Use of Spent Grains, Cheese Whey, Gypsum, and Compost for Reclamation of Sodic Soils and Improvement of Corn Seed Germination

Emad F. Aboukila[1]

ABSTRACT

Incubation and germination experiments were carried out to evaluate spent grain, cheese whey, gypsum and compost for reclamation of sodic soils and enhancing Corn (*Zea mays L.*) germination. Seven treatments included two levels of mozzarella cheese whey, two levels of compost, one level of gypsum, one level of spent grain and an untreated control. The treatments were added to sodic soil, packed in pots and incubated under natural field conditions. One month after the incubation, 4 corn seeds were sown in the soil pots. The germination experiment was lasted for 15 days. Results indicate that all organic amendments most effectively reduced exchangeable sodium percent (ESP), sodium adsorption ratio (SAR), and soil pH; while enhanced soil organic matter, macronutrients, and corn germination percentages, compare to gypsum and control. Spent grain was the most effective amendment in reducing soil sodicity and enhancing soil fertility and corn germination in the sodic soils. Further increasing the application rates of cheese whey and compost did not significantly enhance corn germination or reduce sodicity. The positive impacts of all amendments followed the arranging; spent grain > cheese whey > compost > gypsum > control. Moreover, one-month incubation was enough time for amendments to ameliorate soil sodicity before crop plantation. Spent grain and cheese whey are more effective than gypsum and compost in remediating sodic soils and are much inexpensive.

Keywords: Sodic soils; Industrial by-products; Cheese whey; Organic amendments; *Zea mays L*

INTRODUCTION

Worldwide salt-affected soils are estimated to be greater than 950 Mha of land (Choudhary, 2017). These soils are classified as sodic, saline, and saline-sodic. Salt-affected soils spread within at least 75 countries (Szabolcs, 1994) and represent more than 20 % of the world irrigated area. Globally, more than 60 % of salt-affected soils classified as sodic soils (Choudhary, 2017). Presently, the worldwide expansion of sodic soils is increasing because of using low quality of irrigation water and poor land management (Qadir and Oster, 2004). Soil sodicity and salinity, in arid and semi-arid regions, consider the two main environmental issues caused land degradation in irrigated areas (Mahmoodabadi et al., 2013). Generally, soil lost as a result of degradation is 10 to 40 times more than soil formation process (Pimentel and Burgess, 2013).

Due to high exchangeable sodium percentage, cultivation of sodic soils faces many challenges, such as poor structure, low aggregate stability, dispersion of clay particles, surface crusting, low water infiltration, low hydraulic conductivity, low water holding capacity, high pH, high bulk density, high sodium concentrations in soil solution (Levy, 2012; Dodd et al., 2013), low fertility (Wong et al., 2010), low biological activity (Rao and Pathak, 1996), nutrient deficiencies or imbalances, and specific ion toxicities (Choudhary, 2017). Under such deleterious characteristics, economic yield is hard to achieve.

Sodic soils reclamation is generally more expensive compared to saline-sodic or saline soils (Seelig et al. 1991) and may take years (Qadir and Oster, 2002). However, sodic soil could be remediated by incorporation of organic matter, chemical amendments, and tillage (Qadir and Oster, 2002). Gypsum is an important source of calcium and consider the most common chemical amendment for sodic soils reclamation. (Ghafoor et al., 2001). Other chemical amendments include acid-forming amendments such as elemental S and sulfuric acid, which supply the required Ca^{2+} to replaces the exchangeable Na^+ by solubilize native calcite ($CaCO_3$) (Sadiq et al., 2007), thus remediating the physical limitations of the sodic soil. Moreover, Ca and Mg provided by gypsum, increases plant growth (Clark et al., 2001). Nevertheless, natural gypsum has seldom been applied due to the expensive of exploration, crushing, and transportation (Wang et al., 2017). Gypsum requirement application rates can be estimated by considering current and target ESP values, and soil cation exchange capacity (Ashworth et al., 1999). After application of chemical amendments, salts and excess sodium are leached with the drainage water (Pessarakli and Szabolcs, 1999). Nevertheless, gypsum is not capable of recover the biological activities of soil that consider the key of sustainable soil fertility (Clark et al., 2007). Furthermore, chemical amendments are generally not readily attainable in many regions particularly in low-income countries (Qadir et al., 2001).

Furthermore, the application of chemical amendments leads to later enhance of soluble salts level in the drainage water which have negative influences on the environment (Qadir and Oster, 2004).

On the other hand, using organic amendments for sodic soil reclamation could be a beneficial practice of remediating the adverse impacts of soil sodicity as it prompts the solubilization of calcium from calcite and other Ca-carrying minerals via enhancing microbial decomposition and organic acids (Choudhary et al., 2011). As a result, Ca ions increase and displaced Na ions from the cation exchange sites (Walker and Bernal, 2008). Moreover, the addition of organic amendments improves soil structure through enhancing soil aggregation by restore soil microbial and enzymatic activities (Lakdhar et al., 2009). Developments in soil aggregation enhance soil porosity, soil permeability, and water infiltration (Haynes and Naidu, 1998). The application of organic matter (OM) to sodic soil likely the most effective reclamation strategy as its wide availability, low cost, and the suitability of recycling organic waste (Wang et al., 2014).

Because of the lack of organic farm waste in Egypt, as in many regions around the world, industrial organic by-products, such as brewer's spent grain (SG) and cheese whey, could be used as substitutional to conventional organic fertilizers. SG is a byproduct of the beer production, constituting almost 85% of the total byproducts produced matters (Mussatto et al., 2006). Spent grain is acidic, rich in macro and micronutrients, amino acids, and vitamins (Mussatto and Roberto, 2006) as well as cellulose, hemicelluloses, lipid, protein, arabinoxylan, ash, and lignin (Tang et al., 2009). Therefore, it is good candidate for recycle in agriculture.

Cheese whey is a liquid byproduct of cheese and cottage cheese manufacture and produced from processed milk. For each kg of cheese produced, 9 kg of cheese whey is generated (Robbins and Lehrsch, 1998). Cheese whey is generally acidic, containing approximately 8% solids and 40-50 g kg^{-1} of easily decomposable organic materials, mostly lactose and proteins (Kelling and Peterson, 1981). Acid whey contains useful plant nutrients like phosphorous, nitrogen, potassium, magnesium, calcium, and sulfur. Application of low sodium whey to sodic soil could ameliorate sodicity (Jones et al., 1993). Soluble salts in the cheese whey decrease the thicknesses of electric diffuse double layer of clay particles and enhancing flocculation. Application of whey lactose and proteins to soil activate aerobic microorganisms, which create polysaccharides and other organic compounds, and enhance fungi growth (Sonnleitner et al., 2003) that help

the stabilization and development of soil aggregates (Roldán et al., 1996; Amézketa, 1999).

SG and cheese whey disposal are often environmental issue; thus, reuse of these by-products is a serious problem to deal with. The properties of SG and cheese whey make them ideal candidates for recycle in agriculture. Few researchers have studied the effect of SG or cheese whey as sodic soil amendments. Thus, the research objective was to evaluate the possibility for using SG and cheese whey as organic amendments for sodic soil. Developing this practice may mitigate the economic and environmental issues of degraded soil and excess wastes. The specific objectives of this research are to assess the capacity of SG, cheese whey, compost, and gypsum to reduce soil sodicity, improve soil sequestration of macronutrients, and enhance the of maize growth on sodic soils.

MATERIALS AND METHODS

Soil Location and Sampling

Sodic soil used for the experiment was collected from the region of Abees, Alexandria, Egypt (approximate latitude is 31° 12' 15.94" N and 29° 58' 58.2" E). Soils are classified as *Typic Torrifluvents* (Soil Survey Staff, 2014), with clay loam texture. The climate of the study area is Mediterranean with hot dry summer and wet cool winter. The average yearly temperature is 20.6° C (mean high temperature is 25.0° C and average low temperature is 16.3° C). Yearly rainfall is 18.3 cm, mostly precipitated from November till February (Climate-Data.org, 2019). Soil were collected from 0 to 30 cm depth, air-dried, ground, and passed through a 2-mm sieve. Sub-samples were analyzed for selected chemical and physical properties (Table 1).

