Effects of vermicompost and water treatment residuals on soil physical properties and wheat yield

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A b s t r a c t. The application of vermicompost and water treatment residuals to improve the physical properties in the salt affected soils is a promising technology to meet the requirements of high plant growth and cost-effective reclamation. Therefore, the aim of this study was to investigate the effect of vermicompost and its mixtures with water treatment residuals on selected physical properties of saline sodic soil and on wheat yield. The treatments were vermicompost, water treatment residuals, vermicompost + water treatment residuals (1:1 and 2:1 wet weight ratio) at levels of 5 and 10 g dry weight kg^{-1} dry soil. The considered physical properties included aggregate stability, mean weight diameter, pore size distribution and dry bulk density. The addition of vermicompost and water treatment residuals had significant positive effects on the studied soil physical properties, and improved the grain yield of wheat. The treatment of (2 vermicompost + 1 water treatment residuals) at level of 5 g kg^{-1} soil gave the best grain yield. Combination of vermicompost and water treatment residuals improved the water treatment residuals efficiency in ameliorating the soil physical properties, and could be considered as an ameliorating material for the reclamation of salt affected soils.

K e y w o r d s: bulk density, pore size distribution, aggregate stability, wheat yield, vermicompost, water treatment residuals

INTRODUCTION

Soil salinity is one of the major problems for agriculture in semi arid regions, such as Egypt. Under salinity conditions, dissolved salts may accumulate in soils and inhibit plant growth. When soluble salts accumulate, Na$^+$ often becomes the dominant counter ion in the soil complex, causing the soil to become disperse. This results in a number of physical problems such as poor structure, surface crusting and poor drainage (Qadir and Schubert, 2002). The application of soil amendments to improve the physical properties of salt affected soils is a promising technology to meet the requirements for high plant growth and cost-effective reclamation. Organic materials are important soil amendments in improving soil physical properties and sustaining soil productivity, particularly in arid and semi-arid regions where there is low input of organic matter. This is because the soil physical properties have a very high degree of correlation with crop production and a high influence on soil fertility and crop performance (Nnaji, 2009). Soil amendment with manures, composts, municipal biosolids and other organic wastes has been found to improve the physical and chemical properties of soil (Barzegar *et al*., 2002; Šimon *et al*., 2013; Unagwu *et al*., 2013). Beneficial effects of organic soil amendments include decreased soil bulk density and increased water holding capacity, aggregate stability, saturated hydraulic conductivity, water infiltration rate and biochemical activity (Martens and Frankenberger, 1992; Turner *et al.,* 1994). Furthermore, soil aggregates can physically protect soil organic matter from biodegradation and improve the soil structure and the pore size distribution (Tisdall and Oades, 1982), all of which can affect the soil hydraulic properties. Oluwadare and Osakwe (2014) showed that the effects of organic soil amendments on soil physical properties improved by enhancing soil organic carbon status. Although several organic materials have been researched in the aspect of improving soil physical properties (Angin *et al.,* 2013; Barzegar *et al.,* 2002; Lordan *et al.,* 2013; Moodley *et al.*, 2004; Moodley and Hughes, 2006), limited literature is available on the combination of vermicompost (VC) and water treatment residuals (WTR) for improving saline-sodic soils.

Vermicompost (VC) which is produced by the fragmentation of organic wastes by earthworms, contains nutrients in forms that are readily available for plant uptake (Atiyeh *et al.,* 2000). There is good evidence that VC application promotes growth of plants and it has been found to have a positive effect on growth and productivity of cereals and legumes (Azarmi *et al.,* 2008; Benik and Bejbaruah, 2004; Glenda *et al.,* 2009; Suthar, 2006). There is an increasing interest in the potential use of VC as soil amendment, where the addition of VC improves the soil physical and chemical properties (Angin *et al.,* 2013; Azarmi *et al.,* 2008; Lordan *et al.,* 2013).

