomized design with three replications at a research greenhouse at Ferdowsi University of Mashhad, Iran in 2011. The five treatments were:

1) control (no amendment),

2) municipal solid waste compost (MC),

3) vermicomposting (VM),

4) poultry manure (PM),

5) gypsum powder (G).

A saline-sodic soil was selected (Table 1) and 10ton/ha of each treatment was added to the soil. Based on initial bulk density ($1.5 gcm^{-3}$), the soils were repacked into boxes 40 cm in length, 30 cm in width, and 30 cm in depth. The properties of the amendments are shown in Table 2. After addition of the treatments, the soils were kept under greenhouse conditions for 6 mo and irrigation was done every week using tap water ($EC = 0.5\ dSm^{-1}$).

At the end of experiment, saturated hydraulic conductivity (Ks) was measured using a single ring using the Beerkan method and constant head (Lassabatere *et al*, 2006), the MWD of the aggregates using the wetting method (Kemper and Rosenau, 1986), bulk density using the clods method (Blake and Hartge, 1986), and water dispersible clay using the method described by Rengasamy (1984). The undisturbed soil cores (5 cm in diameter by 5 cm in length) were prepared for determination of the soil moisture characteristic curve. To do this, soil moisture were measured at 0, -10, -30, -50, -100, -300, -1000, and 1-500 kPa pressure head using a pressure plate apparatus. The slope of the retention curves at the S_{gi} index, PAWC, and aeration porosity were determined using the soil moisture characteristic curve data. The soil moisture characteristic curve data was then fitted to the Van Genuchten equation (1980) using RETC software. The parameters of the

Van Genuchten equation (1980) were then used to determine S_{gi} index as follows:

$$\theta_g = (\theta_{gs} - \theta_{gr})[1 + (\alpha h)^n]^{-m} + \theta_{gr}; h \geq 0(cm) \quad 1(a)$$

$$\Theta = \frac{\theta_g - \theta_{gr}}{\theta_{gs} - \theta_{gr}} = [1 + (\alpha h)^n]^{-m}; 0 \leq \Theta \leq 1 \quad 1(b)$$

where θ_g ($kgkg^{-1}$) is the gravimetric water content, θ_{gs} ($kgkg^{-1}$) is the saturated gravimetric water content, θ_{gr} ($kgkg^{-1}$) is the residual gravimetric water content, Θ(−) is the normalized water content or degree of saturation, and α (hPa^{-1}), n (−) and m (−) are empirical curve fitting parameters, and m = 1−(1/n). Eqs. 1(a) and 1(b) are fitted to the soil moisture characteristic curve data using nonlinear least squares optimization in RETC (2008). The slope of the θ(h) vs. ln(h) function, Sg(h) (−), is given by:

$$S_g(h) = \frac{d(\theta_g)}{d(\ln h_i)} = -mn(\theta_{gs} - \theta_{gr})\alpha^n h^n [1 + (\alpha h)^n]^{-(m+1)} \quad (2)$$

and the magnitude of the slope at the inflection point, S_{gi} (−), is:

$$S_{gi} = \frac{d(\theta_{gi})}{d(\ln h_i)} = \left| -n(\theta_{gs} - \theta_{gr})\left[1 + \frac{1}{m}\right]^{-(m+1)} \right| \quad (3a)$$

where

$$\theta_{gi} = (\theta_{gs} - \theta_{gr})\left[1 + \frac{1}{m}\right]^{-m} + \theta_{gr} \quad 3(b)$$

and

$$h_i = \frac{1}{\alpha}\left(\frac{1}{m}\right)^{\frac{1}{n}} \quad 3(c)$$

where θ_{gi} and h_i are the gravimetric water content and pressure head at the inflection point, respectively. The Sg(h) function and the S_{gi}, θ_{gi} and h_i values for a measured moisture characteristic curve are provided by Eqs. 2 and 3(a)–3(c), after n, m, α, θ_{gs} and θ_{gr} are determined by fitting Eq. Details of the derivation of Eqs. 2 and 3(a)–3(c) can be obtained from Dexter (2004).

