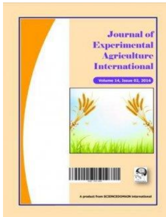

Journal of Experimental Agriculture International

32(3): 1-11, 2019; Article no.JEAI.47638
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Use of Maize Straw or Animal Manure as an Alternative to Gypsum to Ameliorate Saline-Sodic Soils

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Authors' contributions

The author KNJ is a PhD and this author conducted the study, collected the analyzes in the field and did the statistical analysis of the data, wrote the protocol and wrote the first draft of the manuscript. The authors TDA, AMPM and ARS were the masters of the first author, they designed the study and monitored and supervised all of this study. The authors JCRM, DCP and ACDA assisted in literature searches, writing in the manuscript and discussing the data. The authors RSCM, RNAF and EVSBS helped in the search of the literature and in the translation of the same into English language. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2019/v32i330102
Editor(s):
(1) Dr. Peter A. Roussos, Assistant Professor, Lab. Pomology, Agricultural University of Athens, Greece.
Reviewers:
(1) Hillary Moses Omondi Otieno, University of Nairobi, Kenya.
(2) Primitva Andrea Mboyerwa, Sokoine University of Agriculture, Morogoro, Tanzania.
Complete Peer review History: http://www.sdiarticle3.com/review-history/47638

Original Research Article

Received 19 December 2018
Accepted 26 February 2019
Published 14 March 2019

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ABSTRACT

This work aimed to evaluate the effect of the addition of animal manure or maize straw, combined or not with gypsum, on the recovery of the productive capacity of a Fluvic Entisol affected by salts cultivated with maize (*Zea mays* L.). The experiment was conducted in a greenhouse, in PVC columns in a 10 x 4 factorial scheme, with ten treatments and four replicates (gypsum, 15 t ha-1 manure, 30 t ha-1 manure, 15 t ha-1 maize straw, 30 t ha-1 maize straw, 15 t ha-1 gypsum plus manure, 30 t ha-1 gypsum plus manure, 15 t ha-1 gypsum plus maize straw, 30 t ha-1 gypsum plus maize straw and control, no input) in a randomized block design. Soils that received maize straw increased both the soil water infiltration rate and the amount of salts leached at the bottom of the column compared to soils that received gypsum. However, maize straw reduced the growth of maize plants, probably due to the immobilization of nutrients. In soils that received 15 t ha-1 manure, the growth of maize plants was higher compared to soils that received gypsum, indicating that the application and organic inputs can improve soil physical conditions, reduce salinity and promote plant growth without the need for the acquisition of gypsum, which gives farmers more autonomy and reduces costs.

Keywords: Exchangeable sodium; manure; maize straw; fluvic entisol; Zea mays L.

1. INTRODUCTION

Soil salinity and sodicity are limiting factors for the utilization of land resources, especially in arid and semi-arid regions of the world [1]. The problem reaches about 230 million hectares of irrigated land area in the world [2]. In Brazil, this problem occurs mainly in the northeastern region, where approximately 25% of irrigated areas have high salinity levels [3].

Due to the high evaporation rate and low rainfall, soils of semi-arid regions generally present high concentrations of soluble salts [4]. In addition to naturally halomorphic soils, many are salinized and/or sodified due to inadequate irrigation water [5]. The use of soils degraded by salinization in subsistence agriculture cannot be neglected, and it is necessary to develop economically viable techniques for their remediation, allowing their return to productive agricultural use.

Salinity, as well as other soil physical and chemical properties, presents natural spatial and temporal variability due to the management practices used, depth of the water table, soil permeability, evapotranspiration rate, rainfall, underground water salinity and other hydrogeological factors [6]. In the process of recovery of these soils, the immediate removal of salts is essential, since salts can drastically reduce drainage and, therefore, make them unfeasible for agriculture [7]. Therefore, the identification of adequate, viable and low-cost management practices is essential for the effectiveness of the recovery process [8].

The application of gypsum is widely accepted as a significant source of calcium for soils and has long been studied as the most common and primary chemical remediation method for saline-sodic soils [9]. However, this practice requires financial investments for the acquisition and application of gypsum. In addition, in some regions, the availability of agricultural gypsum may be limited, making this practice unfeasible. In these situations, the solution of the problem has to be based on low-cost strategies easily applied by farmers in remote regions. A practice with these characteristics may be the incorporation of organic materials into the soil, such as manure, green fertilizer, maize straw and other organic residues [10,11]. Several studies have demonstrated highly significant soil salinity reduction and increase of the agricultural production after incorporation of different sources of organic matter [12,13,14].