Water treatment residuals (WTR) is the by-product of the production of potable water and its disposal amount is huge (Babatunde and Zhao, 2007). It was traditionally disposed to landfill but there is growing interest in applying this waste to land as an alternative disposal option (Moodley *et al.,* 2004). WTR consists mainly of flocculated fine silt and clay, Al and Fe salts, and organic polymers which are frequently used as coagulating agents in drinking water treatment to aid settling of suspended particles and to clarify water (Ippolito *et al.,* 2006). Previous studies have shown that the application of WTR to land as a soil amendment improved the physical soil properties by decreasing bulk density and increasing hydraulic conductivity and water retention, because of the sustained performance of the polymer in binding the silt and clay into gravel-sized aggregates. Such changes were only significant at the 1.28Mg ha^{-1} application rate (Moodley and Hughes, 2006). Therefore, very large amounts of WTR would have to be applied in order to markedly change these inherent physical properties of soils. However, high application rate of the WTR (>10%) causes deficiency of plant available phosphorus, which results in reducing plant growth (Dayton and Basta, 2001). Therefore, it is necessary to add fertilizer and/ or organic matter for mitigate soil P deficiencies when WTR is reused actually as a growth medium (Park *et al.*, 2010).

The objective of this study is, therefore, to investigate the effect of VC, WTR and their mixtures at ratios of 2:1 and 1:1 wet weight (VC:WTR), on selected physical properties of saline sodic soils and on the yield of wheat (*Triticum aestivum*).

MATERIALS AND METHODS

Wheat (*Triticum aestivum)* cultivar Sakha 93 was sown in pots on November 15, 2009. Nine treatments were applied in a randomised complete blocks design with three replicates. The treatments used in this experiment were: T0: Control; T1 :VC at 5 g kg^{-1}; T2 :VC at 10 g kg^{-1}; T3 :WTR at 5 g kg^{-1}; T4 : WTR at 10 g kg^{-1}; T5 :VC + WTR (1:1) at 5 g kg^{-1}; T6:VC + WTR (1:1) at 10 g kg^{-1}; T7 : VC + WTR (2:1) at 5 g kg^{-1}; T8 : VC + WTR (2:1) at 10 g kg^{-1}. Vermicompost used in this experiment was made of rice straw and animal wastes with earthworm species *Eisenia*

fetida and *Dendrobaena veneta*. Water treatment residuals (WTR) were collected from El-Beharia, Egypt, water treatment plant. The properties of VC and WTR are illustrated in Table 1. Each pot contained 10 kg soil from surface soil samples (0-30 cm) after air-drying, crushing and passing through an 8 mm sieve to reflect natural soil conditions. The soil portions were uniformly mixed with the VC and WTR, and packed in plastic pots of 23 cm diameter and 25 cm height. The soil samples were collected from El-Hamoul area (31-07'N Latitude, 30-57'E Longitude, with elevation of about 6 m above mean sea level), Kafr El-Sheikh Governorate, Egypt. Some physical and chemical properties of the studied soil samples are presented in Table 1. Nitrogen fertilizer was added in three equal doses as NH_4No_3 33.5% N at the rate of 178.6 kg ha^{-1} and a basal dose of phosphorus was applied as super phosphate 15% P at the rate of 35.7 kg ha^{-1}. The amount of irrigation water was determined by weighting the pots to raise the moisture content to the field capacity of each treatment, with the addition to 15% as leaching requirement.

Wheat plants were harvested after 140 days from sowing, when the grains were ripened. The grains were separated from the vegetative part and the yield of these two components was measured in g per pot. After wheat harvesting, a representative soil sample was taken from each pot and analyzed for selected soil physical properties.

Electrical conductivity (EC) and pH were determined in extract of the saturated vermicompost, WTR and soils using pH and conductivity meters, respectively. The cations ($Na^+ Mg^{++}$, Ca^{++}, K^+) and anions (HCO^{3-} and Cl^-) were determined in soil paste extract as described by Rhoades (1954). Ash content was determined in a muffle oven at 550°C for 8 h, and organic matter of vermicompost was calculated as the difference between ash and dry weight (50% of OM of compost was considered organic C) (AFNOR, 1991). Organic matter of WTR and soil was determined according to Walkely and Black rapid titration method, as outlined by Kim (1996). Organic matter of soil and WTR was calculated by multiplying the organic carbon value by 1.724 based on the assumption that organic matter contains 58% organic carbon.

Particle size distribution of the soil samples was determined using the international pipette method, as described by Kim (1996). Bulk density was determined using the core method by weighing undisturbed soil samples of a volume of 250 cm^3 (Blake and Hartge, 1986).

