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Effect of Gypsum, Sulfuric Acid, Nano-Zeolite Application on Saline-Sodic Soil Properties and Wheat Productivity under Different Tillage Types

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ABSTRACT

Soil degradation due to soil salinity and sodicity is considered a serious concern in arid and semiarid ecosystems. Due to arid climate even, normal soils are converted to saline-sodic soils. Recently, reduced tillage proved successfully increasing soil organic matter contributing to soil carbon sequestration leading to improvements in soil physical and chemical properties. However, exploring effect of reduced tillage in saline sodic soils, even under amendments application has less attention so far. Therefore, the present study was conducted to investigate the combined effects of inorganic soil amendments (Nano zeolite, sulphuric acid and gypsum) and tillage systems (reduced and deep tillage) on saline-sodic soil physical and chemical properties and wheat productivity. Deep tillage with sulphuric acid application significantly reduced soil electrical conductivity (EC), exchangeable sodium percentage (ESP), penetration resistance (PR) and bulk density (Bd) and increased soil hydraulic conductivity (HC), mean weight diameter (MWD) and aggregation index (AI) compared to control. Deep tillage showed a significant improvement of saline-sodic soils, despite increasing SOC with reduced tillage. Moreover, sulphuric acid, gypsum and Nano-zeolite applications with deep tillage increased wheat grain yield significantly compared to control. Nano-zeolite application gave the superiority in increasing soil organic carbon compared with sulphuric and gypsum, enhancing wheat productivity to be close to yield under gypsum application without significant differences. Nevertheless, application of Nano-zeolite in improving saline sodic soils not preferable economically compared with sulphuric acid and gypsum. In conclusion, sulphuric acid, gypsum applications in combination with deep tillage improved physical and chemical properties of saline-sodic soils, and consequently enhanced growth and yield of wheat, confirming the importance of deep tillage in reclaiming saline-sodic soils compared with reduced tillage.

Keywords: deep tillage; reduced tillage; Nano zeolite; sulphuric acid; saline-sodic soils; wheat, economic evaluation

INTRODUCTION

Soil salinity and sodicity are considered two major concerns in irrigated agricultural, particularly in arid and semiarid regions due to water scarcity and climate change. Worldwide, the area of salt-affected soil is about 935 Mha (Rengasamy, 2006), and about 560 Mha of the total salt affected soil is categorized as saline-sodic soils (Zia *et al*., 2007; Mahdy, 2011). These salt-affected soils need effective, low-cost, and environmentally acceptable management (Seleiman and Kheir, 2018b; Kheir *et al*., 2019). In Egypt, about 33.0% of total land is categorized as saline-sodic soils. Saline-sodic soils have poor aeration and hydraulic conductivity (HC) due to dispersion, translocation and deposition of clay platelets in the conducting pores (Emami and Astaraei, 2012; Hafez *et al*., 2015; Luo *et al*., 2015; Matosic *et al*., 2018). Saline-sodic soils have an adverse effect on the growth and yield of crops due to the low fertility (Mahdy, 2011; Hafez *et al*., 2015; Matosic *et al*., 2018) and sea water intrusion in response to sea level rise as well as a biotic stress (Kheir *et al*., 2019).

Sodic soils are generally ameliorated by providing calcium (Ca^{2+}) to replace excess Na^{+} in the cation exchange complex (Hafez *et al*., 2015; Luo *et al*., 2015; Singh *et al*., 2016). The replaced Na^{+} is directly leached by the irrigation from the rhizosphere zone. However, saline-sodic soils might contain Ca^{2+} in the form of calcite ($CaCO_3$) at different depths and need to be dissolved through adding acid to the soil (Matosic *et al*., 2018). Saline-sodic soil amelioration with physical amendments such as ploughing, and subsoiling (Mahdy, 2011) or chemical amendments such as gypsum (Mace *et al*., 1999, Hafez *et al*., 2015), sulphuric acid (Mahdy, 2011), and/or polyacrylamide (Seleiman and Kheir, 2018a) is considered a valuable technology. However, integration between tillage and proposed amendments on saline sodic soils in arid environments has less attention.

Gypsum ($CaSO_4$ x $2H_2O$) is considered one of the most important and commonly applied amendment in saline-sodic soil due to its low cost (Hafez *et al*., 2015) and availability (Gharaibeh *et al*., 2009, improving hydraulic conductivity (HC), bulk density (BD) and macro-porosity (Emami and Astaraei, 2012). Sulphuric acid is considered another vital chemical soil amendment and essential plant nutrient involved in plant growth and productivity (Matosic *et al*., 2018), and can improve a reclamation processes in non-carbonate saline-sodic soils (Matosic *et al*., 2018). Nano-zeolite ((K_2 Ca) Al_2O_3 $Sio.H_2O$) is considered one of the most recent important amendments for soil properties improvement in terms of reducing soil BD and improving water holding capacity due to its porous structure (Ming and Allen, 2001; Wehtje *et al*., 2003), rather than enhancing soil nutritional status (i.e. nitrogen, phosphorus and potassium) and soil organic matter (Burger and Zipper, 2011). However, exploring the assessment and economic feasibility of Nano-zeolite on saline-sodic soils has less attention so far.

Tillage process is fundamental practices that can influence soil fertility, crop production, and consequently the sustainability of cropping systems (Munkholm *et al*., 2013; Souzaa *et al*., 2018). It can increase soil mulching ability, infiltration rate and leaching different salts from the soil surface to deeper layers. Thus, tillage process can be considered a great practice in reclamation of saline-sodic soils. On the other hand, reduced tillage is one of the most applicable management practices for gaining the mutual advantages in terms of carbon sequestration, erosion control and lessening the input of energy (Lawrence *et al*., 1994; Souzaa *et al*., 2018). However, reduced tillage was not studied well before in combination with soil amendments, particularly in salt affected soils.

Deep tillage can cause an increase in water infiltration, internal drainage and aeration, and consequently can enhance rooting depth in saline-sodic soils (Strudley *et al*., 2008; Bogunovic and Kisic, 2017). In addition, it could improve water use efficiency and crop production as appeared recently with soybean (*Glycine max* L.) (Henry *et al.* 2018). Nevertheless, sustaining crop yields is considered a challenge, when adopting reduced tillage in many traditional cereals-based cropping systems (Morris *et al*., 2010). In addition, tillage types can not result in the target goal of high crop production and soil quality without apposite agronomic practices and soil amendments, particularly in salt affected soils.

Bread wheat (*Triticum aestivum* L.) accounts for almost 30.0% of the worldwide cereal productivity, as well as it contributes over than 50.0% of total human calorie input (FAOSTAT, 2015). Wheat represents nearby 10.0 and 20.0% of the Egyptian agricultural production and imports, respectively (FAOSTAT, 2015). The demand of grain wheat in Egypt is approximately 18.9 Mt/annum, however, the production of grain wheat is roughly 9.0 Mt (Malr, 2014). Therefore, Egypt is the largest wheat importer country worldwide, requiring an urgent need to increase crop production for lessening such gap (Asseng *et al*. 2018).

Therefore, the purposes of our investigation are to study the combined effects of tillage systems (i.e. reduced and deep tillage) and soil amendments (i.e. Nano-zeolite, sulphuric acid and gypsum) on saline-sodic soil physical and chemical properties as well as growth and yield of bread wheat.