Table 1. Basic physico-chemical properties of sodic soil used for experimentation

Analyte	Soil
pH (1:2.5 w:w)	8.72
EC$_e$ (dS m^{-1})	3.91
Available N (mg kg^{-1})	78.45
Available P (mg kg^{-1})	4.45
Available K (mg kg^{-1})	352.12
Total CaCO$_3$ (%)	6.88
CEC (Cmol$^+$ kg^{-1})	26.75
Organic Matter (%)	1.66
Organic C (%)	0.96
SAR	26.87
ESP (%)	30.95
Bulk density (g cm^{-3})	1.27
Sand (%)	41
Silt (%)	22
Clay (%)	37
Texture	Clay Loam

Amendments

Four types of amendments were applied in this study included; spent grain, cheese whey, compost, and gypsum. The spent grain was brought from Al Ahram Beverages Company, Abu Hammad, Egypt. The mozzarella cheese whey was brought from the Arabian Food Industries Company (Domty), 6th of October City, Egypt. The characterizations of the SG, cheese whey and compost were calculated using methods outlined in Kehres (2003). The amendments characterizations are shown in Table 2.

Experimental Design and Treatments

In spring of 2018, 2 pot experiments were conducted at the farm of the College of Agricultural, Damanhour University, Damanhour, Egypt.

Incubation Experiment

Seven treatments were applied in this research included: 2 levels of cheese whey (W1 and W2), 2 levels of compost (C1 and C2), gypsum (G), spent grain (T) and control (Ctrl) (Table 3). The application rates of cheese whey were 1%, and 2% dry matter content. The base level of spent grain (T) and compost (C1) was the quantity of spent grain or compost required to increase SOM by 1%. Compost was also added twice the base level (C2). Gypsum was added at equivalent rate of gypsum requirement to reduce ESP to 10%.

Amendments were incorporated with 5 kg of sodic soil and packed in polyethylene pots. To let added treatments to affect soil properties, all pot treatments were incubated under natural field conditions, without plants, for a month beginning of 1st of April 2018. The pots were distributed in a randomized complete block design with four replications of each treatment. Tap water was applied to the pots regularly to obtain 60% of soil saturation capacity. The 60% saturation capacity possesses high microbial activity (Doran et al., 1990), which leads to increases of aggregate stability (Kandeler and Murer, 1993). After a month of incubation, sub-samples were analyzed for selected chemical properties.

Table 2. Characterization of organic amendments used in this study (oven dry weight basis)

Analyte	Compost	Spent grain	Cheese whey
pH (1:5 w:w)	6.95	4.16	3.82
EC (dS m^{-1}, 1:5 w:w)	5.91	1.45	5.12
Organic Matter (%)	42.5	75	3.15
Total N (%)	2.26	6.12	2.63
Total P (%)	1.13	1.86	0.14
Total K (%)	0.59	2.74	0.33
Organic carbon (%)	24.65	43.5	1.83
C:N ratio	10.91	7.1	0.69
Moisture (%)	23	75	96
Fe (mg kg $^{-1}$)	930	1130	nd[*]
Zn (mg kg $^{-1}$)	215	368	nd
Mn (mg kg $^{-1}$)	98	210	nd
Cu (mg kg $^{-1}$)	67	98	nd
B (mg kg $^{-1}$)	23	39	nd

[*]nd: not determined

Table 3. Treatments used in this study (oven dry weight basis)

Treatment		application rates g kg^{-1}
Control	Ctrl	no amendment
Cheese whey	W1	10
Cheese whey	W2	20
Compost	C1	23.5
Compost	C2	47
Gypsum	G	5.6
Spent grain	T	12.5

Germination Experiment

After incubation, the pots were sown with 4 Corn seeds (*Zea mays L.*). Moisture levels were frequently observed and kept in pots at 60% of saturation capacity. The germination experiment continued for 15 days. At the end of the germination experiment, the germination percentage was determined. The over-ground plants were reaped, oven dried at 65°C for 48 hours, then dry weight was recorded.

Soil Analysis

Samples were air-dried, crushed, and 2-mm sieved, and analyzed for different soil properties. Soil pH were measured in 1:2.5 soil water suspensions following Jackson (1958). Electrical conductivity (EC_e) were measured in saturated paste extracts (Jackson, 1958). Sodium adsorption ratio (SAR) was determined as described by Richards (1954). Soil cation exchange capacity (CEC) was estimated following the Bower saturation method as outlined by Richards, (1954). Extractable sodium was extracted with 1 M ammonium acetate solution (Normandin et al., 1998). Exchangeable Na was then calculated by subtracting soluble Na from total extractable Na. Exchangeable sodium percentage (ESP) was determined as the amount of exchangeable sodium expressed in percent of the CEC. Calcium carbonate equivalent (CCE) was estimated by the pressure-calcimeter method (Nelson, 1982). Available N was calculated by Microkjeldehl method (Bermner and Mulvaney 1982). Available phosphorus was analyzed in 0.5 N $NaHCO_3$ extracts by Olsen's method (Olsen and Sommers, 1982). Available K was extracted with 1 N ammonium acetate solution and determined by a flame photometry (Jackson, 1958). Soil OM was calculated by the modified Walkley-Black method as outlined by (Nelson and Sommers, 1982). Soil texture was determined by hydrometer method (Gee and Bauder, 1986).

Data Analysis

An analysis of variance (ANOVA) was conducted, to test for statistical differences, using SAS software (SAS Institute, 2013). Significant differences among the treatment averages were tested by Tukey's test at 95% significance level (P < 0.05). Regression analysis was utilized to estimate the relationship between the soil OM, N, P, K, pH, ESP, and SAR in soils and crop growth parameters.

RESULTS AND DISCUSSION

1. Incubation Experiment

Soil salinity

High soil salinity affects crops by making water less available (osmotic effects) and is considered a physiological drought. Soil EC_e differences among various treatments are shown in Fig. 1. The soil EC_e of W2, C1, C2, G, and T treatments were significantly differed in comparison to the control. While EC_e of W1 did not differ significantly from control. It is worth noting that, all treatments produced significant decreases in soil EC_e compared to the respective initial values. This reduction of salt concentration is attributed the high leaching of solute in the treated soil. The high leaching in the treated soil might due to presence of large pores that enhance the solute convective process. The lowest EC_e value were observed in the compost-amended soils (C1 and C2), The positive (reduction in the solute concentration) of the treatments followed the order: C2>C1>G>T>W2>W1>Ctrl. Generally, EC_e of post incubated soil decreased by 9, 16, 17, 37, 38, 34, and 31% for Ctrl, W1, W2, C1, C2, G, and T treatments, respectively in comparison to their initial concentration.

Similar decreases in soil salinity were outlined by Tejada et al. (2006), Ghafoor et al. (2001, 2012), and Mahdy (2011) with the application of composts and organic manures to salt affected soils. However, this finding is disagreeing with the results of Wang et al. (2015) who recorded increasing the salinity levels with the addition of Flue gas desulfurization gypsum.

This reductions in soil EC_e can be illustrated by the mobilizing of Ca via increasing the dissolution of soil calcite, which exchange Na at cation exchange complex and forms Na_2SO_4, $MgSO_4$, and other high solubility salts. Moreover, these reactions promote water infiltration, soil flocculation, and stability (Clark et al., 2001). As a result, the majority of these soluble salts leached with the drainage water.

Soil pH

Soil pH is a significant factor which controls nutrients solubility and availability to plant. Reducing soil pH of sodic and alkaline soils produces increasing in availability of plant nutrients. Post incubation soil analysis showed that soil pH was significantly decreased in all treatments compare to control (Fig. 2). During incubation, Soil pH was affected quickly by all treatment additions. Post incubation, soil pH reduced to less than 8.5; the critical value of pH for salt-affected soil. There were significant differences in the soil pH values between the treated soils and the Ctrl. Spent grain (T) produced the smallest pH values in comparison to the other amendments. However, gypsum (G) was less effective treatment in decreasing soil pH. The values of soil pH for the amended soil followed the order Ctrl>G>C1>C2>W1>W2>T. The reduction of pH values was influenced by the type of amendment and application rate. Increasing the application rate of compost and cheese whey enhanced the pH reduction.