Aggregate stability (AgSt) was determined in undisturbed soil samples using a wet sieving method (Kemper and Rosenau, 1986). Forty grams of each air dried soil sample, which passes through an 8 mm sieve, was transferred to the upper sieve of a set of sieves having 2.00, 1.00, 0.5 and 0.25 mm screen mesh, in the wet sieving apparatus, wetted by immersion and agitated for 5 min. The fractions over each sieve, at the end of sieving, were collected and oven dried at 105°C for 24 h. Correction for sand content in each aggregate was made after the fractions were dispersed

T a b l e 1. Selected physical and chemical properties of the studied soil samples and soil amendments (vermicompost VC and water treatment residuals WTR)

Properties	Units	Soil (n=20)	VC (n=3)	WTR (n=3)
pH (soil paste extracts)		8.56	7.6	7.62
Electrical conductivity (EC)	dS m^{-1}	25.82	4.65	3.23
Ca^{++}	meq l^{-1}	85.3	16.3	20.3
Mg^{++}	meq l^{-1}	70.2	12.6	5.3
Na^{+}	meq l^{-1}	166.5	20.3	6.3
K^{+}	meq l^{-1}	1.4	3.2	2.9
Al^{3+}	mg kg^{-1}			3315
Cl^{-}	meq l^{-1}	102.0	31.5	28.8
HCO$_3^{-}$	meq l^{-1}	2.56	3.6	2.5
SAR		18.8	5.34	1.76
CaCO$_3$	%	4.6		
Organic matter (OM)	%	0.92	32.6	4.86
Bulk density (BD)	g cm^{-3}	1.53		
Clay	%	34.18		65.7

chemically. Three samples were wet-sieved per treatment. AgSt was expressed as a percentage of the total sieved sample.

The mean weight diameter (*MWD*, mm) was calculated using the following equation:

$$MWD = \sum_{i=1}^{n} XiWi,$$

where: *Xi* is the mean diameter of each size fraction (mm), *Wi* is the proportion of the total sample mass in the corresponding size fraction, and *n* is the number of samples.

Pore size distribution was calculated from the water retention curves using pressure cooker at pressures of 10 and 33 kPa, and pressure plate apparatus at 1 500 kPa. The pore diameter corresponding to pressures of 10, 33 and 1 500 kPa is equal to 28.4, 8.62 and 0.19 μ, respectively. The values of moisture content on volume basis used for calculating the percentage of quickly drainable pores (QDP): >28.84 μ diameter, slowly drainable pores (SDP): 28.84-8.62 μ diameter, water holding pores (WHP): 8.62-0.19 μ diameter, and fine capillary pores (FCP): <0.19 μ diameter, were determined according to De-Leenher and De-Boodt (1965). All measurements were made in triplicate.

Treatment mean differences were statistically analysed by the least significant difference (LSD 0.05) test (SAS Institue, 1996).

RESULTS

Bulk density (BD) of the studied soil was decreased significantly at (p<0.05) for all treatments except for the WTR alone at 5 g kg^{-1} soil and 5 or 10 g of (1 VC + 1 WTR) kg^{-1} soil, compared to the control treatment (Table 2). The VC treatment recorded higher BD decrease than that of the WTR treatment. Treatment with 10 g of VC resulted in the highest BD decrease (12.5%) in comparison to the control treatment. Data also showed that treatments with mixtures of various ratios between VC / WTR influenced differently the soil BD when compared with VC or WTR treatments alone. As shown in Table 2, the decrease of BD compared to the control treatment was in the following order of treatments: 5g of [2VC+1WTR] >10 g of [2VC+1WTR] < 5 g of [1VC+1WTR] <10 g of [1VC+1WTR].

The effect of soil amendments on the distribution of the different fractions of pores is given in Table 2. Pore size distribution was affected significantly at (p<0.05) by the treatments. The most positively affected categories of pores were the quickly-drainable pores (QDP), slowly drainable pores (SDP) and the water-holding pores (WHP). These three categories also represent major portions of soil porosity, and they are of a very important significance in soil fertility and plant growth.