The definition and optimal range of thed physical quality indicators are presented 2in Table 3. The results of the treatments were statistically analyzed using SAS9.1 software. The means of the treatments were compared using the Duncan test at p<0.05..

Table 1. Some properties of studied soil

texture	-	Loam
EC_e	(dS m^{-1})	4
ESP	%	35.4
pH	-	9.1

Table 2. pH and EC of studied amendments

	pH	EC* (dS m^{-1})
PM	8.10	12
VC	8.25	7.5
MC	7.61	**9**

* EC was measured in 1:5 of amendment: distilled water.

Table 3. Definition and optimal range of soil physical quality indicators

Indicators	Define[e]	Scope of changes
AC[a]	$AC = \theta_S(\psi = 0) - \theta_{FC}(\psi = -1m)$	$0 \leq AC \leq \theta_S$
PAWC[b]	$PAWC = \theta_{FC}(\psi = -1m) - \theta_{PWP}(\psi = -150\,m)$	$0 \leq PAWC \leq \theta_{FC}$
BD[c]	$BD = M_S / V_b$	-
MWD[d]	$MWD = \sum_{i=1}^{n} x_i w_i$	-

[a] Cited from White (2006); [b] Cited from White (2006); [c] Cited from Hao (2008); [d] Cited from Kemper and Rosenau(1986); [e] θ_S (m^3m^{-3}): the saturated soil water content, θ_{FC} (m^3m^{-3}): field capacity water content, and Ψ(m): soil pressure head. θ_{PWP} ($m^{-3}m^{-3}$): permanent wilting point water content. M_S (g): weight of oven dry soil. V_b (cm^3): soil volume. w_i (g): weight of aggregates remaining on each sieve. x_i (mm) Average diameter of two consecutive sieves.

3. Results and discussion

3.1. Effect of soil amendments on MWD

The results of MWD showed that the application of amendments increased MWD significantly (p<0.05); the highest MWD was observed for MC and was 1.5 the magnitude of the control. The G, VM, and PM treatments increased MWD values by 1.26, 1.12 and 1.12, respectively, over that of the control (Table 4). The increase in MWD as a result of the organic amendments was the result of organic carbon, which provided a carbon source for micro-organisms. The activity of the micro-organisms increased and components such as polysaccharides and Fungi mycelium were produced that bonded the soil particles and formed macro-aggregates. Gypsum formed by flocculation of clay particles from the substitution of calcium for exchangeable sodium and an increased concentration of electrolytes, formed and stabilized the clay clusters (Chorom and Rengasmy, 1997). Tejada *et al*. (2006) found that the application of organic matter, especially high values of organic waste, increased soil structural stability. An increase in MWD by the application of G, vinyl alcohol acrylic acid hydrogel, and urban solid waste compost has been reported by Emami and Astaraei (2012).

Table 4. Effect of experimental treatments on soil physical properties.

treatments	Mean Weight of diameters (mm)	Water dispersible clay (%)	Bulk density (g/cm^3)	Saturated hydraulic conductivity (cm/min)	S_{gi} index (-)	Plant available water contents (m^3/m^3)
Control	0.314^{c}	92.64^{a}	1.54^{a}	0.01^{cd}	0.046^{c}	0.154^{b}
Gypsum powder	0.709^{ab}	20.83^{c}	1.40^{c}	0.255^{a}	0.088^{a}	0.151^{b}
Urban solid waste compost	0.793^{a}	40.04^{b}	1.45^{b}	0.01^{cd}	0.088^{a}	0.209^{a}
Vermin-compost	0.667^{b}	40.02^{b}	1.44^{b}	0.03^{bc}	0.083^{b}	0.208^{a}
Poultry manure	0.667^{b}	43.88^{b}	1.43^{b}	0.07^{b}	0.082^{b}	0.212^{a}

* same letters in each column are not significant at $P < 0.05$.

3.2. Effect of soil amendments on water dispersible clay

A comparison of the treatments on water dispersible clay content showed that the application of organic amendments and G decreased water dispersible clay content significantly (p<0.05) over the control; it decreased from 92.64% to 20.82% for the G treatment. The different organic treatments showed no significant differences (Table 4). After the addition of G, Ca^{+2} cations released in soil solution, that replaced the Na^{+} at exchangeable sites. The diffuse double layer then decreased and the concentration of electrolytes increased. As a result of these processes, the clay particles flocculate. The results of this research are consistent with those of Sadana and Bajwa (1985) and Chorom and Rengasmy (1997).