Spent grain and cheese whey are acidic. Thus, they might be preferable used than compost as organic amendments for decreasing soil pH and reclamation of sodic soils.

It is likely that incubation of organic treatments probably enhanced the partial pressure of CO_2 because of increases of the microbial activity. This possibly caused by the formation of organic and inorganic acids, which lead to decreasing pH in organic treated soils (Wong et al., 2009). Furthermore, solubilization of minerals such as Ca and Mg (Qadir et al., 2007) because of microbial activity (Sahin et al., 2011) assists the decrease of pH in sodic soils by exchanging with Na from cation exchange complex (Chaganti and Crohn, 2015).
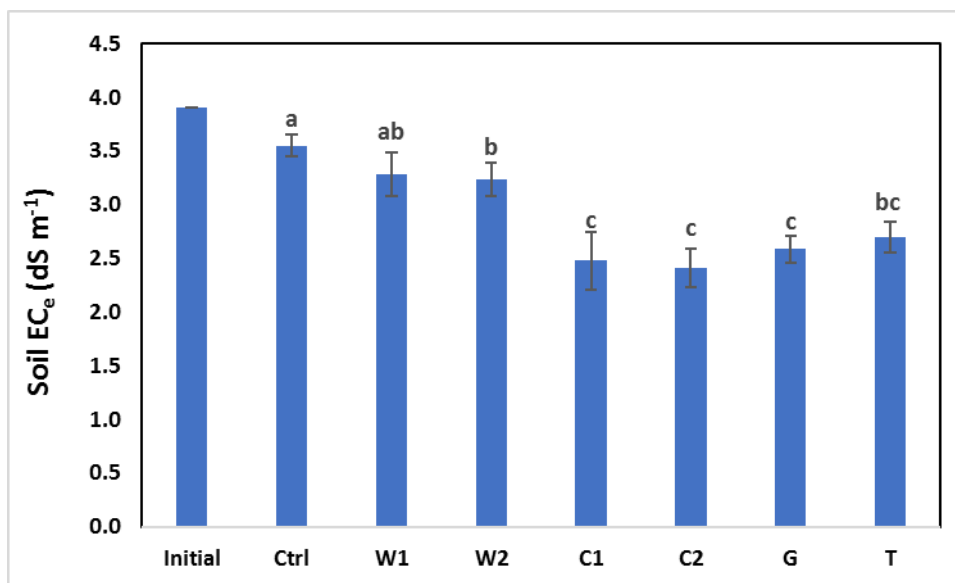
Fig. 1. Change in EC_e of soils (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)
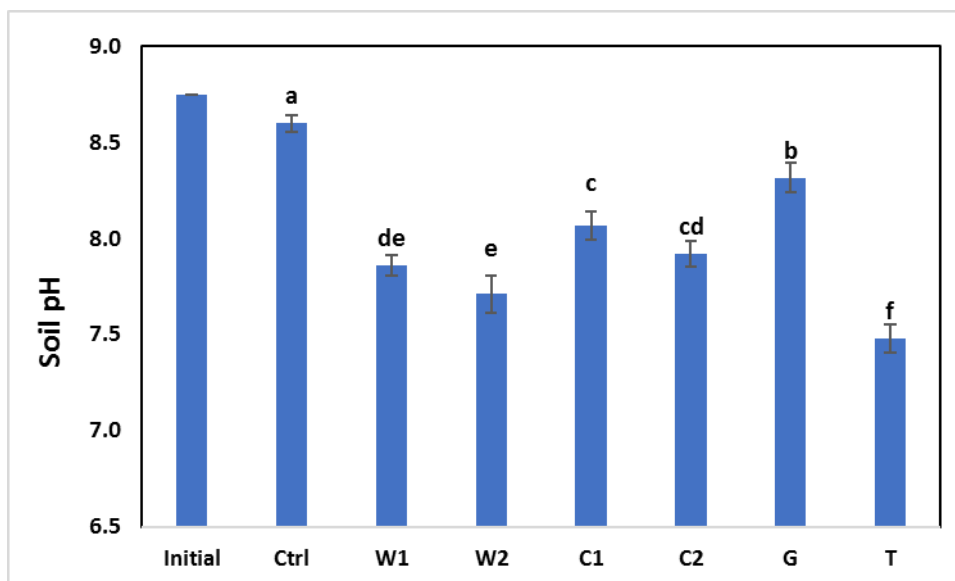

Fig. 2. Soil pH (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)

Sánchez-Monedero et al. (2001) mentioned that nitrification was responsible for the decreasing pH values during organic waste decomposing. Similarly, Aboukila et al., (2018b) stated that increasing application rate of mozzarella cheese whey decreased the pH in both clay and calcareous soil. Reductions in pH with application of organic amendments to salt-affected soils were also stated by other researchers (Wong et al., 2009; Mahdy, 2011; Franco-Otero et al., 2012; Chaganti et al., 2015).

There are contrasting reports after the application of organic amendments to salt-affected soils. For example, Sun et al. (2016) recorded decreases in soil pH with the addition of different biochars rates. While Wang et al., (2014) and Qayyum et al. (2015) recorded increases in alkalinity after the biochar and green waste compost addition. Whilst no reductions in EC, pH, or the concentration of soluble Ca, Mg or Na were observed (Walker and Bernal, 2008).

Soil SAR

Post-incubation, SAR levels decreased significantly in all treatments (Fig. 3) because of sodium removal by leaching. While G and organic treated soils (W1, W2, C1, C2, T) had more Na^+ leached and consequently had significantly less SAR compared to the untreated control. The calculated SAR values in the incubated soil samples followed the order: W2<T<W1<C2<C1<G<control. In comparison with the initial value in the soils, the SAR levels reduced by 25.3, 65.7, 69.4, 59.2, 61.5, 59.0, and 66.1 % for Ctrl, W1, W2, C1, C2, G, and T, respectively.

The enhance releasing of Ca and Mg by organic treatments increased their contents in soil solution and facilitated the exchange with exchangeable Na on the cation exchange complex and release Na to soil solution. Thus, helped Na loss by leaching. As a result, soil SAR reduced. Furthermore, extra Ca release from gypsum promoted the exchangeable Na release to soil solution, and consequently enhanced additional decreases of soil SAR (Chaganti et al., 2015). Soils with SAR values more than 13 are classified as saline-sodic or sodic soils (Soil Science Society of America, 2009). In this experiment, the average SAR of treated soil was reduced from 26.9 to 9.1 after incubation. These results agree with those reported by Mahdy (2011), and Chaganti et al. (2015) who observed significant decreases in SAR after leaching salt-affected soils treated with organic amendments and gypsum. The results of this study propose that sodic soils could be ameliorated and turned into non-sodic soils by applying cheese whey, compost, gypsum, or spent grain.

Soil ESP

Increasing the concentration of exchangeable sodium proportional to the other exchangeable cations (for instance Ca, Mg, and K) lead to increase in soil ESP. Fig. 4 shows the initial and the studied treatments for soil ESP. All treatments, except for control, were effective in decreasing the soil ESP to less than 15%. Before soil amending, the ESP was 30.95%, The ESP levels ranged from 23.7 to 9.5% after soil amending. Additionally, the levels of exchangeable Na reduced significantly after incubation with cheese whey, compost, gypsum, or spent grain (Fig. 4).
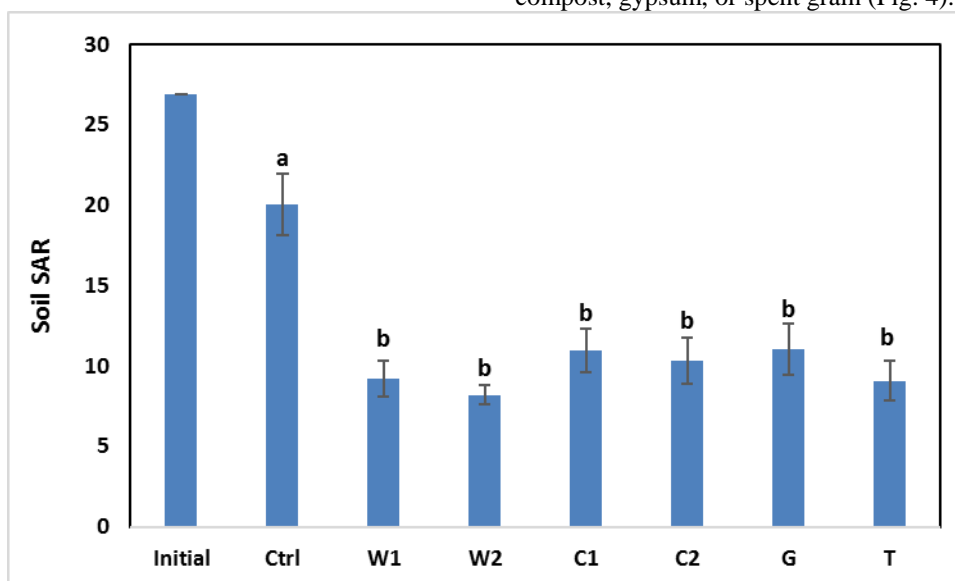