T a b l e 2. Effect of vermicompost and its mixtures with water treatment residuals on soil bulk density (BD) and pore size distribution after harvest of wheat crop

Treatment	BD (g cm^{-3})	Pore size distribution (%)			
		QDP	SDP	WHP	FCP
T0	1.52 a	21.36 c	14.54 b	25.38 d	38.70 a
T1	1.42 b	30.69 ab	24.00 ab	26.85 cd	18.46 b
T2	1.33 b	25.96 b	21.99 ab	35.75 a	16.30 b
T3	1.46 a	30.12 ab	24.12 ab	26.73 cd	19.02 b
T4	1.42 ab	32.39 a	26.74 a	23.12 e	17.74 b
T5	1.48 a	32.68 a	19.53 ab	28.91 bc	18.89 b
T6	1.51 a	30.94 ab	23.30 ab	26.73 cd	19.02 b
T7	1.30 b	26.15 b	24.05 ab	30.98 b	19.03 b
T8	1.41 ab	30.22 ab	24.50 b	27.47 cd	17.81 b
LSD$_{0.05}$	0.08	3.89	7.17	2.05	3.91

QDP – quickly drainable pores, SDP – slowly drainable pores, WHP – water-holding pores, FCP – fine capillary pores. T0 – control, T1 – VC at 5 g kg^{-1}; T2 – VC at 10 g kg^{-1}; T3 – WTR at 5 g kg^{-1}; T4 – WTR at 10 g kg^{-1}; T5 – VC + WTR (1:1) at 5 g kg^{-1}; T6 – VC + WTR (1:1) at 10 g kg^{-1}; T7 – VC + WTR (2:1) at 5 g kg^{-1}; T8 – VC + WTR (2:1) at 10 g kg^{-1}. The same letter do not differ significantly (p<0.05).

The addition of soil amendments increased significantly at (p<0.05) the quickly drainable pores (QDP) compared to the control (Table 2). The obtained data indicated that vermicompost addition at levels of 5 g kg^{-1} soil and 10 g kg^{-1} soil increased the QDP by 43.67 and 21.53% compared to the control treatment, respectively. The increments of the QDP upon the addition of 5 g kg^{-1} soil and 10 g kg^{-1} soil WTR were 41.01 and 51.63%, respectively, compared to the control treatment. These results indicate that increasing the levels of vermicompost resulted in lower QDP value. Inversely, the highest values of QDP were obtained with the highest application level of 10 g kg^{-1} soil of WTR. Moreover, the differences between the high levels of the added VC and the control treatment are statistically significant. On the other hand, the difference between the low and high level of the added WTR is not statistically significant. The QDP in the pots treated with the WTR and VC combinations at two levels were enhanced when compared to VC alone.

The slowly drainable pore (SDP) was increased significantly for all treatments except for treatments with WTR and VC at the level of 5 of (1 VC+1 WTR) kg^{-1} soil (Table 2). The highest increment in SDP (84%) over the control was obtained from 10 g WTR kg^{-1} soil treatment. The SDP in the soil treated with the WTR and VC combinations at two levels was not significantly different from the other treatments.

Mean values of water holding pore (WHP) increased significantly for all soil amendment treatments as compared to the control (Table 2). The highest increment in WHP (41%) over the control was obtained from 10 g VC kg^{-1} soil treatment, whereas the lowest WHP value was observed at 10g WTR kg^{-1} soil treatment. Increasing VC application from 5 to 10 g kg^{-1} soil increased WHP by 33.15%, whereas the increase of WTR from 5 to 10 g kg^{-1} soil decreased WHP by 15.61%.

The addition of soil amendments and their mixture treatments decreased significantly, at p<0.05, the FCP as compared to the control (Table 2). At the same time, there is no significant difference among all the treatments and between each other. The decrement in FCP ranged from 50.82% at 5g (2 VC+1 WTR) to 57.88% at level 10 g VC kg^{-1} soil. Combinations of VC with WTR at levels of 5 or 10 g kg^{-1} soil had no significant effect on the FCP when compared to VC treatment alone.