MATERIALS AND METHODS

Experimental design and agricultural practices

A field experiment was conducted in saline-sodic soil at North Nile Delta of Egypt (Metobus district; 31° 1' N, 30° 6' E) during two growing seasons (2015/2016 and 2016/2017) to explore the combined effects of chemical soil amendments (i.e. Nano-zeolite, sulphuric acid and gypsum) and tillage systems (i.e. reduced and deep tillage) on soil physical and chemical properties, growth and yield of a new high yielding bread wheat (Tritucum aestivum L., cv Sakha 95).

The experiment was conducted in a split plot design with three replications. Tillage systems (i.e. reduced and deep tillage) were placed in main plots, while chemical soil amendments (i.e. control, Nano-zeolite, sulphuric acid and gypsum) were placed in sub-plots. The area of each sub plot was 40 m^2 (5 m × 8 m). The reduced tillage included rotary tiller at depth of 0-10 cm, whereas the deep tillage was assigned to sub-soiling up to 60 cm depth alongside the traditional ploughing with tractors up to 30 cm depth. Soil amendments (i.e. Nano-zeolite and gypsum) were added with tillage process and directly before sowing of grains wheat, meanwhile sulphuric was added with first irrigation. The amendments were added to the soil at the rate of 3.0, 4.3 and 17.0 t ha^{-1} for Nano-zeolite, sulphuric acid (H_2SO_4) and gypsum ($CaSO_4.2H_2O$), respectively. The doses of gypsum and sulphuric were estimated according to the gypsum requirements (GR) for the investigated soil. Gypsum requirements (GR) were calculated as follows:

$$\mathbf{GR} = \frac{(\mathbf{ESP_1} - \mathbf{ESP_2})}{\mathbf{100}} \times \mathbf{CEC} \times \mathbf{1.72} \times (\frac{\mathbf{100}}{\mathbf{G\ purity}}) \quad (\mathbf{1})$$

Where: ESP1 = initial value (22.0%); ESP2= required value (10.0%); CEC= cation exchange capacity; Purity = 85.0%

Gypsum characterizes with (pH 7.0, EC 2.2 dS m^{-1}, purity 85.0%, particle size diameter 50×10^{-3} m, and solubility 2.9 g L^{-1}) was calculated as the total of GR to lessen soil ESP from 22.0% to 10.0%, while the liquid reagent-grade of commercial sulphuric acid was calculated to be 25 % of GR (Sadiq *et al*.,2007). Nano-zeolite rate was calculated to be 0.1% (w/w). Zeolites are crystalline and hydrated alumina silicates of alkali (Na^+, K^+) and alkaline earth cations (Ca^{2+} or Mg^{2+}). It was characterized by an ability to hydrate/dehydrate reversibly and to exchange some of their constituent cations with aqueous solutions without a major change in structure (Pabalan and Bertetti, 2001). The synthesis of Nano-zeolite material had been made by the hydrothermal transformation of natural kaolin in NaOH solutions at 100 °C for 20 h. The analysis of the nature Kaolin as reported by National Research Centre, Egypt: SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 and loss on ignition (LOI) was 53.86, 0.74, 32.45, 0.65, 0.03, 0.08, 0.13, 0.08, 0.54, 0.16 and 11.26% as wt., respectively.

The grains of wheat (i.e. cv. Sakha 95) were sown at the rate of 142.8 kg ha^{-1} on 16^{th} November 2015 and on 18^{th} November 2016. The preceding crop was rice (Oryza sativa L.) in first and second seasons. The recommended dose of synthetic fertilizers of NPK were applied. Phosphorus fertilizer (35 kg P_2O_5 ha^{-1}) in the form of super phosphate 15% P_2O_5 was applied during the soil preparation stage. Nitrogen fertilizer (180 kg N ha^{-1}) in the form of ammonium nitrate 33.0% N was divided into two equal doses and was applied directly before the first and the second irrigations. However, the total dose of potassium fertilizer (57 kg K_2O ha^{-1}) in the form of potassium sulphate 48% K_2O was added directly before the first irrigation. Irrigation of wheat plants during the two growing seasons was applied at 50% depletion from soil available water. The plants were irrigated five times per season. In addition to calculated irrigation applied water, calculated leaching requirements were added to applied water in each irrigate. The main source of irrigation water is El-Nor branch canal with salinity ranges between 0.5 to 0.7.

Weeds grown with wheat were controlled by using Granstar 75% DF (tribenuron-methyl; 19.2 g ha^{-1}) at 25 days after sowing (DAS) (BBCH stage 13; Meier, 2001), and Topic 15% WP (Clodinafop-propargyl; 350 g ha^{-1}) at 45 DAS (BBCH stage 30; Meier, 2001).

Soil samples from three different depths (0-20, 20-40 and 40-60 cm) were collected before sowing of wheat for analysing soil initial physiochemical properties (Table 1). The type of the soil in the experimental farm was clay texture and categorized as saline-sodic soils. Soil pH, EC (dS m^{-1}) and ESP in upper layer (0-20 cm depth) were 8.1, 6.5 and 22.5, respectively. For both growing seasons, daily weather data of temperature, solar radiation and precipitation were recorded from interior and closer automated weather station that belongs to Central Laboratory of Agricultural Climate, Egypt (Fig. 1; www.clac.edu.eg).

Table 1. Initial soil chemical and physical analysis of the experimental site before sowing (Data shown are average of both seasons)

Soil depth (cm)	pH	$CaCO_3$ (%)	EC (dS m^{-1})	ESP	Available (mg kg^{-1}) N	P	K	
0-20	8.1	6.8	6.5	22.5	58.0	10.8	220	
20-40	8.2	7.5	6.8	23.4	55.0	10.0	212	
40-60	7.8	5.8	7.3	24.5	48.5	9.5	195	
Soil depth (cm)	SOC (%)	CEC (Cmol kg^{-1})	FC (%)	PWP (%)	BD (Mg m^{-3})	AI	MWD (mm)	
0-20	0.87	32.5	41.0	20.5	1.30	0.25	0.30	
20-40	0.85	30.7	41.5	21.5	1.35	0.24	0.27	
40-60	0.78	29.0	42.0	22.0	1.38	0.22	0.25	
Soil depth (cm)	Soluble cations (Cmol L^{-1})				Soluble anions (Cmol L^{-1})			
	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
0-20	44.2	0.65	10.4	10.3	0.0	4.0	26.4	34.6
20-40	41.5	0.68	10.9	14.9	0.0	4.5	27.6	35.9
40-60	49.6	0.73	11.7	10.9	0.0	4.0	34.2	34.8
Soil depth (cm)	Sand %	Silt %	Clay %	Texture class	PR (N cm^{-2})	HC (cm d^{-1})		
0-20	18.7	31.5	49.8	Clay	250	2.7		
20-40	15.7	32.6	51.7	Clay	265	2.5		
40-60	16.5	35.1	48.2	Clay	270	2.2		

EC: electrical conductivity (salinity); ESP: exchangeable sodium percentage; SOC: soil organic carbon; FC: field capacity; PWP: permanent wilting point; BD: soil bulk density; AI: soil aggregation index; MWD: mean weight diameter of soil particles; PR: soil penetration resistance; HC: soil hydraulic conductivity

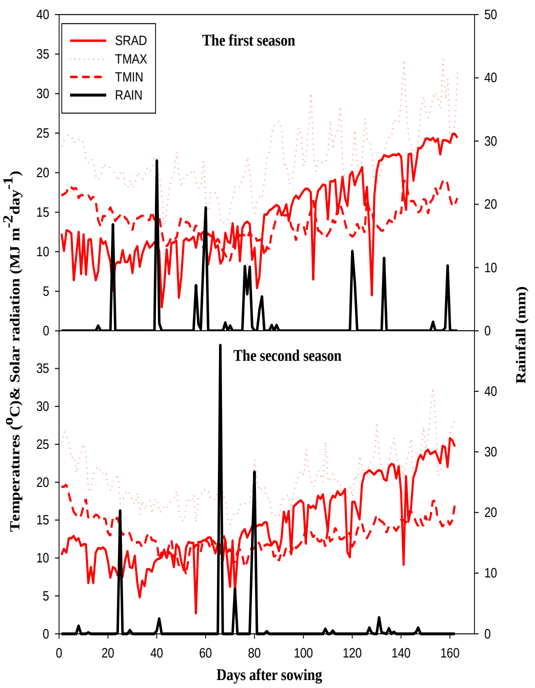

Fig. 1. Maximum (TMAX), minimum (TMIN) temperature, solar radiation (SRAD) and rainfall rates (black bar) during two wheat growing seasons (2015/2016) and (2016/2017).