Fig. 3. SAR of soils (average ± standard deviation) after incubation with various amending treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)
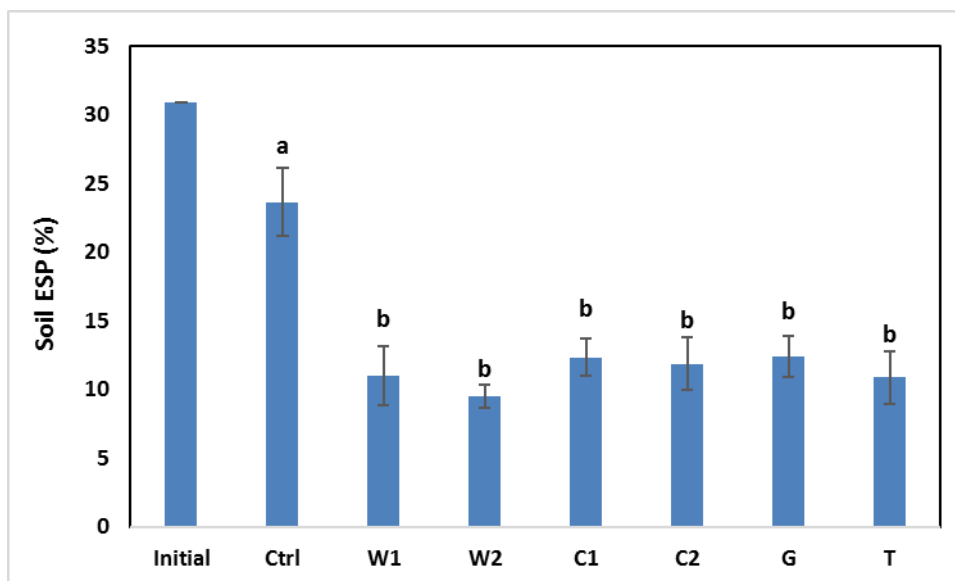
Fig. 4. ESP of soils (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)

The significant decrease in the exchangeable Na levels led to the reduction in the soil ESP.

Organic amendments and gypsum were statistically equally successful in decreasing the soil ESP. This reduction could be attributed to the releasing of Ca from; gypsum, organic amendments, and the solubilization of soil calcite by organic amendments that probably promote the Na-Ca exchange rate among the cation exchange complex and soil solution.

Consequently, improves soil aggregates, and permeability. Reductions in soil ESP, with the additions of gypsum and other organic amendments, were also observed by other researchers (Tejada et al., 2006; Gharaibeh et al., 2011; Chaganti et al., 2015; Day et al., 2019). The ESP reduction ranged between 60.2% to 69.2% for organic amendments while that reduction resulted for using G application was 60.0%. Control soils showed the lowest ESP reduction of 23.5%. The experimental results suggest that the application of cheese whey, compost, gypsum, or spent grain reduced the ESP markedly.

Soil organic matter

With sustainable management, soil can act as a C sink to mitigate climate change. On the other hand, non-responsible management causes soil to lose carbon, which contribute to climate change. Soil organic carbon (SOC) is the most dominate form of the C existed in the soil. Generally, the SOC content in salt-affected soil is low. Lal and Bruce (1999) estimated that the worldwide reclamation of salt-affected soils could enrich SOC by 20-40 Mt C a^{-1}, which could contribute to the CO_2

mitigation. Figure 5 shows the percentage of SOM in treated soil by the various amendments used. All organic treatments produced significant increases in SOM. The greatest increases were recorded with the T, and C2 treatments compared to control. The OM ranged between 1.47% (G) to 2.8 % (T). The mean relative increase in OM% in comparison to control were 20.8, 26.1, 47.6, 60.3, and 78.3 % at W1, C1, W2, C2 and T treatment, respectively. It is noted that SOM in gypsum treated soil decreased by 6.6%.

The size of the increase in SOM tends to correlate with the quantities of organic matter applied by each amendment. So, as the addition level of cheese whey or compost increased, the SOM increased compared to the initial or Ctrl treatments. Comparable results were observed by Aboukila et al. (2018a) who reported significant level of SOM in calcareous soil treated with SG or compost compared to the untreated ones. Similarly, Aboukila et al., (2018b) stated that increasing application rate of mozzarella cheese whey led to increasing SOM in both clay and calcareous soil.

The application of organic amendments to salt-affected soils could enhance the soil carbon sequestration which will participate in the greenhouse gas mitigation (Oo et al., 2015; Sun et al., 2016). In the present study, the application of various organic treatments increased the quantity of soil OM, especially with the spent grain application, useful for sodic soils deficient in organic matter. The significant increases of SOC and available nutrients with the spent grain application, which could be concluded that the spent

grain can improve the sodic soil fertility and probably the soil carbon sequestration in the long-range.

Soil Available Macronutrients

Soil available N, available P, and available K concentration were increased using all amendments compared to the Ctrl. The percentage increases varied from 16 to 329 % for N; 5 to 135 % for P; and 8 to 96 % for K. Therefore, all of amendments were efficient at contributing soil available N, P and K to sodic soil (Fig.6, 7, 8). The spent grain significantly produced

larger levels of N, P, and K compare to other organic amendments. However, W2 was statistically equally to T in increasing soil K, and C2 was statistically comparable to T in increasing soil N, compare to other organic treatments. Soil available N, P and K were enhanced with increasing the addition level of cheese whey or compost. The positive effects of all treatments for increasing soil N, and P in sodic soil followed the order: T>C2>C1>W2>W1>G>Ctrl. While, for soil K, the order was: T>W2>C2>W1>C1>G>Ctrl.
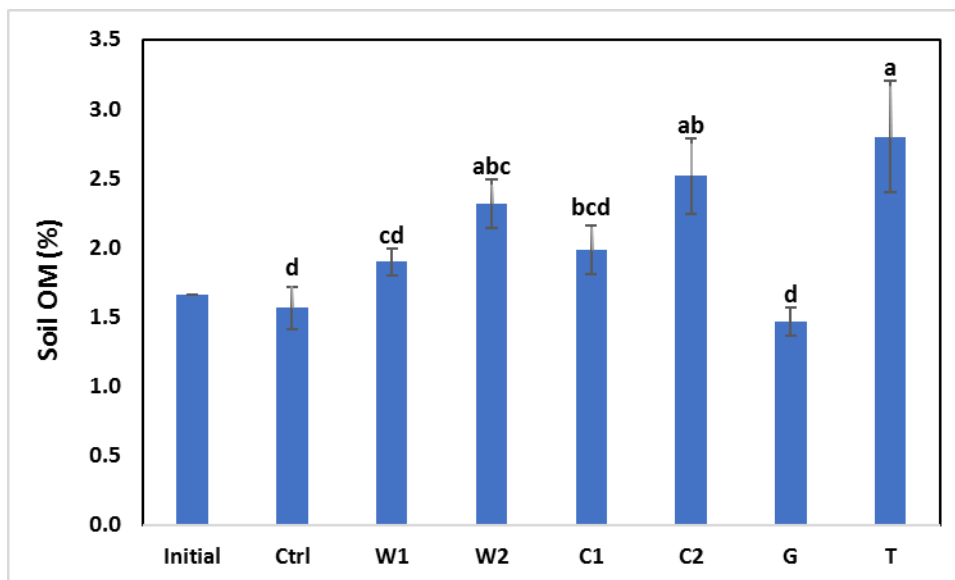