The addition of VC and WTR and their mixture treatments increased significantly, at p<0.05, the AgSt as compared to the control (Fig. 1). However, the increment of the AgSt resulting from the addition of VC and WTR combination was not significant. Increasing the VC application rate from 5 to 10 g kg^{-1} soil increased the AgSt by 31.27 and 48.84%, respectively, when compared to the control treatment. The highest increment in AgSt (63.4%) over the control was obtained from 10 g WTR kg^{-1} soil treatment. The AgSt in the soil treated with the WTR and VC combinations at two levels was not significantly different from the other treatments.

As shown in Fig. 1, the effect of the soil amendment additions on the MWD had the same trend as that on the AgSt. Values of MWD increased significantly, at p<0.05,
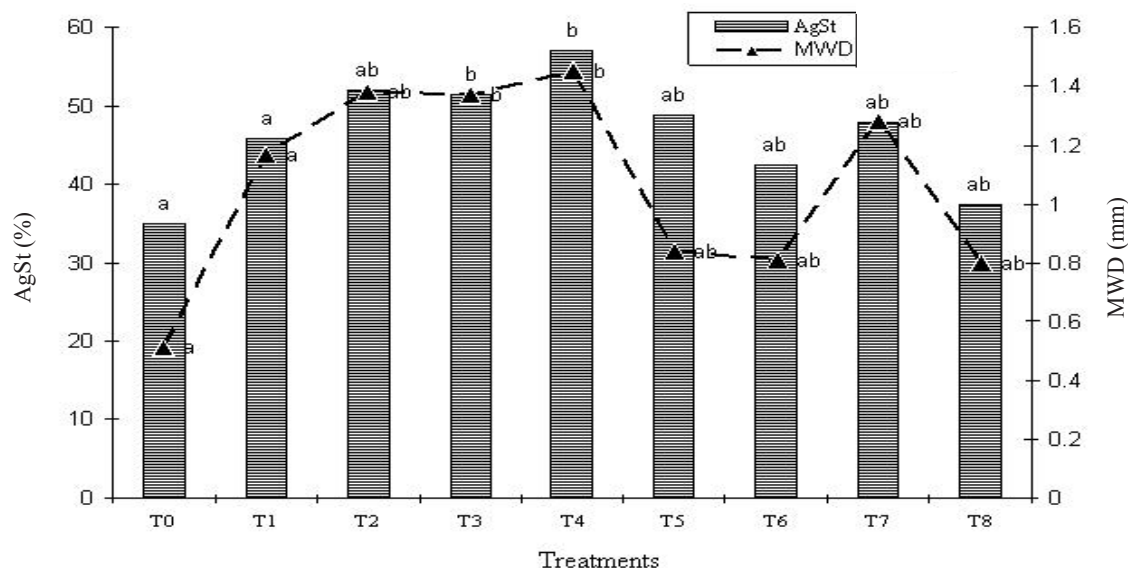
Fig. 1. Effect of vermicompost and its mixtures with water treatment residuals on aggregate stability (AgSt) and mean weight diameter (MWD) of the soil after harvest of wheat crop. Explanations as in Table 2.

by 168 and 184% upon the addition of 5 and 10 g WTR kg^{-1} soil, respectively, as compared to the control treatment, whereas the increment of MWD values upon the addition of 5 and 10 g kg^{-1} soil was 129 and 170% for VC, respectively, as compared to the control treatment. For the VC/WTR mixture treatments, the increase of MWD values was not significantly different (p < 0.05) as compared to the VC alone.

The application of WTR and VC increased significantly the straw and grain yield of wheat plants at levels of 5 and 10 g kg^{-1} soil, compared with the control (Fig. 2). Straw weight increased by 40.37 and 31.19% for the applications of 10 g of WTR and VC kg^{-1} soil, respectively. The grain yield of wheat plants ranged between 8.5 and 14 g pot^{-1}. The highest straw weight and grain yield of wheat plants was observed across all treatments with the addition of 10 g WTR kg^{-1} soil and 5 g (2 VC+1 WTR) kg^{-1} soil treatments, respectively. The grain yield decreased with the addition of WTR at 5 g kg^{-1} soil compared with the levels of 10 g kg^{-1} soil. The straw weight and grain yield of wheat plants did not differ significantly among the treatments (Fig. 2).