Measurements

Soil chemical and physical analysis

Soil chemical analysis (ESP, SOC and EC) before sowing and at harvest was done by using the procedures described by Cottenie *et al*. (1982), Klute (1986) and Burt (2004). The cation exchange capacity (CEC) was determined with a 1.0 M (NH_4Cl) solution in ethanol/water (60:40, v/v) at pH (8.0) (Tucker, 1954). Total calcium carbonate was determined volumetrically using Collins calcimeter (Cottenie *et al.*, 1982)

Soil physical traits and moisture were determined in undisturbed soil samples as explained by (Klute 1986 and Delgado and Gómez 2016). Where soil field capacity (FC) and permanent wilting point (PWP) moistures were measured by pressure cooker apparatus after saturating soil samples with water by capillary rise and exposing to the required pressure 0.3 and 15.0 bar for FC and PWP, respectively. Soil hydraulic conductivity was measured in situ by constant head method through a novel device called Guelph Permeameter as described in Reynolds and Elrick (1985). By this device, soil hydraulic conductivity could be measured accurately and fast using the following equation:

$$K_{fs} = (0.0041)(Y)(R_2) - (0.0054)(Y)(R_1) \qquad (2)$$

Where: **K_{fs} = soil saturated hydraulic conductivity; R_1= rate of water level change in the first well with depth (H1) set at 5.0 cm; R_2 = the rate of water level change in the second well with depth (H2) set at 10.0 cm; Y= reservoir constant used when the inner reservoir was used in clay soil = 2.14 cm^2.**

Soil penetration resistance (PR) was determined by hand penetrometer device at soil field capacity as described by Herrick and Jones (2002). To determine soil organic carbon (SOC), samples were air dried, ground and passed through 2.0-mm sieve, and determined using described method by Miyazawa *et al*. (2000). Soil samples for aggregate stability were taken in undisturbed form (Kemper and Rosenau, 1986), and used to characterize the aggregation index (AI) and mean weight diameter (MWD) of wet-sieved aggregates (Rohošková and Valla, 2004). Briefly, the sieves were arranged in descending size order in wet sieving device (2.0, 1.0, 0.5 and 0.25 mm) from top to bottom. On the top sieve, about 50.0 g of soil < 4.75 mm aggregates were placed on after immersing these samples in distilled water. Then, the device was set to move vertically to sieve samples. The retained soil part by each sieve was dried at 105 °C for 24 h to obtain the proportion of water-stable aggregates, then MWD was calculated as follows:

$$\mathbf{MWD} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{Wi\ Xi} \qquad (3)$$

Where: **Xi = mean diameter of each size fraction (mm); Wi = total of water stable aggregates.**

Wheat growth yield and yield components

Day from sowing to anthesis and from sowing to maturity of wheat was recorded in each plot. Furthermore, chlorophyll in terms of SPAD values (SPAD-502 chlorophyll meter, Minolta, Japan) were recorded at 40, 60, 80 and 100 days after sowing (DAS) (i.e. at tillering, stem elongation, booting, heading and flowering; Meier 2001). SPAD values were recorded from the middle of flag leaf of ten wheat plants in each plot. Then, the average of the recorded ten readings from each plot was obtained and recorded.

At maturity, ten wheat plants from each sub-plot were randomly selected for counting number of spikelets per spike and reordering 1000-grain weight. In addition, at maturity, wheat plants of three m^2 were manually harvested from the middle of each sub-plot. The number of spikes per m^2 were recorded, then the whole harvested plants of the three m^2 were weighted to obtain the biological yield per ha. Afterward, grains of the harvested wheat plants were threshed with a thresher machine, dried in oven over night at +70 °C and finally grain yield was recorded. Straw yield was obtained by subtracting the weight of grain yield from the weight of biological yield. Lastly, harvest index (%) was expressed as the ratio of grain yield to biological yield and multiplied by 100 to be presented as percent.

Economic assessment

Cash inflow and outflow for all treatments according to local markets were calculated. In addition, some economic parameters (i.e. net return and economic efficiency) were estimated using equations outlined by (FAO, 2000).

Statistical analysis

Row obtained from the effects of tillage system, soil amendments and their interaction on wheat grown during the two growing seasons were subjected to analysis of variance (ANOVA) using PASW statistics 21.0 (IBM Inc., Chicago, IL, USA). Means of different treatments were compared using Tukey's multiple range test, when the ANOVA showed significant differences (P < 0.05). Also, LSD (least significant difference) was obtained from the analysis for each trait to compare means.

RESULTS

Effect of tillage practices and chemical amendments on saline-sodic soil properties

Deep tillage practice resulted in a significant reduction for EC (only at 0-15 cm depth), ESP, penetration resistance (PR) and BD at both depths (0-15 and 15-30 cm) in saline-sodic soil compared to reduced tillage practice, (Tables 2and 3). Penetration resistance was higher in subsurface depth (223.4 N cm^{-2} at 15 -30 cm) than soil surface layer (205.5 N cm^{-2} at 0-15 cm). However, there were no significant differences between deep and reduced tillage effects on soil organic carbon (SOC), despite lowering SOC in case of deep tillage than reduced tillage (Table 4). On the other hand, the HC (Table 3), aggregation index (AI) and mean weight diameter (MWD) of saline-sodic soil at both depths were higher with a significant increment when deep tillage was applied than reduced tillage (Table 4).

Table 2. Effect of tillage and soil amendments on electrical conductivity (EC, salinity), exchangeable sodium percentage (ESP) and organic carbon (SOC) of saline-sodic soil after wheat harvest.

Parameters	EC (dS m^{-1})				ESP				SOC (%)			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm		0-15 cm		15-30 cm	
Treatments	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Tillage (T)												
Reduced tillage	6.0a	6.0a	7.2	6.7	21.1a	19.8a	22.9a	20.7a	0.95	1.08	0.89	0.94
Deep tillage	5.4b	5.3b	6.8	6.3	18.9b	18.2b	20.5b	19.0b	0.91	0.93	0.83	0.86
$LSD_{0.05}$	0.46	0.59	0.49	0.56	1.65	0.32	1.03	1.07	0.05	0.19	0.06	0.11
Amendments (A)												
Control	6.6a	7.2a	8.0a	8.0a	23.3a	23.5a	25.0a	25.6a	0.92c	0.83d	0.77c	0.68d
Gypsum	5.5c	5.3c	6.9b	6.2b	19.1c	17.4c	20.8c	18.0c	0.94b	1.07b	0.91a	0.98b
Sulphuric acid	5.3c	4.7d	6.1c	5.6c	16.4d	15.6d	18.8d	16.5d	0.90c	0.98c	0.92a	0.93c
Nano-Zeolite	6.0b	5.6b	7.0b	6.3b	21.1b	19.5b	22.2b	19.5b	1.17a	1.28a	0.99a	1.21a
$LSD_{0.05}$	0.39	0.24	0.3	0.21	0.93	0.72	0.32	0.53	0.02	0.07	0.03	0.07
Significant												
T	*	*	ns	ns	*	*	*	*	*	*	ns	ns
A	**	**	**	**	**	**	**	**	**	**	**	**
T×A	ns	ns	ns	ns	**	**	ns	ns	**	*	*	ns

S1 = first season; S2 = second season. LSD = Least Significant Difference; NS = P > 0.05; * = P < 0.05; ** = P < 0.01.