Fig. 5. Change in soil organic matter (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)
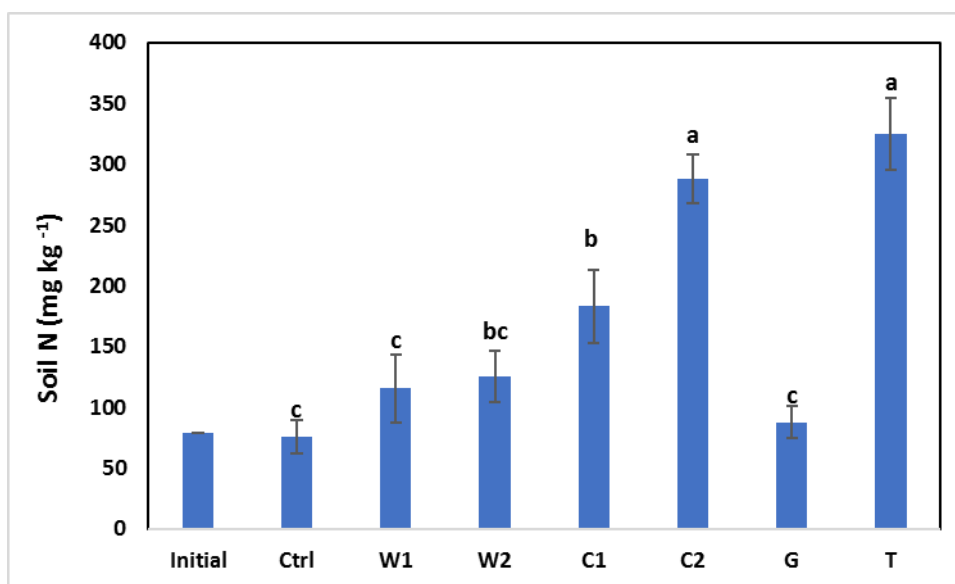

Fig. 6. Change in soil available nitrogen (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)
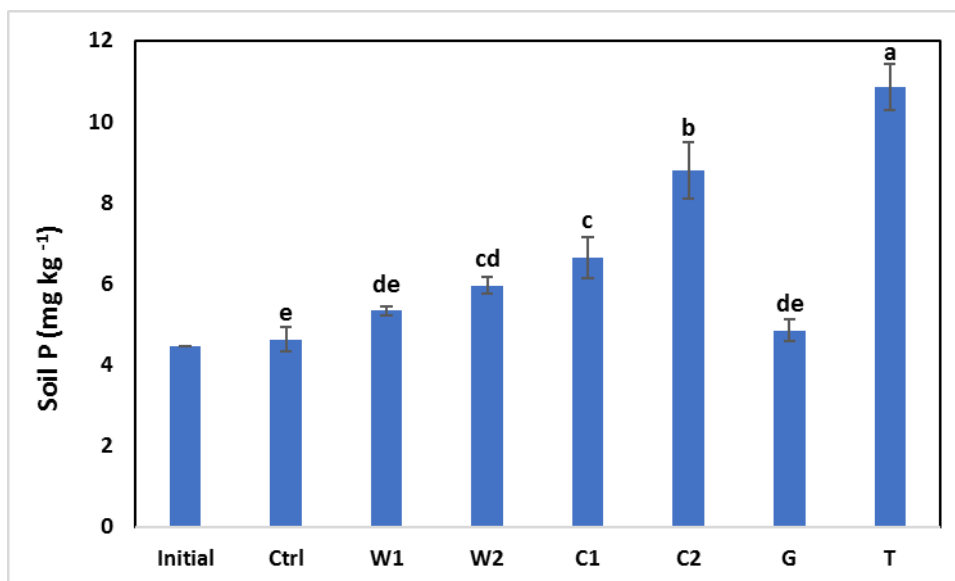
Fig. 7. Change in soil available phosphorus (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)
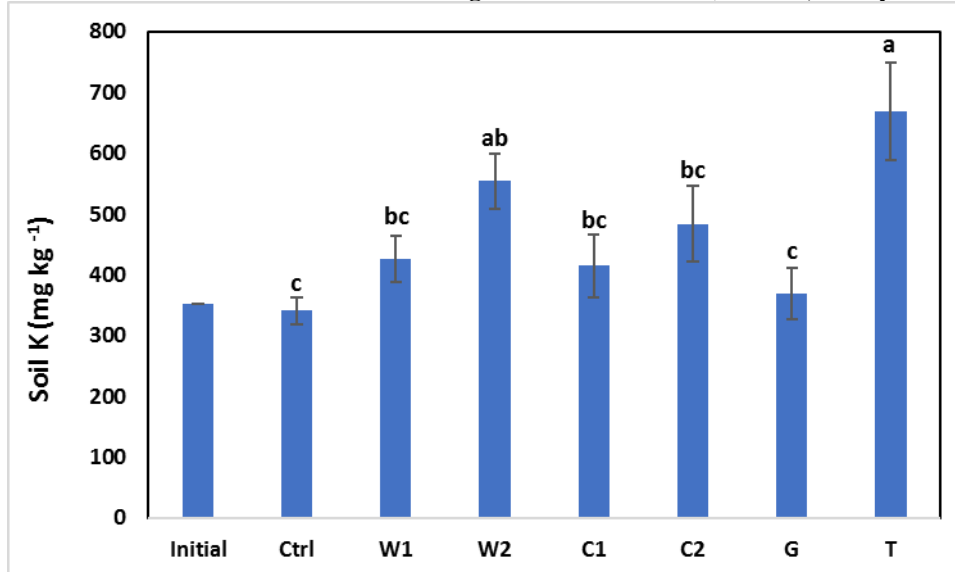

Fig. 8. Change in soil available potassium (average ± standard deviation) after incubation with various treatments. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)

Mineralization of organic materials present in the added organic treatments leads to increases in the soil available N, P, and K. Organic amendments used in the present research have considerable levels of readily decomposable OM, which are mineralized and increased soil organic carbon and nutrients content. Furthermore, organic amendments must add before sowing to have enough time for the mineralization processes of organic compounds thus increases the availability of plant nutrients.

Comparable conclusions are reported by Aboukila et al. (2018a) who reported that the incubation of spent grain or compost in calcareous soil led to reducing soil pH and increasing SOM, dissolved OM, macronutrients, micronutrients soil water holding capacity, germination parameters and squash yield. The present results also agree with the results of of Yu et al. (2013) who reported that the addition of organic amendments caused increase of SOM and soil available P. This enhancement in available P is caused by the decrease in soil pH, which due to OM mineralization. Ketterings et al. (2017) recorded that acid whey supplies soils with N, P,

and K. In average, an addition level of 16.84 m^3 h^{-1} supplies about 185 kg h^{-1} of total N, 279 kg h^{-1} of P$_2$O$_5$, and 336 kg h^{-1} of K$_2$O. Aboukila et al. (2018b) reported that application of cheese whey to calcareous and clay soils led to increasing SOM, soil available N, P, and K.

2. Germination Experiment

No significant differences in the final germination percent (FGP) were found between treatments in sodic soil. The FGP ranged from 75% in the control to 100% in W1 and C1 treatments. However, there were significant differences in biomass yield among the treatments. The biomass yields of corn plants at the end of the germination experiment are illustrated in Figure 9. Spent grain (T) was the most effective one in enhancing seed germination in sodic soil. The biomass yield of T significantly increased to 312% in comparison with untreated soil (Ctrl). This was due to the superior effect of the spent grain (T) in amelioration soil sodicity by decreasing soil pH, exchangeable Na, soluble Na, ESP, and SAR, and increasing N, P, and K. Cheese whey treatments were the next most effective treatments in enhancing seed corn germination and the biomass yield that produced 226, and 214% more yield than the control for W1, and W2, respectively. The biomass yield in compost treatments were 130, and 148% larger than the untreated Ctrl for C1, and C2, respectively. Increasing application rates of cheese whey or compost

did not produce significant increases in soil fertility, or corn growth. Gypsum treated soil was less effective amendment and produce poor seed germination as control. This may due to that the gypsum was less effective treatment in decreasing soil pH. Moreover, it doesn't support sodic soil with any remarkable amount of OM, N, P, or K, compare to organic treatments.