3.3. Effect of soil amendments on bulk density

The application of the amendments decreased bulk density significantly (p<0.05) over the control. G decreased bulk density for water dispersible clay more than did the organic treatments. The differences between organic treatments were not significant at p<0.05 (Table 4). The decrease in bulk density on the effect of organic matter was caused by aggregate formation and the increase in soil porosity. The larger decrease in bulk density for G was caused by increased aggregation in saline-sodic soil. The decrease in bulk density after addition of G has been reported by Southard *et al*. (1988).

Tejada *et al*. (2006) investigated the effect of poultry manure and grain cotton compost on the properties of saline soil and concluded that application of these amendments decreased bulk density. The decrease in bulk density upon application of compost has also been reported by Wang and Yang (2003) and is similar to the findings of this research. Emami and Astaraei (2012) reported that the application of gypsum powder, urban solid waste compost and vinyl alcohol acrylic acid resulted in a significant decrease in bulk density; the lowest bulk density was observed for urban solid waste compost.

3.4. Effect of soil amendments on Ks

The application of G decreased Ks significantly (p<0.05), 24 times greater, than that for the control (Table 4). Among the organic amendments, only the PM treatment increased Ks significantly (p<0.05) over the control. Roosta *et al*. (2001) found that, because of water clay dispersion and the occlusion of soil pores, that low and medium amounts of organic matter (10 and 20 ton/ha) without G produced no major increase Ks in sodic soils. If organic carbon prevents clay dispersion, it should be expected that the application of organic matter would increase Ks. Hanay *et al*. (2004) and Mace and Amrhein (2001) concluded that the application of G to poorly structured soils flocculated the soil particles, increased Ks, and improved the reclamation of salinity–sodicity. Mann *et al*. (1982) found that the application of G to saline-sodic soil decreased the percentage of sodium exchange and increased Ks and outlet leachate.

3.5. Effect of soil amendments on S_{gi} index

The application of the amendments increased the S_{gi} index significantly ($p<0.05$) over the control (Table 4). The maximum increase was significant ($p<0.05$) for G from all other treatments except for MC. Application of the amendments increased the ratio of macro-aggregates to micro–aggregates and it resulted in an increased S_{gi} index. In fact, the amendments improved soil structure (increasing MWD) and increased structural and macro-porosity, hence, the S_{gi} index increased and bulk density decreased. An increase in S_{gi} index as organic matter increased was reported by Dexter (2004) in loamy sand and silty loam of England. Emami *et al*. (2012) found a linear and significant correlation between organic matter and the S_{gi} index. Emami and Astaraei (2012) concluded that the application of G, urban solid compost, and vinyl alcohol acrylic acid increased S_{gi} index to at least 0.035.

3.6. Effect of soil amendments on PAWC

The application of organic matter increased PAWC significantly ($p<0.05$) over the control and G treatments. The difference between G and the control for PAWC was not significant at $p<0.05$ (Table 4). Organic amendments have a high capacity to retain water, so for field capacity pressure head, most moisture content was retained in the soils. Soils with high amounts of organic carbon released water gradually, so the PAWC in these soils was higher than those with low organic carbon. Gupta *et al*. (1977) and Webber (1978) found that the application of organic matter increased water-holding capacity. The increase in PAWC caused by urban solid compost and absorbent has been reported by Emami and Astaraei (2012).

4. Conclusion

The results of this research showed that the application of all amendments decreased bulk density significantly ($p<0.05$) and increased MWD and the S_{gi} index significantly ($p<0.05$) over the control. The Ks for the G treatment was significantly higher than for the other treatments ($p<0.05$). Also, organic amendments increased PAWC significantly ($p<0.05$) over the control. The results of this research show that the application of gypsum powder and, especially, organic amendments are suitable solutions to reclaiming and improving the physical properties of saline-sodic soils.

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