Sulphuric acid application resulted in the lowest EC, ESP, PR and BD in saline-sodic soil followed by gypsum and/ or Nano-zeolite application in comparison to untreated soil during the growing seasons (Tables 2 and 3). Application of sulphuric acid led to a reduction in EC by 38.0%, gypsum by 27.7% and Nano-zeolite by 19.0% at 0-15 cm soil depth in comparison to untreated soil (Table 2). Also, ESP of saline-sodic soil treated with sulphuric acid, gypsum and Nano-zeolite was decreased by 46.2%, 28.2% and 15.2% respectively than the untreated soil at surface depth. In contrast, the highest HC (Table 3), AI and MWD (Table 4) of saline-sodic soil at both depths were obtained from plots treated with sulphuric acid followed by gypsum and

Nano-zeolite applications in comparison to the untreated plots. Nao-zeolite application (Table 2) achieved the highest values of SOC followed by gypsum and sulphuric acid respectively. Mean weight diameter of soil at surface depth was increased in plots treated with sulphuric acid, gypsum and Nano-zeolite by 157.0%, 129.1% and 98.0%, respectively in comparison to untreated soil. The interaction effect of tillage and chemical amendments on soil ESP and PR was highly significant under surface soil layer (0-15 cm), while it was not significant in second soil layer (15-30 cm).

Table 3. Effect of tillage and soil amendments on hydraulic conductivity (HC), bulk density (BD) and penetration resistance (PR) of saline-sodic soil after wheat harvest.

Parameters	HC (cm day^{-1})				BD (Mg m^{-3})				PR (N cm^{-2})			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm		0-15 cm		15-30 cm	
Treatments	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Tillage (T)												
Reduced tillage	2.72b	3.42b	2.34b	2.98b	1.29a	1.26a	1.31a	1.28a	215.0a	208.0a	232.6a	224.7a
Deep tillage	3.22a	3.74a	2.65a	3.33a	1.24b	1.23b	1.28b	1.25b	202.0b	197.7b	226.0b	210.5b
$LSD_{0.05}$	0.38	0.31	0.24	0.31	0.03	0.02	0.02	0.01	5.28	6.84	4.25	3.95
Amendments (A)												
Control	2.26c	2.41d	1.95d	2.22d	1.32a	1.35a	1.37a	1.35a	242.3a	246.1a	255.0a	253.6a
Gypsum	2.92b	3.96b	2.63b	3.48b	1.25c	1.21c	1.27c	1.25bc	205.0b	195.5c	225.0c	213.0b
Sulphoric acid	3.95a	4.40a	3.15a	4.00a	1.22d	1.18d	1.23d	1.21c	179.3c	168.6d	202.5d	186.6c
Nano-Zolite	2.73b	3.55c	2.25c	2.92c	1.28b	1.25b	1.29b	1.27b	207.5b	201.3b	234.8b	217.3b
$LSD_{0.05}$	0.40	0.36	0.16	0.28	0.01	0.02	0.22	0.04	3.65	2.65	5.07	4.97
Significant												
T	*	**	*	*	*	*	*	**	*	*	*	**
A	**	**	**	**	**	**	**	**	**	**	**	**
T×A	ns	ns	ns	ns	ns	*	*	ns	*	**	ns	ns

S1 = first season; S2 = second season. LSD = Least Significant Difference; NS = P > 0.05; * = P < 0.05; ** = P < 0.01.

Table 4. Effect of tillage and soil amendments on mean weight diameter (MWD) and aggregation index (AI) of saline-sodic soil after wheat harvest.

Parameters	MWD (mm)				AI			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
Treatments	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Tillage (T)								
Reduced tillage	0.48b	0.52b	0.42b	0.45b	0.29b	0.34b	0.25b	0.29b
Deep tillage	0.52a	0.61a	0.45a	0.51a	0.33a	0.39a	0.30a	0.34a
$LSD_{0.05}$	0.03	0.04	0.01	0.04	0.02	0.05	0.04	0.02
Amendments (A)								
Control	0.27d	0.27d	0.24d	0.20d	0.24c	0.22d	0.19d	0.23d
Gypsum	0.58b	0.66b	0.49b	0.56b	0.32b	0.41b	0.30b	0.35b
Sulphuric acid	0.65a	0.74a	0.57a	0.60a	0.38a	0.45a	0.35a	0.39a
Nano-Zeolite	0.49c	0.58c	0.43c	0.52c	0.29b	0.37c	0.27c	0.30c
$LSD_{0.05}$	0.03	0.02	0.02	0.04	0.02	0.03	0.03	0.02
Significant								
T	*	*	**	*	**	*	*	*
A	**	**	**	**	**	**	**	**
T×A	ns	**	**	*	ns	ns	ns	ns

S1 = first season; S2 = second season. LSD = Least Significant Difference; NS = P > 0.05; * = P < 0.05; ** = P < 0.01.

Effect of tillage practices and chemical soil amendments on growth and yield of bread wheat grown in saline-sodic soil

According to the obtained SPAD values during the two consecutive seasons, there were no significant differences between the effect of reduced and deep tillage on SPAD values at all investigated growth stages (i.e. tillering to flowering and anthesis stage) of bread wheat. However, the highest SPAD values were obtained from wheat grown in soil treated with sulphuric acid followed by gypsum and/or Nano-zeolite applications in comparison to those grown in untreated soil (Fig. 2).

Number of days from sowing to anthesis and sowing to maturity were higher with deep tillage than application of reduced tillage (Table 5). Also, the highest number of spikes per m^2 and 1000-grain weight were obtained from wheat grown in soil treated with deep tillage in comparison to reduced tillage application (Table 5). However, there was no significant difference between the effect of deep and reduced tillage on number of spikelets per spike. On the other hand, application of sulphuric acid resulted in a greater number of days from sowing to anthesis, number of days from sowing to maturity and 1000-grain wheat followed by the application of gypsum and Nano-zeolite in comparison to untreated soil. Data presented in Table (5) revealed that either sulphuric acid or gypsum or Nano-zeolite markedly promoted growth of wheat crop in terms of the highest number of spikes per m^2 and number of spikelets per spike in comparison to those grown in untreated soil (i.e. control).