While gypsum provides improvements in soil chemical characteristics, the regeneration potential of organic fertilizers has been attributed in literature as an important factor in the stability of soil aggregates, improving water permeability [15].

Thus, the aim of the present study was to investigate the effect of the addition of animal manure or maize straw, combined or not with gypsum, on the recovery of the productive capacity of a Fluvic Entisol affected by salts cultivated with maize (*Zea mays* L.) in the semi-arid region of northeastern Brazil.

2. MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Department of Nuclear Energy of the Federal University of Pernambuco. The study used soil of the irrigated perimeter of the Experimental Station of "Belém de São Francisco", belonging to the Agronomic Institute of Pernambuco (IPA), located at "Ilha do Estreito", municipality of Belém do São Francisco - PE, 455.8 km southwest of the city of Recife, mesoregion of São Francisco and microregion of Itaparica. The area is located at approximately 08°45'00 "S and 38°59'00" W, and 305 meters a.s.l. The climate is tropical, semi-arid, dry, with average maximum temperatures of 36.7° C and minimum of 15.6° C, with summer rains. The rainy season begins in November, ending in April. The average annual rainfall is 525 mm. Due to the combination of high temperatures and low rainfall, average annual evaporation of 1647 mm is recorded, which is three times the average annual precipitation [16].

The soil of the experimental area was classified as Fluvic Entisol [17]. Crops at the IPA experimental station and in the surrounding region are mainly composed of maize, onion, tomato, beans and sorghum, mostly cultivated under irrigation. In order to diagnose soil salinity and sodicity, in addition to the other chemical and physical properties in the study area, soil samples were obtained from the 0-20, 20-40 and 40-60 cm layers before the beginning of the experiment. Physical and chemical analyses of soils, which do not depend on the structure, were conducted in air-dried fine soil (ADFS) samples. For this, soil samples were air-dried, crushed and passed through a 2 mm sieve. In the physical attributes tests that depend on the structure, sampling was performed using volumetric rings, inserted into the soil with the aid of an Uhland type sampler.

Exchangeable cations Ca^{2+} and Mg^{2+}, K^+ and Na^+ were extracted with 1 mol L-1 ammonium acetate solution; Ca^{2+}, Mg^{2+} were determined by titration and K^+ and Na^+ by flame emission photometry; the cation exchange capacity (CEC) by the sodium acetate and 1 mol L^{-1} ammonium acetate method [18]. The pH in water (1: 2.5 ratio) was measured with stirring for one minute and reaction time of one hour [19]. Based on the results of analyses, the sum of bases (SB), percentage of exchangeable sodium (PES) and sodium adsorption ratio (SAR) were calculated according to USSL [18] (Table 1).

For the evaluation of chemical attributes, soil samples were submitted to analysis of soluble elements, with the preparation of the saturated extract using method described by USSL [18].

In the saturated paste extract, electrical conductivity (EC at 25°C) and pH were measured; soluble cations Ca^{2+} and Mg^{2+} were determined by titration; Na^+ and K^+ by flame emission photometry; and Cl by titration [18] (Table 2).

The granulometric analysis (Table 3) was performed by the pipette method according to [20]. Soil density was determined using the volumetric ring method (Table 3).

The density of particles was determined by the volumetric flask method (Table 3). Both procedures were performed according to Embrapa [20].

Water samples from the São Francisco River at the Experimental Station were collected in August 2009 to diagnose the water quality used in irrigation. Samples were taken to the Laboratory of Water, Plant and Ration - LAPRA, Agronomic Institute of Pernambuco - IPA and analyzed for their physicochemical properties. EC and pH measurements were carried out, determining the Ca^{2+} and Mg^{2+} contents by titration and Na^+ and K^+ by flame photometry [18]; and anions Cl^-, CO_3^{2-}, SO_4^{-2} and HCO_3^- by titration, and the other parameters according to recommendations of [21] (Table 4). These data were used to calculate the sodium adsorption ratio (SAR). With the results obtained, water was characterized as low salinity and low sodicity according to Daker [22].