The enhancement of the biomass with organic amendments could be because of OM effects, which decreases sodicity and increases soil aeration, soil water holding capacity, SOM, and available plant nutrients. Berova et al. (2010) found high concentrations of nutrients and the enhancement of plant growth promoting substances resulted from the decomposition of organic amendments have a favorable impact on crop yield.

In this study, significant positive linear correlations were observed among biomass yield and; soil OM (r = 0.76, P < 0.01) (Fig. 10), soil available K (r = 0.89, P < 0.001), soil available P (r = 0.65, P < 0.01), and soil available N (r = 0.56, P < 0.05), as well as significant negative linear correlations between biomass yield and; soil pH (r = 0.90, P < 0.001) (Fig. 11), SAR (r = 0.60, P < 0.01), and ESP (r = 0.56, P < 0.05). The results of this study concurred with those of Mahdy (2011), and Aboukila et al. (2018a).

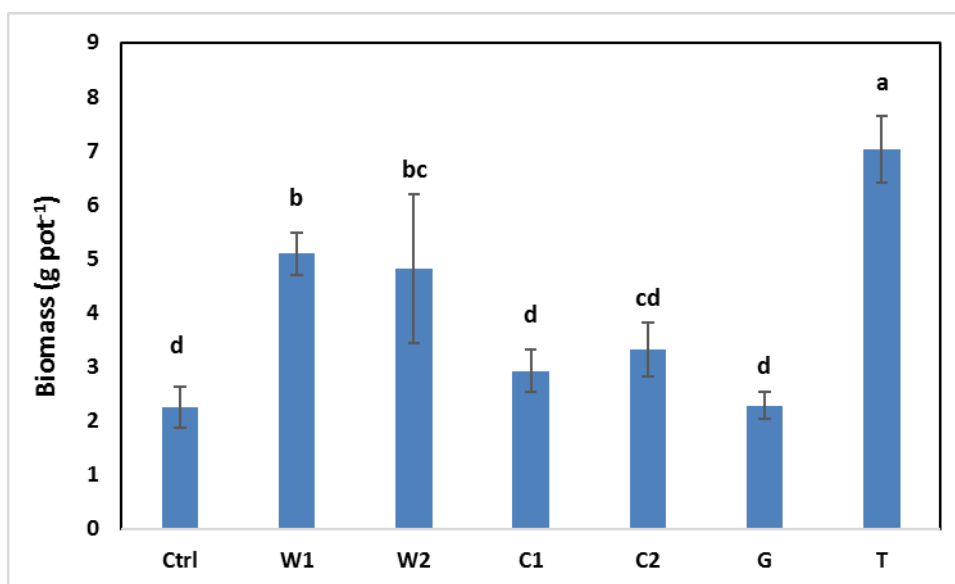**Fig. 9. Total biomass yield of corn (average ± standard deviation) by treatment. Same letters within columns indicate no significant differences (P < 0.05, Tukey's test)**
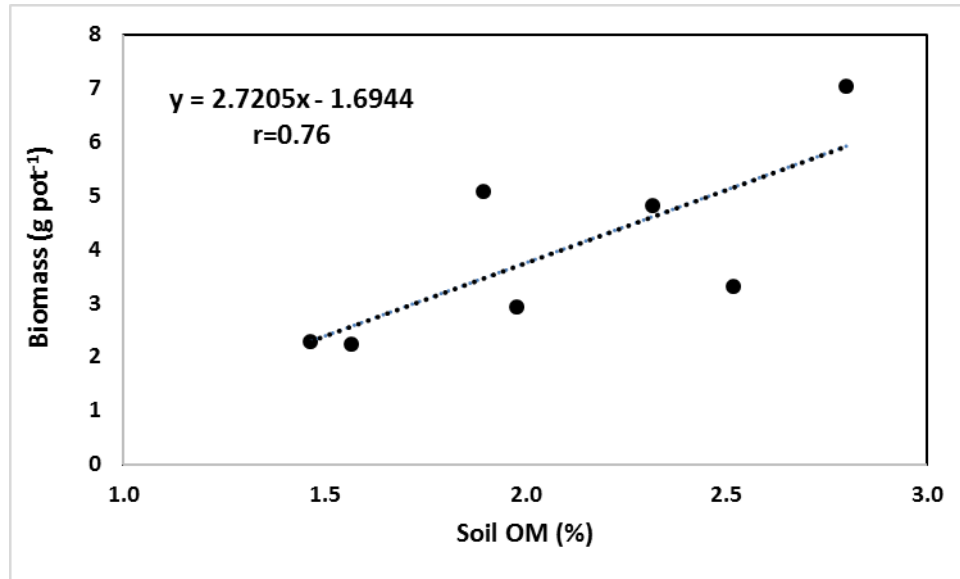
Fig. 10. Relationships between biomass yield of corn and soil organic matter after the application of soil amendments
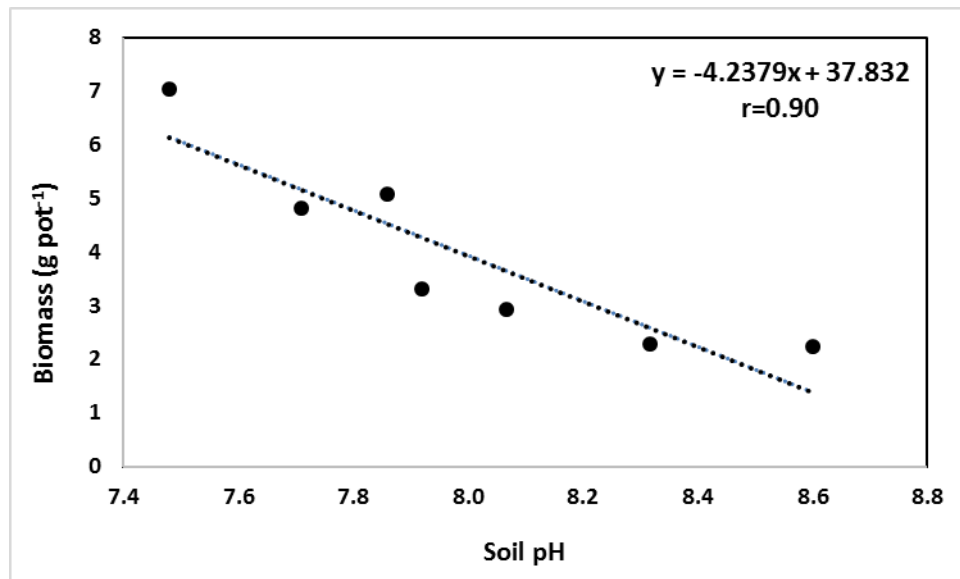

Fig. 11. Relationships between biomass yield of corn and soil pH after the application of soil amendments

CONCLUSION

All organic amendments examined in the present study were efficient at remediating of sodic soil properties and improving seed corn germination. The commonly used amendment gypsum was less effective than organic amendments in in ameliorating sodicity and improves seed corn germination in sodic soils. Hence, use of such industrial organic wastes as spent grain and cheese whey in sodic soil reclamation provides an environmentally friendly and economic practice of

disposal. However, enhancing soil quality and crop yield. The addition of spent grain or cheese whey to sodic soil confirmed to be very efficient method of decreasing pH, ESP, SAR and increasing organic matter, nitrogen, phosphorous, potassium, and corn yield. Demonstrating the capability of these amendments to improve physical and chemical limitations and provide a hospitable environment for vegetation. Increasing the application rates of cheese whey and compost did not significantly enhance biomass yield or reduce sodicity compare to lower application rates. The

economics of sodic soil reclamation require low-cost method for successful implementation. Spent grain and cheese whey avoid the charge of composting. thus, they are more economical amendments than compost. The tested amendments need to carry out as long-term field experiments to demonstrate if the outcomes reported in this short-term and controlled study could happen with variable field conditions.

REFERENCES

Aboukila E.F., I.N. Nassar, M. Rashad, M. Hafez, and J.B. Norton. 2018a. Reclamation of calcareous soil and improvement of squash growth using brewers' spent grain and compost. Journal of the Saudi Society of Agricultural Sciences; (2018) 17, 390-397.