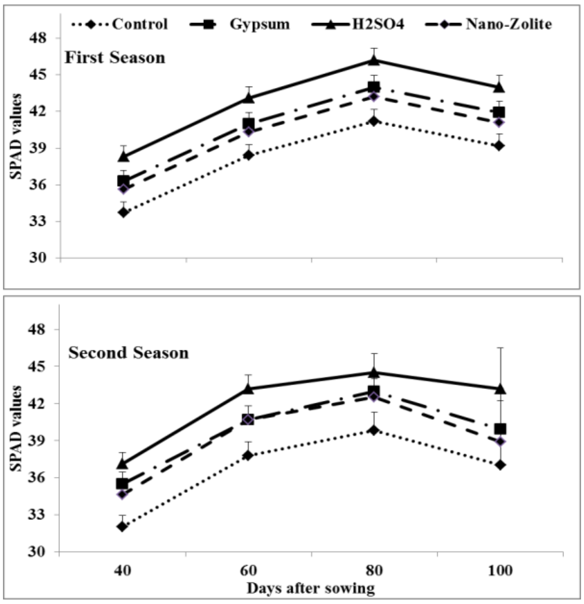

Fig. 2. Effect of soil amendments on chlorophyll (SPAD) of bread wheat grown in saline-sodic soil during the two growing seasons. Bars are least significant difference.

Deep tillage resulted in a significant increase in grain and biological yields of wheat and harvest index, while there were no significant differences between reduced and deep tillage on straw yield (Table 5). The results indicated that grain and biological yields of wheat grown in soil treated with deep tillage was higher than reduced tillage by 14.0% and 6.0%, respectively. On the other hand, sulphuric acid application resulted in the highest grain and biological yield of wheat with a significant increment followed by gypsum and/or Nano-zeolite in comparison to those grown in untreated soil, whereas, the highest straw yield and harvest index were obtained from soil treated with sulphuric acid or/and gypsum in comparison to other treatments (Table 6). Grain yield of wheat grown in soil treated with sulphuric acid, gypsum and Nano-zeolite was 41.5%, 35.2% and 24.9% higher than those grown in untreated soil, respectively.

Economic evaluation

To assess different treatments economically, economic evaluation includes net return and economic efficiency was conducted. Data in Table 7 showed that, the lowest values of economic efficiency and net return for wheat yield were obtained with Nano-zeolite application and reduced tillage. Meanwhile, the highest values were recorded with sulphuric acid application and deep tillage. This confirms the importance of using sulphuric acid and deep tillage to improve soil properties and crop production in saline sodic soils from the economic view (Table 7).

Table 5. Effect of tillage and soil amendments on some growth and yield components of bread wheat grown in saline-sodic soil.

Parameters	*Days from sowing to anthesis*		*Days from sowing to maturity*		No. of Spikes m^{-2}		No. of spikelets $spike^{-1}$		1000-grain weight (g)	
Treatments	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Tillage (T)										
Reduced tillage	96.3b	96.4b	126.0b	126.5b	357.6b	360.2b	21.6	21.0	35.1b	34.4b
Deep tillage	98.2a	98.8a	128.8a	129.6a	365.3a	367.9a	22.3	22.6	37.4a	39.8a
$LSD_{0.05}$	1.29	2.21	0.94	0.95	7.66	7.35	1.43	1.89	2.17	0.95
Amendments (A)										
Control	93.0d	92.0c	121.8d	120.0c	356.6b	352.5b	19.3b	19.3b	34.3a	32.0d
Gypsum	98.8b	99.3b	129.1b	130.5b	363.0ab	365.3a	22.6a	23.0a	36.6b	39.1b
Sulphuric acid	101.0a	101.6a	132.1a	133.3a	365.3a	371.0a	23.6a	23.3a	38.5a	41.1a
Nano-Zolite	96.3c	97.5b	126.5c	128.5b	361.8ab	366.5a	22.3a	22.6a	36.0b	38.5b
$LSD_{0.05}$	1.35	2.03	1.99	2.20	8.47	7.16	1.51	1.11	0.81	1.40
Significant										
T	*	*	*	*	*	*	ns	ns	*	*
A	**	**	**	**	ns	**	*	*	**	*
T×A	ns	ns	ns	ns	ns	ns	ns	ns	ns	*

S1 = first season; S2 = second season. LSD = Least Significant Difference; NS = P > 0.05; * = P < 0.05; ** = P < 0.01.

Table 6. Effect of tillage and soil amendments on yields and harvest index of bread wheat grown in saline-sodic soil.

Parameters	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Biological (kg ha^{-1})		Harvest index (%)	
Treatments	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Tillage (T)								
Reduced tillage	4780b	4804b	8412	8003	13193b	12807b	36.0b	36.9b
Deep tillage	5503a	5486a	8617	8121	14121a	13608a	38.7a	39.7a
$LSD_{0.05}$	296.0	168.0	404.2	334.7	634.2	346.4	1.17	1.5
Amendments (A)								
Control	4216c	3224d	8251b	8003	12467d	11228d	33.7b	28.7c
Gypsum	5583b	5904b	8552ab	7994	14135b	13898b	39.4a	42.4a
Sulphuric acid	6154a	6559a	8824a	8138	14979a	14697a	41.0a	44.6a
Nano-Zeolite	5200b	5500c	8433ab	8114	13633b	13614b	38.9a	40.4a
$LSD_{0.05}$	405.8	396.5	491.0	538.2	514.6	393.1	2.72	3.18
Significant								
T	*	*	ns	ns	*	*	*	*
A	**	**	*	ns	**	**	**	**
T×A	ns	ns	ns	ns	ns	ns	ns	ns

S1 = first season; S2 = second season. LSD = Least Significant Difference; NS = P > 0.05; * = P < 0.05; ** = P < 0.01.

Table 7. Values of total revenue, total cost, net return, economic efficiency and net return from water unit as affected by different treatments through both growing seasons

Variables		Treatments					
		Control	Gypsum	SA	NZ	DT	ZT
First season							
Grain yield revenue (LE.ha^{-1})		11256.72	14906.61	16431.18	13884	14693.01	12762.6
Straw yield revenue (LE. ha^{-1})		6600.8	6841.6	7059.2	6746.4	6893.6	6729.6
Total revenue (LE.ha^{-1})		17857.52	21748.21	23490.38	20630.4	21586.61	19492.2
Costs according to the local market price (LE.fed^{-1})	Amendments and tillage costs (LE ha^{-1})	0	2550	3225	2875	240	0
	Costs of VAP (LE ha^{-1})	5750	5750	5750	5750	5750	5750
	Land rent for winter season (LE. ha^{-1})	5000	5000	5000	5000	5000	5000
Total cost (LE.ha^{-1})		10750	13300	13975	13625	10990	10750
Net return (L.E. ha^{-1})		7107.52	8448.21	9515.38	7005.4	10596.61	8742.2
Economic efficiency	Biological yield	0.66	0.64	0.68	0.51	0.96	0.63
	Grain yield	0.05	0.12	0.18	0.02	0.34	0.19
Second season							
Grain yield revenue (LE.ha^{-1})		12180	16531.2	18365.2	15400	15360.8	13451.2
Straw yield revenue (LE. ha^{-1})		8003	7994	8138	8114	8121	8003
Total revenue (LE.ha^{-1})		20183	24525.2	26503.2	23514	23481.8	21454.2
Costs according to the local market price (LEfed^{-1})	Amendments and tillage costs (LE ha^{-1})	0	2550	3225	2875	240	50
	Costs of VAP (LEha^{-1})	6000	6000	6000	6000	6000	6000
	Land rent for winter season(LE. ha^{-1})	5000	5000	5000	5000	5000	5000
Total cost (LE.ha^{-1})		11000	13550	14225	13875	11240	11050
Net return (L.E. ha^{-1})		9183	10975.2	12278.2	9639	12241.8	10404.2
Economic efficiency	Biological yield	0.83	0.81	0.86	0.69	1.09	0.94
	Grain yield	0.11	0.22	0.29	0.11	0.37	0.22

VAP: Variable costs of agricultural practices; Net return = total cost/total return; Economic efficiency = net return/total cost; SA: Sulphuric acid; NZ: Nano-Zeolite; DT: Deep tillage; ZT: Zero tillage; Cost of SA= 1500 LE/ton; Cost of NZ= 2500 LE/ton.