Based on this, soil samples from this site were collected from the 0-20, 20-40 and 40-60 cm layers to perform the greenhouse studies in leaching columns at the Department of Nuclear Energy, Federal University of Pernambuco - UFPE. Leaching columns were made with PVC pipes of 20 cm in internal diameter and 65 cm in length and internally paraffinized to eliminate the flow in the wall during washing. A silk screen was placed on the base of columns, previously glued to a plastic funnel filled with washed sand to support the soil weight and drain effluents during washing. At the tip of the funnel, a plastic screen with an opening of 0.5 mm was used to retain the sand in the funnel and prevent it from being lost. For the support of the leaching columns, tables of metal structure were used to fix the columns and to maintain verticality throughout the experiment. The leachate was collected in sterile flasks and stored in a refrigerator at 4ºC for further analysis.

The amount of soil placed in each column was determined based on soil density. After calculating the soil mass for each layer, the columns were filled. In the filling of the columns, layers of approximately 4 cm thick of air-dried soil (ADFS) were successively added and passed through a 4mm sieve, and each overlapped layer was compacted by light pressure of a wooden stick of diameter well below the inner diameter of the cylinder. Layers were overlapped one by one starting with the 40-60 layer, then 20-40 and finally 0-20 cm, stopping 4 cm below the top edge of the columns to ensure uniformity and homogeneity in all columns.

The experimental design was a randomized block design, consisting of 10 treatments and four replicates. The following treatments were applied: T1: incorporation of gypsum; T2: incorporation of 15 t ha^{-1} manure; T3: incorporation of 30 t ha^{-1} manure; T4: incorporation of 15 t ha^{-1} maize straw; T5: incorporation of 30 t ha^{-1} maize straw; T6: gypsum plus 15 t ha^{-1} manure; T7: gypsum plus 30 t ha^{-1} manure; T8: gypsum plus 15 t ha^{-1} maize straw; T9: gypsum plus 30 t ha^{-1} maize straw; T10: control. All treatments, except for the control, were fertilized with 1.6 g N-P-K according to soil chemical analysis.

The need for gypsum was based on the soil chemical characterization using the following equation: NG = (PSTa -PSTf) * CEC*86*h*ds, where NG = gypsum requirement (kg ha^{-1}); PSTa = percentage of current exchangeable Na; PSTf = percentage of desirable exchangeable Na (stipulated at 2%); CEC = cation exchange capacity (cmolc kg^{-1}); 86 = molecular weight of gypsum ($CaSO_4.2H_2O$); h = depth of soil to be recovered (0.65 m), and ds = soil density (kg dm-3).

After the application of treatments, the first maize planting (*Zea mays* L.) was carried out to evaluate the effect of treatments on dry matter production and nutrient absorption by this crop, of economic importance in the region. After sowing, successive amounts of 500 mL of distilled water were applied to wash the soil for two weeks, and all leachate collected at the bottom of the columns was taken to the laboratory for chemical analysis.

After 30 days of planting, the biomass above the soil was collected to obtain the dry matter production of the crop [19]. The material was placed in the oven with forced ventilation at 65 ° C for 72 hours until constant weight, and then productivity was weighed and quantified [19]. After harvesting the first maize planting, three infiltration tests were performed to determine the infiltration rate of the water layer applied to treatments. After the tests, maize was sown the second time, harvested 30 days after germination to determine the dry matter production. After the second maize planting, soil samples were collected at 0-20 cm layer for chemical analysis to verify the effects of the treatments on soil salinity. Data were submitted to analysis of variance, and the means were compared by the Scott Knott test at 5%. Statistical analyses were performed using the Sisvar statistical software [23].

3. RESULTS AND DISCUSSION

The water infiltration rate in soils that received maize straw (30 t ha^{-1}) was significantly higher than in soils that received only gypsum or only manure. However, the use of gypsum, when combined with the two organic materials, generated a significant synergistic effect on the water infiltration rate [9]. Thus, among the treatments tested, the only one that significantly increased the water infiltration rate in all evaluation dates was the application of gypsum combined with 30 t ha^{-1} maize straw (Fig. 1), but maize straw (30 t ha^{-1}) has also been shown to be a very effective practice to increase the water infiltration rate.