Aboukila E.F., E.A. Abdelraouf, and I. Gomma. 2018b. Effects of cheese whey on some chemical and physical properties of calcareous and clay soils. International Journal of Plant & Soil Science. 21(3): 1-12

Amezketa E. 1999. Soil aggregate stability: a review. J. Sustain. Agric. 14 (2–3), 83–151.

Ashworth J., D. Keyes, J-M. Crépin. 1999. A comparison of methods for gypsum requirement of brine-contaminated soils. Can. J. Soil Sci. 79, 449-455.

Bremner J.M., and C.S. Mulvaney. 1982. Nitrogen-total. In: Page et al. (Eds.), Methods of Soil Analysis, Part 2. second ed. American Society of Agronomy, Madison, WI, pp. 595-624.

Berova M., G. Karanatsidis, K. Sapundzhieva, and V. Nikolova. 2010. Effect of organic fertilization on growth and yield of pepper plants (Capsicum annuum L.). Folia Hort. 22, 3-7.

Chaganti V.N., and D.M. Crohn. 2015. Evaluating the relative contribution of physiochemical and biological factors in ameliorating a saline-sodic soil amended with composts and biochar and leached with reclaimed water. Geoderma 259–260, 45-55.

Chaganti V.N., D.M. Crohn, and J. Simunek. 2015. Leaching and reclamation of a biochar and compost amended saline–sodic soil with moderate SAR reclaimed water. Agricultural Water Management 158 (2015) 255-265.

Choudhary O.P., S.R. Grattan, and P.S. Minhas. 2011. Sustainable crop production using saline and sodic waters. In Alternate Farming Systems, Biotechnology, Drought Stress and Ecological Fertilisation (E. Lichtfouse, Ed), Sustainable Agriculture Reviews 6, 293-318, DOI 10.1007/978-94-007-0186-1, Springer Dordrecht, New York.

Choudhary O.P. 2017. Use of Amendments in Ameliorating Soil and Water Sodicity. In: Arora S., Singh A., Singh Y. (eds) Bioremediation of Salt Affected Soils: An Indian Perspective. Springer, Cham. pp 195-210.

Clark G.J., N. Dodgshun, P.W.G. Sale, C. Tang. 2007. Changes in chemical and biological properties of a sodic clay subsoil with addition of organic amendments. Soil Biol Biochem. 39: 2806-2817.

Clark R.B., K.D. Ritchey, and V.C. Baligar. 2001. Benefits and constraints for use of FGD products on agricultural land. Fuel 80 (6), 821-828.

Climate-Data.org. 2019. Climate: Alexandria. https://en.climate-data.org/africa/egypt/alexandria-governorate/alexandria-515/ . (accessed 15.05.16).

Day S.J., J.B. Norton, C.F. Strom, T.J. Kelleners, and E.F. Aboukila. 2019. Gypsum, langbeinite, sulfur, and compost for reclamation of drastically disturbed calcareous saline-sodic soils. Int. J. of Environ. Sci. and Tech. 16 (1): 295-304.

Dodd K., C.N. Guppy, P.V. Lockwood, and I.J. Rochester. 2013. The effect of sodicity on cotton: does soil chemistry or soil physical condition have the greater role? Crop and Pasture Science 64, 806-815.

Doran J., L. Mielke, and J. Power. 1990. Microbial activity as regulated by soil water-filled pore space. In: Transactions 14th International Congress of Soil Science, Kyoto, Japan, August 1990 Volume III, pp. 94-99.

Franco-Otero V.G., P. Soler-Rovira, D. Herna´ ndez, E.G. Lo´ pez-de-Sa´, and C. Plaza. 2012. Short-term effects of organic municipal wastes on wheat yield, microbial biomass, microbial activity, and chemical properties of soil. Biol. Fertil. Soils 48, 205-216.

Gee G.W., and J.W Bauder. 1986. Particle-size analysis. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods. second ed. American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 383-411.

Ghafoor A., M. Gill, A. Hassan, G. Murtaza, and M. Qadir. 2001. Gypsum: an economical amendment for amelioration of saline–sodic waters and soils, and for improving crop yields. Int. J. Agric. Biol. 3, 266-275.

Ghafoor A., G. Murtaza, M. Rehman, and M. Sabir. 2012. Reclamation and salt leaching efficiency for tile drained saline–sodic soil using marginal quality water for irrigating rice and wheat crops. Land Degrad. Dev. 23 (1), 1-9.

Gharaibeh M., N. Eltaif, and A. Albalasmeh. 2011. Reclamation of highly calcareous saline–sodic soil using Atriplexhalimus and by-product gypsum. Int. J. Phytoreme. 13 (9), 873-883.

Haynes R., and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr. Cycl. Agroecosyst. 5 (2), 123-137.

Jackson M.L. 1958. Soil Chemical Analysis. Prentice-Hail, Inc., Englewood Cliffs, NJ, USA.

Jones SB, Robbins CW, Hansen CL. 1993. Sodic soil reclamation using cottage cheese (acid) whey. Arid Soil Res. Rehab.7:51-61.

Kandeler E., and E. Murer. 1993. Aggregate stability and soil microbial processes in a soil with different cultivation. Geoderma 56 (1), 503-513.

Kehres B. 2003. Methods Book for the Analysis of Compost. Federal Compost Quality Assurance Organization (FCQAO); Bundesgutegemeinschaft Kompost e.V. (BGK), Koln-Gremberghoven, Germany.

Kelling K.A, and A.E Peterson. 1981. Using whey on agricultural land- A disposal alternative. University of Wisconsin -Extension, A3098. 1981;1-6.

Ketterings Q., K. Czymmek, S. Gami, G. Godwin, and K. Ganoe. 2017. Guidelines for Land Application of Acid Whey. Department of Animal Science Publication Series No. 247. Cornell Univ., USA.

Lakhdar A., M. Rabhi, T. Ghnaya, F. Montemurro, N. Jedidi, and C. Abdelly. 2009. Effectiveness of compost use in salt-affected soil. J. Hazard. Mater. 171 (1–3), 29-37.

Lal R., and J.P. Bruce. 1999. The potential of world cropland soils to sequester C and mitigate the greenhouse effect. Environ. Sci. Policy 2, 177-186.

Levy G. 2012. Sodicity. In: Huang PM, Li Y, Sumner ME, editors. Handbook of soil sciences: resource management and environmental impacts. CRC Press; 2012.

Mahdy A.M. 2011. Comparative effects of different soil amendments on amelioration of saline-sodic soils. Soil Water Res. 6:205-216

Mahmoodabadi M., N. Yazdanpanah, L.R. Sinobas, E. Pazira, and A. Neshat. 2013. Reclamation of calcareous saline sodic soil with different amendments (I): redistribution of soluble cations within the soil profile. Agric. Water Manag. 120, 30-38.

Mussatto S.I., and I.C. Roberto. 2006. Chemical characterization and liberation of pentose sugars from brewer's spent grain. J. Chem. Technol. Biotechnol. 81, 266-274.

Mussatto S.I. 2014. Brewer's spent grain: a valuable feedstock for industrial applications. J. Sci. Food Agric. 94, 1264-1275.

Mussatto S.I., G. Dragone, and I.C. Roberto. 2006. Brewers' spent grain: generation, characteristics and potential applications. J. Cereal Sci. 43, 1-14.

Nelson D.W., and Sommers L.E. 1982. Total carbon, organic carbon and organic matter. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis. American Society of Agronomy, Madison, 539-549.

Nelson R.E. 1982. Carbonate and gypsum. In: Page A.L., Miller R.H., Keeney D.R. (eds): Methods of Soil Analysis. American Society of Agronomy, Madison, 181-197.

Normandin V., J. Kotuby-Amacher, and R.O. Miller. 1998. Modification of the ammonium acetate extractant for the determination of exchangeable cations in calcareous soils. Commun. Soil Sci. Plant Anal. 29 (11–14), 1785-1791.

Olsen S.R., and L.E. Sommers. 1982. Phosphorus. In: Page et al. (Eds.), Methods of soil analysis. Part 2. second ed. American Society of Agronomy, Madison WI, pp. 403-430.

Oo A.N., C.B. Iwai, and P. Saenjan. 2015. Soil properties and maize growth in saline and nonsaline soils using cassava-industrial waste compost and vermicompost with or without earthworms. Land Degrad. Dev. 26, 300-310.