DISCUSSION

Effect of tillage practices and chemical amendments on saline-sodic soil properties

Saline and sodic soils management is considered a great challenge due to the poor physical and chemical properties in addition to the low soil microbial activity, consequently causing a reduction in soil quality and crop productivity (Matosic *et al*., 2018). Suitable tillage and soil amendments are considered the main factors for alleviating the negative effects, amelioration of salt-affected soils and improving crop productivity. In saline-sodic soil, Na^+ cations are very soluble and weakly attracted. For this reason, the main problem of such soils appears when Na^+ starts to accumulate and dominate over the Ca^{2+} cations. Such process can lead to structural deterioration through physical processes for instance slaking, swelling and dispersion of clay forming soil compaction (Qadir *et al*., 2001; Qadir *et al*., 2003).

In the current study, deep tillage resulted in a significant improvement in soil quality in terms of chemical and physical soil properties. It caused higher decline in EC and ESP as well as improving soil structure by increasing HC, AI and MWD of saline-sodic soil than reduced tillage practice (Tables 2, 3, 4). At harvest, soil EC was higher at 15–30 cm soil depth than at 0–15 cm soil depth. Deep tillage also resulted in a higher reduction in BD and PR than those obtained from reduced tillage plots. The general trends were that higher PR occurred at the greater BD. The decline in BD could be probably due to loosening soil and thus temporarily forming macro-pores (Matosic *et al*., 2018). Tillage practices can improve the aeration and alleviate the compaction of soil, whereas, the organic matter obviously promotes binding soil particles into aggregates (Matosic *et al*., 2018). It improved soil physical properties through changing the conditions in the current study, and accordingly has a vital influence on the crop growth and yield (Jabro *et al*., 2011). The higher levels of salinity at lower depth of soil could be due to leaching of salts from the topsoil as well as secondary salinization by capillary rise in arid regions. Deep tillage, mix subsoil with topsoil to cause a complete destruction of soil horizons, is considered a great challenge in poor soils since it could alleviate high subsoil strength, facilitating deeper rooting, and consequently the plant-availability of subsoil resources for instance nutrients (50% of total nitrogen stocks and 25–70% phosphorus stocks) and retain water even under drought stress (Schneider *et al*., 2017).

The interaction effect of tillage and amendments, soil ESP and PR were highly significant in top soil (0-15 cm) and non-significant in sub soil (15-30 cm). Sulphuric acid application resulted in the highest improvement in soil quality traits in terms of the lowest EC, ESP, PR and BD, followed by gypsum and/ or Nano-zeolite application in comparison to untreated soil (Tables 2, 3). In contrast, the highest HC, AI and MWD of saline-sodic soil at both depths were obtained from plots treated with sulphuric acid followed by gypsum and Nano-zeolite applications in comparison to the untreated plots (Table 2, 3, 4). Nano-Zeolite improved SOC in comparison with other amendments, it may be due to its higher content from OC compared to other amendments (Pabalan and Bertetti, 2001). Sulphuric acid can be used instead of gypsum in calcareous saline-sodic soil, because it can react with lime to form gypsum ($CaSO_4.2H_2O$). In saline-sodic soil treated with acid, the presence of lime is a vital factor because it can provide Ca^{2+} during the initial steps of soil reclamation (Ali and Aslam, 2005). The effectiveness of sulphuric acid application in ameliorating the saline-sodic soil in the current investigation could be due to the significant formed amounts of bicarbonate (HCO_3^-) during the reaction of sulphuric acid (H_2SO_4) with carbonate ($CaCO_3$) resulting in an extra Ca^{2+} in soil solution and enriched displacement of exchangeable Na^+ (Mace *et al*., 1999).

The increased HC in soil treated with sulphuric acid certainly was resulted from less clay swelling and dispersal, associated with the lower ESP and pH as well as the higher ionic strength (Mace *et al*., 1999). During the two growing seasons of the current investigation, the particle mean diameter size of soil was significantly larger when H_2SO_4 was applied (diameter was 0.69 mm after acid application and 0.27 mm in untreated soil), signifying a better clay tactoid preservation. This improvement in the mean diameter size might be attributed to the low pH and high ionic strength caused by acid application and the subsequent compression of the diffuse double-layer, edge-to-face bonding and better flocculation in comparison to the gypsum application (Lebron *et al*., 1993; Mace *et al*., 1999). Gypsum can do the same action, but slowly due to its low solubility leading to the superiority of sulphuric acid in saline-sodic soil amelioration.

Effect of tillage practices and chemical soil amendments on growth and yield of bread wheat grown in saline-sodic soil

Deep tillage of soil improved chemical and physical traits of soil in the current study, this could be due to the leaching of salts from the surface to deeper layer of soil, improving soil aeration through breaking the hard pan layer and improving soil drainage. These could be vital reasons attributed to the improvement of growth traits and the increment of wheat grain yield in the current study. Significant differences in wheat yields because of different tillage practices could be due to the hydrophobic nature of crop and poor root expansion in reduced tillage soil. The increase in the yield with deep tillage could be attributed to the cutting of the soil layers up to deeper depths, which in turn could have increased the mulching ability and the infiltration rate. Deep tillage can improve the accessibility of nutrients from the subsoil, which increases crop yield if the nutrient availability in the topsoil is deficient. This is illustrated by significantly higher yield increases after deep tillage in un-fertilized trials compared to trials with fertilized topsoil (Schneider *et al*., 2017).

Sulphuric acid, gypsum and Nano-zeolite applications significantly increased chlorophyll in terms of SPAD values, 1000-grains weight, number of spikes per m^2 and grain, straw and biological yields of wheat per ha in comparison to untreated soil (Tables 5, 6, Fig. 2). This improvement could be due to calcium, since it is considered an essential for plant cell wall structure, provides normal transport and retention of other elements as well as strength in the plant (Helmy and Shaban, 2013). In addition, this can probably be due to the increment of calcium and potassium and to the reduction of sodium in soil which can result in healthy environment for plant growth (Helmy and Shaban, 2013). The role of sulphuric acid and gypsum applications on plant growth and yield can be also because of reducing soil pH which can enhance the availability of nutrients in soil and improve their use efficiency such as nitrogen and phosphorus (Mazhar *et al*., 2011). Meanwhile, increasing yield under Nano-Zeolite is mainly due to its higher content of organic matter and other essential elements such as N, P, K, Ca and Mg). The improvement of growth and productivity of wheat in the current investigation can partly be attributed to higher amounts of calcium brought into soil solution through sulphuric acid application which improved soil infiltration (Zia *et al*. 2007). The low yield obtained from untreated soil in the current study could be due to the poor HC, soil porosity and deteriorated infiltration rate. These poor traits resulted from the dispersion, translocation, and redisposition of clay platelets or choking of macro and micro pores owing to which plant roots faced resistance to proliferation, aeration, water absorption, and nutrient uptake (Sadiq *et al*., 2007). Economically, sulphuric acid achieved the higher net return and economic efficiency followed by gypsum, but Nano-Zeolite recorded the lowest values (Table 7). Despite the recent trends of using Nano-materials in agriculture, using these materials in reclaiming saline-sodic soils is not preferable economically. In this study, there are not significant differences between gypsum and Nano-zeolite in wheat yield, however the economic efficiency of first is much better.