Table 1. Mean values of exchangeable basic cations, pH, sum of bases, CEC and PST of a fluvic entisol affected by salts

Depth	pH	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	SB	CEC	PST
------cm------		----------------------cmol$_c$ dm^{-3}-----------------						%
0-20	7.40	2.35	1.45	0.49	1.74	6.03	17.39	28.85
20-40	7.61	2.53	1.70	0.28	1.97	6.48	11.13	30.40
40-60	8.89	2.72	1.82	0.21	2.95	7.70	13.27	38.31

Table 2. Mean values of soluble basic cations, pHes, electrical conductivity and SAR of a fluvic entisol affected by salts

Depth	pH_{es}	Ca^{2+}	Mg^{2+}	K^+	Na^+	CE	SAR
------cm------		----------mmol$_c$ L^{-1}----------				dSm^{-1}	(mmol$_c$ L^{-1})^{0,5}
0-20	7.00	13.8	7.3	0.70	130.68	11.76	40.00
20-40	7.89	15.52	9.64	0.61	150.20	13.51	42.31
40-60	8.4	10.41	7.21	0.37	160.0	14.40	54.05

Table 3. Mean values of grain size composition, soil density and particle size of a fluvic entisol affected by salts

Depth	Coarse sand	Fine sand	Total sand	Silt	Clay	Textural class	DS	Dp
-------cm-----	------------------g kg^{-1}-------------------						--g cm^{-3}--	
0-20	30	470	500	290	210	Frank	1.41	2.64
20-40	34	468	502	328	170	Frank	1.45	2.62
40-60	20	500	520	330	150	Sandy	1.38	2.63

Table 4. Physicochemical analysis of the irrigation water

Parameters					MVA[1]		Values	
Apparent color-uH[2]					15		2.5	
Turbidity-uT					5		1.78	
Electrical conductivity -µS/cm a 25º C					***		68	
pH					6.0 to 9.5[3]		7.1	
Total Dissolved Solids -mg/L					1.000		73	
Alkalinity of Hydroxides in $CaCO_3$-mg/L					***		10.40	
Alkalinity of Carbonates in $CaCO_3$-mg/L					***		0.00	
Alkalinity of Bicarbonates in $CaCO_3$-mg/L					***		10.40	
Total Alkalinity in $CaCO_3$-mg/L					***		10.40	
Total Hardness in $CaCO_3$-mg/L					***		27.20	
Predominant Ionic Composition								
Cations	VMP	mgL^{-1}	mmol L^{-1}	Anions	VMP[1]	mg L^{-1}	mmol L^{-1}	
Ca^{2+}	**	27.25	13,62	Cl^-	250	1,42	1,42	
Mg^{2+}	**	----Absence ----		SO_4^{-2}	250	---- Absence ----		
Na^+	200	3.91	3,91	CO_3^{-2}	**	---- Absence ----		
K^+	**	1.56	1,56	HCO_3^-	**	31,73	31,73	
Irrigation			Values		Classification			
SAR (Sodium Adsorption Ratio)			0.29		Low salinity water with low			
Classification for irrigation			C1S1		sodium concentration			

MVA = Maximum values allowed for human consumption (Ordinance no. 518 of the Ministry of Health/2004); 2uH = Hazin Unit (mg Pt-Co / L); [3] Interval recommended by the Standard Methods for the Examination of Water and Wastewater, 21. Ed., 2005

These results indicate that the use of low-cost organic inputs available on farms can satisfactorily contribute to the recovery of soils affected by salts, but the combination with gypsum may result in an even higher infiltration rate [24,25]. The use of gypsum together with an organic matter source has shown good results both for crops and for the process of improving the physical-water conditions [26,27,28]. Previous studies have also indicated that the addition of crop residues to the soil can improve several aspects of a saline-sodic soil, such as water infiltration rate [29].

In studies on the recovery of saline-sodic soil from the Kerman region (Iran) by Yazdanpanah and Mahmoodabadi [30], treatments with gypsum and crop residues improved salt leaching, and soil infiltration rate.

In a study conducted in salinized soils from an irrigated perimeter, [31] found infiltration rate values below the established standard and related the event to the salinization processes.

According to Miranda et al. [32], the use of agricultural gypsum and organic matter improved the hydraulic conductivity, reduced the electrical conductivity and the sodium contents of the saturation extract. For [33], among correctives and their combinations, gypsum plus manure presented efficiency in increasing porosity, permeability, and hydraulic conductivity.

The application of organic materials also contributed to the removal of soil salts by leaching during irrigation events. Table 5 shows the amounts of Na^+ leached and collected at the bottom of the soil column for each treatment.