DISCUSSION

Bulk density is an index showing soil compaction level, as compaction alone refers to process and inferring root ability. A decrement in BD means an improvement of the
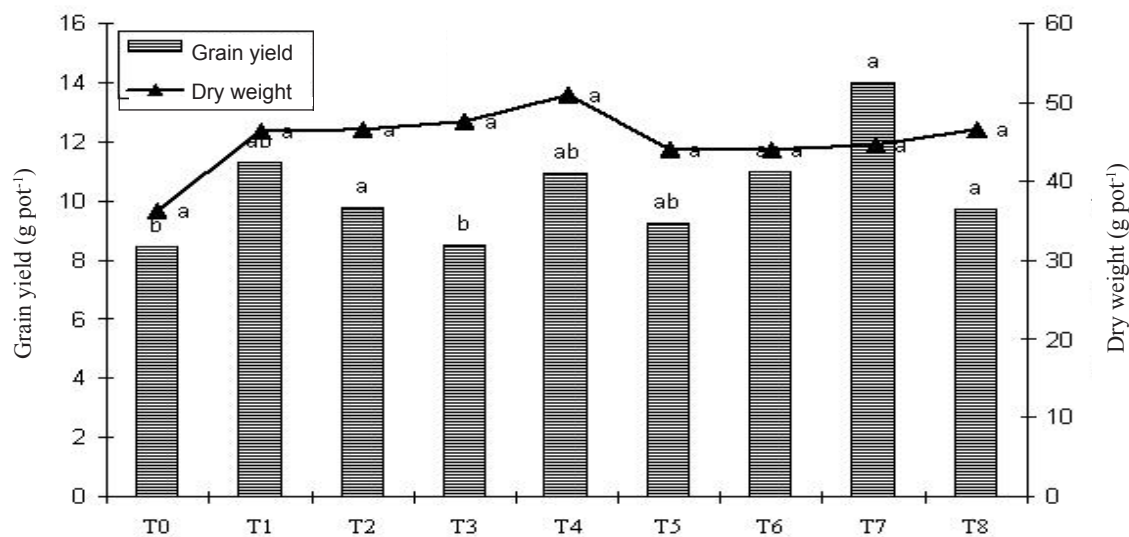

Fig. 2. Effect of vermicompost and its mixtures with water treatment residuals on wheat dry weight and grain yield. Explanations as in Table 2.

structural status. The obtained results showed that the values of BD decreased significantly at p<0.05, compared to the control treatment, upon the addition of VC and its mixtures with WTR. The significant decrease in the soil BD upon the addition of the organic amendments (VC and WTR) could be attributed to the fact that organic matter possesses low BD and could therefore reduce soil BD and compaction level as compaction alone refers to process, which leads to the increase of the soil aggregate stability (Mbah and Onweremadu, 2009). These results are in agreement with those of Smith *et al.* (2000) and Kalantari *et al.* (2010) who found that soil BD decreased under the effect of compost and vermicompost applications. These obtained results indicate that the application of VC with WTR improved the values of BD. However, WTR application alone exhibited no clear effect on BD, especially at low levels. Higher mixing rates and ratios of vermicompost with WTR, 5 g of (2 VC+1 WTR) kg^{-1} soil, improved the unfavourable effect of the WTR on soil BD. In general, the decrement in BD means the improvement of the structural status, water retention, plant available water, root penetration and nutrient uptake, which leads to improved wheat yield.

The obtained results showed that the addition of amendment treatments increased the pore size distribution (QDP, SDP and WHP), decreased fine capillary pores (FCP), and resulted in a better structure. These findings are in agreement with the early findings of Pagliai *et al.* (1981) who found that the number of small and medium sized pores increased in organic amended soils, indicating a better structure and potential plant growth. Moodley and Hughes (2006) pointed out that WTR, when added to soils, changes the pore size distribution, particularly the macro porosity. These occurred at the 1.28 Mg ha^{-1} application rate. Therefore, very large amounts of WTR would have to be applied in order to markedly change the inherent physical properties of the soil. Data also should that the addition of VC to the WTR with different ratios enhanced the increase of soil QDP when compared to VC alone. This may be due to macroporosity increase and capillary porosity decrease of the WTR by the addition of vermicompost (Seok-Gon *et al.,* 2010).