Conclusions and future directions

Deep tillage with sulphuric acid or gypsum application improved physical and chemical traits of saline-sodic soil as well as improved growth and yields of wheat crop in comparison to untreated soil. The EC, ESP, HC, PR and MWD of amended soils revealed that soils treated with sulphuric acid or gypsum being more efficient than Nano-zeolite and control treatments. Nano-zeolite, achieved the highest values of SOC, improving wheat productivity in saline-sodic soils, however its impact on other soil properties was lower than sulphuric and gypsum. Although reduced tillage is beneficial in increasing SOC through carbon sequestration, which might enhance crop productivity, but this action appears well in normal soil rather than saline-sodic soil, favouring deep tillage in salt affected soils. The yields of wheat crop suggest that farmers can get better output after application of some inorganic amendments (e.g. sulphuric acid or gypsum) into saline-sodic soil. Application of sulphuric acid achieved the highest economic return and economic efficiency values followed by gypsum with lowest values under Nano-zeolite application. Nevertheless, there is an urgent forthcoming study to investigate the impacts of different rates of these materials and their combination on saline-sodic soil properties and crop production. In addition, using high quantities of natural zeolite as raw material without Nano forms could improve saline sodic properties significantly with high economic return, requiring future studies.

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Disclosure statement

No potential conflict of interest was reported by the authors.

REFERENCES

Ali, Y., Aslam, Z., 2005. Use of environmental friendly fertilizers in saline and saline sodic soils. Int. J. Environ. Sci. Tech. 1, 97-98.

Asseng, S., Kheir, A.M.S, Kassie, B.T., Hoogenboom, G., Abdelaal, A. I. N., Haman, D. Z., Ruane, A.C., 2018. Can Egypt become self-sufficient in wheat?. Environ. Res. Lett. 13 094012.

Bogunovic, I., Kisic, I., 2017. Compaction of a clay loam soil in pannonian region of Croatia under different tillage systems. J. Agr. Sci. Tech. 19,475-486.

Burger, J.A., Zipper, C.E., 2011. How to restore forests on surface-mined land. Publication 460-123, Virginia Cooperative Extension (VCE), Stanardsville, Va, USA

Burt, R., 2004. Soil Survey Laboratory Methods Manual. USDA–NRCS, Linoln, Nebraska.

Cottenie, A., Verloo, M., Velghe, G., Kiekens, L., 1982. "Biological and analytical aspects of soil pollution. Laboratory of analytical and agrochemistry". State Univ, Ghent- Belgium, p 424.

Delgado, A., Gómez, J.A., 2016. The soil. physical, chemical and biological properties. In: Villalobos FJ, Fereres E (Eds) Principles of agronomy for sustainable agriculture. Springer Nature, Cham, Switzerland, pp 15-26.

Emami, H., Astaraei, A.R., 2012. Effect of organic and inorganic amendments on parameters of water retention curve, bulk density and aggregate diameter of a saline–sodic soil. J. Agric. Sci. Technol. 14,1625–1636.

FAO.,2000. Fertilizers and their use, evaluation of fertilizer demonstrations. Apocket guide for extention officers. 4th edition.

FAOSTAT., 2015. Wheat Sector Review-Egypt. Report number 21, Rome, Italy. Available at: http://faostat. fao.org (http://www.fao.org/3/a-i4898e.pdf. Accessed 12 June 2018

Gharaibeh, M.A., Eltaif, N.I., Shunnar, O.F., 2009. Leaching and reclamation of calcareous saline-sodic soil by moderately saline and moderate-SAR water using gypsum and calcium chloride. J. Plant Nutr. Soil Sci. 172,713-719.

Hafez, E.H., Abou El Hassan, W.H., Gaafar, I.A., Seleiman, M.F., 2015. Effect of gypsum application and irrigation intervals on clay saline-sodic soil characterization, rice water use efficiency, growth, and yield. J. Agric. Sci. 7,208-219.

Helmy, A.M., Shaban, K.A., 2013. Wheat Productivity and nutrient uptake after inhibitory soil salinity adverse by some sulphur sources. Egypt. J. Soil Sci. 53, 281-298.

Henry, C.G., *et al*., 2018. Deep tillage and gypsum amendments on fully, deficit irrigated, and dryland soybean. Agron. J. 110,1-12.

Herrick, J.E., Jones, T.L., 2002. A dynamic cone penetrometer for measuring soil penetration resistance. Soil Sci. Soc. Am. J. 66,1320-1324.

Jabro, J.D., Sainju, U.M., Lenssen, A.W., Evans, R.G., 2011. Tillage effects on dryland soil physical properties in northeastern Montana. Commun. Soil Sci. Plant Anal. 42: 2179–2187.

Kemper, W.D., Rosenau, K., 1986. Size distribution of aggregates. In: Klute A (Ed.), Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods. Am. Soc. Agron., Madison, WI, pp 425-442.

Kheir, A.M.S., El Baroudy, A., Aiad, M. A., Zoghdan, M.G., Abd El-Aziz, M.A., Ali, M.G.M., Fullen, M.A., 2019. Impacts of rising temperature, carbon dioxide concentration and sea level on wheat production in North Nile delta. Sci. Total Environ. 651, 3161–3173.

Klute, A., 1986. Methods of Soil Analysis, Part 1 (2th Ed.): Physical and Mineralogical Methods. ASA, Inc. SSSA, Inc., Publisher, Madison, Wisconsin, USA.

Lawrence, P.A., Radford, B.J., Thomas, G.A., Sinclair, D.P., Key, A.J., 1994. Effect of tillage practices on wheat performance in a semi-arid environment. Soil Tillage Res. 28, 347-364.

Lebron, I., Suarez, D.L., Amrhein, C., 1993. Size of mica domains and distribution of the adsorbed Na-Ca ions. Clay Clay Mineral. 41:380-388.

Luo, J.Q., Wang, L., Li, Q., Zhang, Q., He, B., Wang, Y., Qin, L., Li, S., 2015. Improvement of hard saline–sodic soils using polymeric aluminum ferric sulfate (PAFS). Soil Tillage Res. 149, 12-20.

Mace, J.E., Amrhein, C., Oster, J.D., 1999. Comparison of gypsum and sulfuric acid for sodic soil reclamation. Arid Soil Res. Rehabil. 13, 171-188.

Mahdy, A.M., 2011. Comparative effects of different soil amendmentson amelioration of saline-sodic soils. Soil Water Res. 4, 205-216.

Malr., 2014. Bulletins of Agricultural Statistics, Arab Republic of Egypt. Ministry of Agriculture and Land Reclamation, the Egyptian Economic Affairs Sector: Dokki, Egypt.

Matosic, S., Birkás, S., Vukadinovic, S., Kisic, I., Bogunovic, I., 2018. Tillage, manure and gypsum use in reclamation of saline-sodic soils. Agric. Consp. Sci. 83, 131-138.

Mazhar, A.A.M., Mahgoub, M.H., Abd El-Aziz, N.G., 2011. Response of Schefflera arboricola L. to gypsum and sulphur application irrigated with different levels of saline water. Austral. J. Basic. Appl. Sci. 5, 121-129.

Meier, U., 2001. BBCH-Monograph: Growth Stages of Mono-and Dicotyledonous Plants. 2th Ed.; Federal Biological Research Centre for Agriculture and Forestry.

Ming, D.W., Allen, E.R., 2001. Use of natural zeolites in agronomy, horticulture and environmental soil remediation, Natural Zeolites: Occurrence, Properties, Applications,Ming andD. B. Bish, Eds, Mineralogical Society of America, Geochemical Society,Saint Louis, Mo, USA; Italian National Academy, Accademia Nationale dei Lincei (ANL), Barcelona, Italy, pp 619-654.