It was observed that the application of 15 t ha^{-1} manure and gypsum associated with maize straw (30 t ha^{-1}) significantly removed more salts than the other treatments. The initial tests were significant in Na^+ removal, a result that can be attributed to the release of Ca^{2+} by gypsum, which displaced Na + adsorbed in the exchange complex, which will be leached after washing [34].

According to Silva et al. [3], the application of gypsum in sodic soils has the purpose of transforming into sulfates part of sodium carbonates and displacing the sodium adsorbed to the exchange complex. It was observed that the application of higher doses of manure (30 t ha^{-1}) limited the soil water infiltration, perhaps

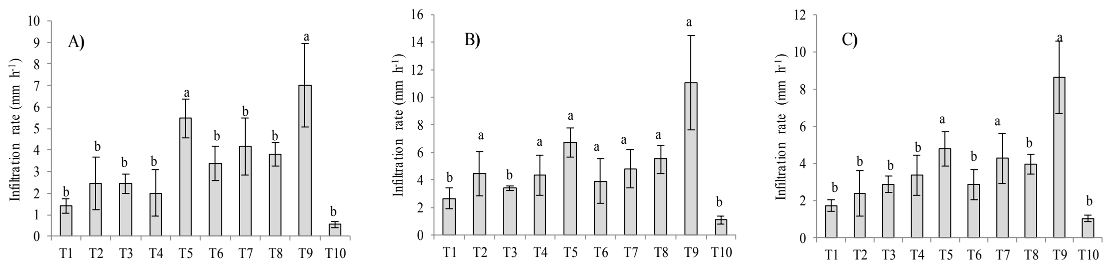

Fig. 1. Water infiltration rate after application of treatments. (A) 1st ; (B) 2nd and (C) 3rd infiltration testsT1 = Incorporation of Gypsum; T2 = Incorporation of 15 t ha^{-1} manure, T3 = Incorporation of 30 t ha^{-1} manure, T4 = Incorporation of 15 t ha^{-1} maize straw, T5 = Incorporation of 30 t ha^{-1} maize straw, T6 = Gypsum plus 15 t ha^{-1} manure, T7 = Gypsum plus 30 t ha^{-1} manure, T8 = Gypsum plus 15 t ha^{-1} maize straw, T9 = Gypsum plus 30 t ha^{-1} maize straw, T10 = Control. Averages followed by the same letter do not differ by the Scott Knott's test at 5% probability

Table 5. Amount of soluble Na^+ leached with water applied to treatments used for the recovery of saline-sodic soil

	Infiltration Tests								
Treatment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
	-- g kg^{-1} --								
T1	3.41a	0.82b	0.56b	0.74a	0.50a	0.59a	0.36a	0.30a	7.28a
T2	3.45a	5.47a	1.29a	0.64a	0.43a	0.45a	0.29 a	0.38a	12.4a
T3	1.17b	2.46b	0.76b	0.42a	0.30b	0.26a	0.25 a	0.20a	5.83b
T4	3.99a	1.86b	0.80b	0.56a	0.45a	0.58a	0.33 a	0.33a	8.9a
T5	3.57a	1.28b	2.08a	0.42a	0.47a	0.58a	0.46 a	0.41a	9.29a
T6	3.46a	1.87b	1.56a	0.79a	0.58a	0.75a	0.50 a	0.24a	9.75a
T7	2.32a	0.93b	0.40c	0.63a	0.57a	0.64a	0.47 a	0.26a	6.23b
T8	1.16b	2.04b	0.69b	0.61a	0.50a	0.60a	0.42 a	0.23a	6.24b
T9	5.19a	2.66b	0.70b	0.60a	0.77a	0.76a	0.40 a	0.36a	11.45a
T10	1.21b	1.85b	0.95b	0.57a	0.37b	0.44a	0.30 a	0.23a	5.92b
VC (%)	56.08	40.84	42.58	28.91	30.44	37.41	30.28	49.37	31.24

T1 = Incorporation of Gypsum; T2 = Incorporation of 15 t ha^{-1} manure, T3 = Incorporation of 30 t ha^{-1} manure, T4 = Incorporation of 15 t ha^{-1} maize straw, T5 = Incorporation of 30 t ha^{-1} maize straw, T6 = Gypsum plus 15 t ha^{-1} manure, T7 = Gypsum plus 30 t ha^{-1} manure, T8 = Gypsum plus 15 t ha^{-1} maize straw, T9 = Gypsum plus 30 t ha^{-1} maize straw, T10 = Control. M.G. = general mean and VC% = variation coefficient. Averages followed by the same letter do not differ by the Scott Knott's test at 5% probability