The increase of water stable aggregates upon the addition of the VC and WTR combinations represents the effect of the amendment treatments on building good soil aggregates and conserving the aggregate stability, at the same time this helps increase the soil potential to improve other physical properties. The addition of VC and WTR and their mixture treatments increased significantly, at p<0.05, the AgSt as compared to the control. The influence of the WTR in increasing the AgSt was high at the higher application of WTR. Aggregates of WTR have high stability due to the tenacity with which the alum that was added during the water treatment process binds silt and clay. The sustained performance of aluminium sulphate (alum) in binding silt and clay enhances gravel-sized aggregates. Accordingly, aggregate stability was higher in the soil treated with the WTR than with vermicompost. These results are in agreement with Moodley and Hughes (2006).

Increases of aggregate stability in a soil are important for sustainable good soil structure. High aggregate stability allows movement of water through the soil, movement of air into and out of the soil, ease of penetration by roots, and protects the soil against erosion. These processes encourage water to flow down and to leach the salt out of the root zone as a main step of salt affected soil reclamation. Combination of VC and WTR amendments would have assisted increasing aggregate stability in the present study due to increases in soil organic matter content.

The results indicate that increasing ratios of the applied VC and WTR increased the MWD values and that the effect of the WTR on increasing MWD was more pronounced than that of the VC. Similar results were obtained by Romina *et al.* (2011) who pointed out that MWD increased linearly with increasing rates of the applied VC. The improved aggregate stability and MWD, upon the addition of the soil amendments, is an indicator of enhanced soil physical properties, which would be conducive for some soil microorganisms and other chemical reactions necessary for optimal plant growth. Organic soil amendments could help conserve and/or enhance the structure, because organic matter is considered an active agent that promotes aggregation through physical and chemical mechanisms (Caravaca *et al.,* 2002). Organic matter is of major importance for the stabilisation of aggregates (Six *et al.,* 2004). Grosbellet *et al.* (2011) showed that when organic particles break down, they surround the aggregates already present in the soil with a fine film and protect them from degradation.

The relative increase in straw weight and grain yield with respect to control may be due to the beneficial effects of increasing organic matter in soil due to the application of soil amendments. This increase in straw weight and grain yield of wheat corresponded with improvement of physical properties (Table, 2 and Fig. 1). Similar results were obtained by Barzegar *et al.* (2002) and Aggag and Mahmoud (2006). The increase of grain yield with the application of vermicompost was attributed to the improving action of vermicompost on the soil physical properties as well as nutrients status in the soil, which enhances plant growth (El-Sanat, 2003). On the other hand, the highest straw weight and grain yield of wheat plants was observed across all treatments with the addition of 10 g WTR kg^{-1} soil and 5 g (2 VC + 1 WTR) kg^{-1} soil treatments, compared with the addition of WTR alone at low level (5 g kg^{-1} soil). This may be due to the low fertilizer value of the WTR. Elliot and Dempsey (1990) showed that WTR generally had little fertilizer value. The addition of fertilizer and /or organic matter, such as compost, can help to improve nutritional value of the WTR. In our experiment, combination of VC and WTR improved the WTR efficiency in ameliorating the soil physical properties, which resulted in the best

wheat yield. Very large amounts of WTR would have to be applied in order to markedly change the inherent soil physical properties and to improve wheat yield. However, high application rate of WTR (>10%) causes a deficiency of plant available phosphorus, which results in reducing the plant growth (Dayton and Basta, 2001). Therefore, it is necessary to add fertilizer and/or organic matter to mitigate soil P deficiencies when WTR is reused actually as a growth medium (Park *et al.,* 2010).

CONCLUSIONS

1. The results obtained indicate that the application of vermicompost alone or in combination with water treatment residuals confirmed its ability to improve the physical properties of the saline sodic soil and wheat yield.

2. Very large amounts of water treatment residuals would have to be applied in order to markedly change the inherent soil physical properties and to improve wheat yield.

3. The application of vermicompost and water treatment residuals at ratio 2:1 at level of 5 g kg^{-1} soil gave the best wheat yield compared to other treatments.

4. Combination of vermicompost and water treatment residuals improved the water treatment residuals efficiency in ameliorating the soil physical properties, and could be considered as an ameliorating material to reclaim salt affected soils and to improve the yield of wheat. Moreover, it can be used as an economical and simple alternative for disposal methods of water treatment residuals.

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