Miyazawa, M., Pavan, M.A., de Oliveira, E.L., Ionashiro, M., Silva, A.K., 2000. Gravimetric determination of soil organic matter. Braz. Arch. Biol. Technol. 43, 475-478.

Morris, N.L., Miller, P.C.H., Orson, J.H., Froud-Williams, R.J., 2010. The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment – a review. Soil Tillage Res. 108, 1-15.
Munkholm, L.J., Richard, J., Heck, B.D., 2013. Long-term rotation and tillage effects on soil structure and crop yield. Soil Tillage Res. 127, 85-91.
Pabalan, R.T., Bertetti, F.P., 2001. Cation-exchange properties of natural zeolites. In: Applications D, Bish L, Ming DW (eds) Natural zeolites: Occurrence, properties. Mineralgical Society of America Reviews in Mineralogy and Geochemistry, Washington, DC, USA, 45, 453–518.
Qadir, M., Schubert, S., Ghafoor, A., Murtaza, G., 2001. Amelioration strategies for sodic soils: a review. Land Degrad Dev 12,357-386.
Qadir, M., Steffens, D., Yan, F., Schubert, S., 2003. Sodium removal from a calcareous saline–sodic soil through leaching and plant uptake during phytoremediation. Land Degrad. Dev. 14, 301-307.
Rengasamy, P., 2006. World salinization with emphasis on Australia. J. Exper. Bot. 57, 1017–1023.
Reynolds, W.D., Elrick, D.E., 1985. In situ measurement of field-saturated hydraulic conductivity, sorptivity, and the alpha-parameters using the guelph permeameter. Soil Sci. 140, 292-302.
Rohošková, M., Valla, M., 2004. Comparison of two methods for aggregate stability measurement – a review. Plant Soil Environ. 50, 379–382.
Sadiq, M., Hassan, G., Mehdi, S.M., Hussain, N., Jamil, M., 2007. Amelioration of saline-sodic soils with tillage implements and sulfuric acid application. Pedosphere 17, 182-190.
Schneider, F., Don, A., Hennings, I., Schmittmann, O., Seidel, S.J., 2017. The effect of deep tillage on crop yield – What do we really know? Soil Tillage Res. 174, 193-204.
Seleiman, M.F., Kheir, A.M.S., 2018a. Maize productivity, heavy metals uptake and their availability in contaminated clay and sandy alkaline soils as affected by inorganic and organic amendments. Chemosphere 204, 514-522.
Seleiman, MF, Kheir, A.M.S., 2018b. Saline soil properties, quality and productivity of wheat grown with bagasse ash and thiourea in different climatic zones. Chemosphere 193, 538-546.
Singh, Y.P., Singh, R., Sharma, D.K., Mishra, V.K., Arora, S., 2016. Optimizing gypsum applications for amelioration of sodic soils to enhance growth, yield and quality of rice (Oryza sativa L.). J. Ind. Soc. Soil Sci. 64(1), 33-40.
Souzaa, L.H.C., *et al*., 2018. Soil carbon and nitrogen stocks and physical properties under no-till and conventional tillage cotton-based systems in the brazilian cerrado. Land Degrad. Devel. Doi: 10.1002/ldr.3105.
Strudley, M.W., Green, T.R., Ascough, J.C., 2008. Tillage effects on soil hydraulic properties in space and time. Soil Tillage Res. 99, 4–48.
Tucker, B.M., 1954. The determination of exchangeable calcium and magnesium in carbonate soils. Austral. J. Agric. Res. 5, 706-715.
Wehtje, G.R., Shaw, J.N., Walker, R.H., Williams, W., 2003. Bermudagrass growth in soil supplemented with inorganic amendments. Hort. Sci. 38, 613–617.
Zia, M.H., Saifullah, M., Sabir, A., Ghafoor, A.G., 2007. Effectiveness of sulphuric acid and gypsum for the reclamation of a calcareous saline-sodic soil under four crop rotations. J. Agron. Crop Sci. 193, 262-269.

تأثير اضافه الجبس، حامض الكبريتيك و النانوزيوليت علي خواص الاراضي الملحيه الصوديه وانتاجيه القمح تحت انواع مختلفه من الخدمه

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يعتبر تدهور الاراضي بالملوحه والقلويه من المشاكل الرئيسيه التي تواجه الزراعه في المناطق الجافه وشبه الجافه. فنتيجه للمناخ الجاف ومحدوديه الموارد المائيه فتتحول الاراضي الغير ملحيه الي ملحيه، الامر الذي يتطلب معه مزيد من الدراسات لبحث علاج لهذه المشكله. فأثبتت بعض الدراسات الحديثه ان الخدمه الخفيفه تؤدي الي زياده محتوي التربه من الماده العضويه وبالتالي تحسين الخواص الفيزيائيه والكيميائيه للتربه الغير ملحيه. وبالرغم من ذلك فان دراسه تأثير الخدمه الخفيفه في الاراضي الملحيه القلويه بجانب استخدام المحسنات الارضيه ومقارنتها بالخدمه العميقه لم تنل القدر الكافي من الدراسه. ولهذا فان الدراسه الحاليه تهدف الي دراسه التأثير المشترك لاضافه بعض المحسنات غير العضويه (كالجبس، حامض الكبريتيك ، النانوزيوليت) مع نوعين من الخدمه (خدمه خفيفه سطحيه واخري عميقه) علي الخواص الفيزيائيه والكيميائيه للاراضي الملحيه القلويه وانتاجيه القمح. واوضحت النتائج ان الخدمه العميقه مع اضافه حامض الكبريتيك حققت خفض معنوي لكل من الملوحه، والصوديه، تضاغط التربه وكذلك الكثافه الظاهريه وادي لزياده التوصيل الهيدروليكي ، متوسط القطر الموزون ودليل البناء الارضي بالمقارنه بالكنترول. ايضا ادت الخدمه العميقه الي تحسين خواص الاراضي الملحيه القلويه علي الرغم من زياده الكربون العضوي في حاله الخدمه الخفيفه عنها في العميقه ادي اضافه النانوزيوليت الي زياده محتوي التربه من الكربون العضوي وما ترتب علي ذلك من زياده انتاجيه القمح حتي قارب بمحصول معامله الجبس. ولكن العائد الاقتصادي في حاله النانوزيوليت كان منخفض بالمقارنه بالجبس وحامض الكبريتيك. مما سبق يمكن استنتاج ان اضافه حامض الكبريتيك، الجبس والنانوزيوليت مع اجراء خدمه عميقه يؤدي الي تحسين الخواص الفيزيائيه والكيميائيه للاراضي الملحيه القلويه وانتاجيه القمح مع اختلاف العائد الاقتصادي والذي كان منخفض في حاله اضافه النانوزيوليت، مما يؤكد اهميه الخدمه العميقه في استصلاح الاراضي الملحيه الصوديه بالمقارنه بالخدمه الخفيفه. وعلي الرغم من انخفاض العائد الاقتصادي من اضافه النانوزيوليت ولكنه ادي الي زياده محتوي التربه من الماده العضويه وادي ايضا الي تقليل الملوحه والصوديه نسبيا ، الامر الذي يتطلب معه دراسه معدلات مرتفعه من خام الزيوليت بدون تحويله الي جزيئات نانو ، حيث يكون سعرها منخفض وربما تؤدي الي زياده العائد الاقتصادي من استخدامها بهذه الصوره.