Table 6. Soil chemical analysis at depth 0-20 cm, after the leaching period and maize harvest

Treatment	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	H+Al	SB	CEC	PST
		--			$cmol_c dm^{-3}$		----------------------------------		%
T1	6.17a	5.01b	0.52a	0.05b	0.21c	0.75b	5.79c	6.55c	0.76b
T2	6.12a	3.20c	1.14a	0.05b	0.22c	1.17a	4.62c	5.80c	0.86b
T3	6.22a	3.52c	1.15a	0.05b	0.23c	1.34a	5.00c	6.32c	0.8b
T4	6.20a	2.90 c	1.19a	0.05b	0.33b	1.42a	4.47c	5.90c	0.8b
T5	6.17a	3.06c	0.95a	0.07b	0.31b	1.42a	4.37c	5.82c	1.2a
T6	6.12a	5.99a	0.74a	0.05b	0.20c	1.01b	6.97b	8.00b	0.6b
T7	5.87a	6.36a	0.90a	0.07b	0.20c	1.29a	7.55b	8.85b	0.8b
T8	5.87a	5.89a	0.75a	0.06b	0.30b	1.03b	7.00b	8.02b	0.7b
T9	6.00a	6.94a	1.70a	0.20a	0.37a	1.17a	9.20a	10.37a	1.9a
T10	6.60a	3.16c	1.06a	0.07b	0.24c	0.88b	4.55 c	5.45c	1.3a
VC (%)	4.18	16.75	51.53	62.77	9.86	25.05	17.33	13.51	11.28

T1 = Incorporation of Gypsum; T2 = Incorporation of 15 t ha^{-1} manure, T3 = Incorporation of 30 t ha^{-1} manure, T4 = Incorporation of 15 t ha^{-1} maize straw, T5 = Incorporation of 30 t ha^{-1} maize straw, T6 = Gypsum plus 15 t ha^{-1} manure, T7 = Gypsum plus 30 t ha^{-1} manure, T8 = Gypsum plus 15 t ha^{-1} maize straw, T9 = Gypsum plus 30 t ha^{-1} maize straw, T10 = Control. M.G. = general mean and VC% = variation coefficient. SB = Sum of Bases, CEC = Cation exchangeable capacity, PST = Percentage saturation exchangeable. Averages followed by the same letter do not differ by the Scott Knott's test at 5% probability.

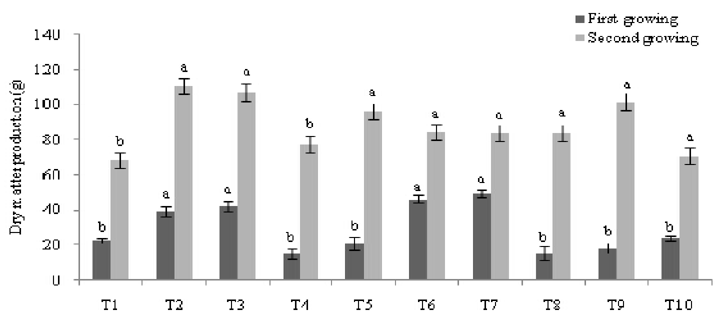

Fig. 2. Maize total dry matter (*Zea mays* L.) as a function of treatments in the first and second plantings. T1 = Incorporation of Gypsum; T2 = Incorporation of 15 t ha^{-1} manure, T3 = Incorporation of 30 t ha^{-1} manure, T4 = Incorporation of 15 t ha^{-1} maize straw, T5 = Incorporation of 30 t ha^{-1} maize straw, T6 = Gypsum plus 15 t ha^{-1} manure, T7 = Gypsum plus 30 t ha^{-1} manure, T8 = Gypsum plus 15 t ha^{-1} maize straw, T9 = Gypsum plus 30 t ha^{-1} maize straw, T10 = Control. Averages followed by the same letter do not differ by the Scott Knott's test at 5% probability

due to interferences in the soil physical properties or hydrophobicity, but these processes have not been evaluated and deserve to be better understood.