Pessarakli M., and I. Szabolcs. 1999. Soil salinity and sodicity as particular plant/crop stress factors. In: Pessarki, M. (Ed.), Handbook of Plant and Crop Stress., seconded., revised and expanded ed. Marcel Dekker, New York, NY.

Pimentel D., and M. Burgess. 2013. Soil erosion threatens food production. Agriculture 3:443-463

Qadir M., and J.D. Oster. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Sci. Total Environ. 323 (1-3), 1-19.

Qadir M., and J.D. Oster. 2002. Vegetative bioremediation of calcareous sodic soils: History, mechanisms, and evaluation. Irrigation Science, 21: 91-101.

Qadir M., S. Schubert, A. Ghafoor, and G. Murtaza. 2001. Amelioration strategies for sodic soils: A review. Land Degradation and Development, 12: 357-386.

Qadir M., J. Oster, S. Schubert, A. Noble, and K. Sahrawat. 2007. Phytoremediation of sodic and saline–sodic soils. Adv. Agron. 96, 197-247.

Qayyum M.F., M. Abid, S. Danish, M.K. Saeed, and M.A. Ali. 2015. Effects of co-composting of farm manure and biochar on plant growth and carbon mineralization in an alkaline soil. Pak. J. Agric. Sci. 51, 977-982.

Rao D.L.N., and H. Pathak. 1996. Ameliorative influence of organic matter on the biological activity of salt affected soils. Arid Soil Res. Rehabil. 10, 311-319.

Richards L.A. 1954. Diagnosis and Improvement of Saline and Alkaline Soils. USDA Handbook No. 60, US Government Printing Office, Washington D.C.

Robbins C.W., and G.A. Lehrsch. 1998. Cheese whey as a soil conditioner. In: Wallace A, Terry RE. (Eds.), Handbook of Soil Conditioners: Substances that Enhance the Physical Properties of Soil. Marcel Dekker Inc., New York, 1998; pp. 167-186

Roldán A., J. Albaladejo, and J. Thornes. 1996. Aggregate stability changes in a semiarid soil after treatment with different organic amendments. Arid Land Res. Manag. 10 (2), 139-148.

Sadiq M., G. Hassan, S.M. Mehdi, N. Hussain, and M. Jamil, M. 2007. Amelioration of saline-sodic soils with tillage implements and sulfuric acid application. Pedosphere 17, 182-190, 24.

Sahin U., S. Eroglu, and F. Sahin. 2011. Microbial application with 498 gypsum increases the saturated hydraulic conductivity of saline–sodic soils. Appl. Soil Ecol. 48, 247-250.

Sánchez-Monedero M.A., and A. Roig. 2001. Paredes C, Bernal MP. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresource Technology.;78:301-308.

SAS Institute, 2013. The SAS system for windows. Release 13.1. SAS Inst., Cary, NC.

Seelig B.D., J.L. Richardson, and Knighton R.E. 1991. Comparison of statistical and standard techniques to classify and delineate sodic soils. Soil Sci Soc Am J 55:1042-1048

Šimek M., and J.E. Cooper. 2002. The influence of soil pH on denitrification: progress towards the understanding of this interaction over the last 50 years. Eur. J. Soil Sci. 53, 345-354.

Soil Science Society of America. 2009. Glossary of soil science terms. Available at: https://www.soils.org/sssagloss/.

Soil Survey Staff. 2014. Keys to Soil Taxonomy. 12th ed. USDA-Natural Resources Conservation Service, Washington, DC.

Sonnleitner R., F. Schinner, and E. Lorbeer. 2003. Effects of straw, vegetable oil and whey on physical and microbiological properties of a chernozem. Appl. Soil Ecol. 22:195-204.

Sun J., F. He, H. Shao, Z. Zhang, and G. Xu. 2016. Effects of biochar application on *Suaeda salsa* growth and saline soil properties. Environ. Earth Sci. 75, 630.

Szabolcs I. 1994. Prospects of soil salinity for the 21st century. In: 15th World Congr. Soil Science. July 10–16, 1994, Acapulco, Vol. I., 123-141.

Tang D., G. Yin, Y. He, S. Hu, B. Li, L. Li, H. Liang, and D. Borthakur. 2009. Recovery of protein from brewer's spent grain by ultrafiltration. Biochem. Eng. J. 48, 1-5.

Tejada M., C. Garcia, J.L. Gonzalez, and M.T. Hernandez. 2006. Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. Soil Biol. Biochem. 38, 1413-1421.

Walker D.J., and M.P. Bernal. 2008. The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil. Bioresour. Technol. 99 (2), 396-403.

Wang J.M., Z.K. Bai, C.Q. Ye, and C. Xu. 2015. Saline and sodic soils properties as affected by the application of desulfurization byproduct and microbial agent. J. Basic Sci. Eng. 23 (6), 1080-1087.

Wang L., X. Sun, S. Li, T. Zhang, W. Zhang, and P. Zhai. 2014. Application of organic amendments to a coastal saline soil in North China: effects on soil physical and chemical properties and tree growth. PLoS One. 9(2): e89185.

Wang S.J., Q. Chen, Y. Li, Y.Q. Zhuo, and L.Z. Xu. 2017. Research on saline-alkali soil amelioration with FGD gypsum. Resour. Conserv. Recycl. 121, 82-92.

Wong V.N.L., R.C. Dalal, and R.S.B. Greene. 2009. Carbon dynamics of sodic and saline soils following gypsum and organic material additions: a laboratory incubation. Appl. Soil Ecol. 41, 29-40.

Wong V.N.L., S.B. Greene, R.C. Dalal, and B.W. Murphy. 2010. Soil carbon dynamics in saline and sodic soils: a review. Soil Use Manage. 26, 2-11.

Yu W., X. Ding, S. Xue, S. Li, X. Liao, and R. Wang. 2013. Effects of organic-matter application on phosphorus adsorption of three soil parent materials. J. Soil Sci. Plant Nutr. 13 (4), 1003-1017.

الملخص العربي

استخدام التفلة، شرش الجبن، الجبس، والكومبوست لاستصلاح الأراضي الصودية وتحسين انبات الذرة

عماد فاروق أبوكيلة

أجريت تجربتي تحضين وانبات لتقييم تأثير كلا من التفلة، شرش الجبنة الموتزريلا، الجبس، والكومبوست على استصلاح الأراضي الصودية وتحسين انبات الذرة (Zea mays L.). استخدمت في التجارب ٧ معاملات هي: معدلين من شرش الجبنة، معدلين من الكومبوست، معدل إضافة واحد من الجبس والتفلة، بالإضافة الى الكنترول. تم خلط المعاملات في الأرض الصودية، ووضعت في قصارى وتم تحضينها تحت الظروف الحقلية لمده شهر. بعد انتهاء فترة التحضين تم زراعة ٤ بذور من نبات الذرة في كل قصريه. استغرقت تجربة التحضين اسبوعان. أوضحت النتائج ان كل المعاملات العضوية (التفلة، شرش الجبن، والكومبوست) كانت أكثر كفاءة من الجبس والكنترول في خفض pH التربة، خفض نسبة الصوديوم المتبادل (ESP)، خفض معدل إدمصاص الصوديوم (SAR)، وزيادة تركيزات المادة العضوية والعناصر الغذائية الكبرى ونمو الذرة. أوضحت النتائج ان التفلة كانت المعاملة الأكثر فاعلية في تخفيض صودية الأرض وزيادة خصوبة التربة وانبات الذرة في الأرض الصودية. زيادة معدل إضافة شرش جبن الموتزريلا والكومبوست لم يؤدى الى زيادة معنوية في انبات الذرة او خفض الصودية وذلك بالمقارنة بمعدلات الإضافة الأقل منهم. ويمكن ترتيب التأثير الإيجابي للمعاملات على النحو التالي: التفلة> شرش الجبن>الكومبوست> الجبس> الكنترول. من ناحية أخرى، تحضين المعاملات لمدة شهر قبل الزراعة كانت فترة كافية للمعاملات لمعالجة صفات التربة الصودية. كلا من التفلة وشرش جبن الموتزريلا أكثر كفاءة من الكومبوست في استصلاح الأرض الصودية، وأيضا غير مكلفة بالمقارنة بالكومبوست.