However, it is important to note that manure action was only effective at 15 t ha^{-1}, and the application of 30 t ha^{-1} presented no difference to the control treatment. In studies by Biswas and Biswas [35], after comparing the effects of gypsum, bovine manure and green fertilizer on sodium leaching of a saline-sodic soil, significant effects were observed for correctives. The results of this study were similar to those reported by Ranjbar and Jalali [36], who reported that soils enriched with manure showed higher accumulation of cations, such as Ca^{2+}, Mg^{2+}, and K^{+}, and showed an increase in Na^{+} leaching, leading to lower percentage of exchangeable sodium.

The chemical analysis of exchangeable cations showed that in treatments with gypsum and organic matter, especially gypsum combined with 15 t ha^{-1} of manure, there was a greater reduction in PST values and higher increases in Ca^{2+} and Mg^{2+} (Table 6).

The use of correctives is necessary to displace the sodium that is adsorbed on soil particles, due to the addition of substances that have calcium. Thus, corrective agents have the function of providing or releasing calcium to replace exchangeable sodium and release it to the soil solution, where it will be leached by washing with irrigation water [4]. Also, soil microorganisms release CO_2 through the decomposition of organic matter which, when combined with water, forms carbonic acid, which can solubilize Ca^{2+} salts precipitated in the soil [37]. In work with saline-sodic soils in northern Egypt, results similar to this study were found [38].

The results found in the present study, are in agreement with those observed by Medeiros et al. [39], who showed that the application of gypsum and organic matter causes an increase in the levels of calcium and magnesium in soil layers. For [40], gypsum alone or associated with organic matter reduced sodium content and increased calcium content in a sodic soil. Evaluating the influence of the use of different chemical and organic conditioners on a saline-sodic Fluvic Entisol, [32] observed a decrease in sodium concentration after leaching with manure. The soil evaluated in the present study has high CEC (Table 6), which indicates good availability of basic cations for plants.

Depending on the presence of saturating cations in the soil exchange complex, in some situations, higher CEC values may represent large proportions of Na^+, which may be indicative of degradation by sodicity, evaluated through PST [41].

Evaluating the maize dry matter production during the first growing period, it was observed that treatments that applied manure to the soil, in combination or not with gypsum, were significantly higher than the others (Fig. 2).

Probably, the nutrients contained in manure promoted the growth of maize plants, while in other treatments, plants were limited by the low availability of nutrients. The benefit of treatments with bovine manure is probably associated with the addition of nutrients, mainly phosphorus (P), as well as with the reduction of electrical conductivity and pH of the soil [42]. Higher plant growth after application of gypsum and organic matter was also observed by Nascente and Carvalho [43] in millet.

During the second growing period (Fig. 2), treatments that received organic inputs presented growth of maize plants significantly higher than the control treatment, except for columns that received 15 t ha-1 of straw. The results of this study were similar to those reported during cultivation of beans [44] and maize [45] under greenhouse conditions.

An increase in plant biomass of approximately 200% was observed in the second growing period compared to the first one for the control treatment, evidencing the positive influence of soil washing without the addition of chemical and/or organic conditioners by leaching throughout the experiment. This higher production of dry matter by maize plants is probably associated with the removal of sodium (Na^+) by treatments due to leaching by the irrigation water (Table 5). According to Souza et al. [46], salinity and/or sodicity reduces plant growth due to osmotic, toxic and nutritional effects with significant reductions in dry matter content of shoots and roots.

4. CONCLUSION

The incorporation of maize straw had better effect compared to gypsum by increasing both water infiltration rate and leaching of soil column salts. The combination of these two inputs; however, had a synergistic effect on these variables. The application of manure at higher doses greatly reduced the infiltration of water into the soil, which deserves further investigation. The growth of maize plants, however, was lower after the application of maize straw, probably due to immobilization of nutrients by the straw decomposition. In soils that received 15 t ha^{-1} manure, the growth of maize plants was higher than in soils that received gypsum. Thus, the results of this study indicate that the application and organic inputs can improve soil physical conditions, reduce salinity and promote plant growth without the need for the acquisition of gypsum by farmers. These responses can give more autonomy and reduce costs of recovering saline-sodic soils to farmers in remote areas in developing countries. The use of gypsum, though, associated to organic ammendments may accelerate soil remediation. In further studies, it is suggested to study the effects of the combination of different doses of straw and manure on the recovery of saline-sodic soils and production of agricultural crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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