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SOIL AND PLANT NUTRITION - Article

Phytodesalination of a moderately saline soil combined with two inorganic amendments

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ABSTRACT: The shortage of water and the increasing salinity are the main limiting environmental factors that directly affect the establishment and the development of crops. In this research, phytodesalination capacity of *Sesuvium verrucosum* was evaluated alone and in combination with agricultural gypsum ($CaSO_4{\cdot}2H_2O$) and Polisul-C, in order to remedy a moderately saline soil at greenhouse level and under nonleaching conditions. The treatments studied were the following: T1 (soil), T2 (soil + *S. verrucosum*), T3 (soil + *S. verrucosum* + Polisul-C), T4 (soil + *S. verrucosum* + $CaSO_4{\cdot}2H_2O$). Polyvinyl chloride (PVC) tubes filled with 8 kg of clay soil with an electrical conductivity of the saturation paste extract (ECe) of 6.21 $dS.m^{-1}$ were used. Soil samples were analyzed to determine the ECe, and the soluble and interchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) content. Then, the halophytic plants were divided into root and aerial parts and the content of Na^+, K^+, Ca^{2+} and Mg^{2+} was determined. In summary, *S. verrucosum* showed potential to desalinate its rhizosphere. Moreover, *S. verrucosum* desalination capacity significantly increases when used in combination with either of the tested amendments. This increase occurred mainly in the upper layers of the clay soil (0-30 cm). $CaSO_4{\cdot}2H_2O$ was shown to be the most effective amendment, since a greater gain in biomass and a large accumulation of sodium (Na^+) in the aerial part of *S. verrucosum* was observed as a consequence of the soil improved physico-chemical properties caused by this chemical.

Key words: gypsum, halophyte, nonleaching, Polisul-C, salinity, *Sesuvium verrucous*.

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INTRODUCTION

Drought and salinity are conditions that limit worldwide crop production and soil fertility (Ruiz and Terenti 2012). Crops exposed to salinity exhibit a series of detrimental effects such as: a) ionic stress (Hasanuzzaman et al. 2014), b) osmotic stress (Chávez and Álvarez 2011), c) disruption of homeostasis (Türkan and Demiral 2009) and a series of morphological, physiological and biochemical changes, which altogether adversely affect the acquisition of nutrients and the transpiration and function of the photosynthetic apparatus. Such effects cause a reduction in plant growth and, generally, plant death (Munns and Tester 2008), which ultimately translates into economic losses (Manzano et al. 2014). A number of studies have proven that the use of halophyte species in agriculture may facilitate crop adaptation to increased salinization while contributing to the improvement of the edaphic quality of the soil derived from low water availability (Nouri et al. 2017). Phytodesalination consists in the use of certain halophytic species' ability to extract large amounts of sodium (Na^+) from the affected environment and remove it through its absorption and translocation to harvestable parts (Al-Nasir 2009). Some species used in phytodesalination studies have shown a greater accumulation of salts in their tissues, such as *Suaeda salsa* (1.9 Mg $Na^+ \cdot ha^{-1}$), *Suaeda fruticosa* (0.8 Mg $Na^+ \cdot ha^{-1}$), *Arthrocnemum indicum* (0.8 Mg $Na^+ \cdot ha^{-1}$), *Sesuvium portulacastrum* (0.5 Mg $Na^+ \cdot ha^{-1}$), and *Suaeda maritima* (0.5 Mg $Na^+ \cdot ha^{-1}$) (Rabhi et al. 2015). Phytodesalination capacity is species-dependent and is also affected by soil properties (salinity, sodicity and porosity) and climatic conditions (mainly rainfall) (Rabhi et al. 2010).

On the other hand, there are different chemical methods to reclaim salty soils, including the use of agricultural gypsum ($CaSO_4 \cdot 2H_2O$) and polysulfides of sulfur, which have been shown to improve the physical and chemical characteristics of soils. They contribute to soil stabilization and permeability by replacing sodium (Na^+) by calcium (Ca^{2+}) in soil colloids, they stimulate soil microbial activity and increase the availability of a number of nutrients (Kim et al. 2018). Furthermore, these chemicals are low-cost and easy to apply. Moreover, there are studies that compare their effectiveness with the potential of some halophyte species – Atriplex halimus, Atriplex lentiformis, and Atriplex amnicola – to extract large amounts of sodium (Na+) from the affected environment (Abdel-Fattah 2015).

However, in some places, soil salinity and sodicity are not too high, and soils are not sandy. Such conditions could cause, that the amount of sodium eliminated could not accumulate exclusively in the halophyte outbreaks, since a considerable part could be leached (Zorrig et al. 2012; Rabhi et al. 2009), hence the need to carry out research at the greenhouse level and under nonleaching conditions. The aim of this work was to evaluate the ability of *Sesuvium verrucosum* to desalinate its rhizosphere alone and in combination with agricultural gypsum and Polisul-C, to improve the physicochemical conditions of a moderately saline clay soil.

MATERIAL AND METHODS

Physical and chemical characteristics of the soil

The soil showed a clayey texture (clay 60%, silt 12%, sand 28%); 6.21 electrical conductivity (ECe), 8.18 pH, 4.12% organic matter (% OM), 41 $g \cdot kg^{-1}$ $CaCO_3$, 1.02 $g \cdot m^{-3}$ apparent density (AD), porosity percentage 61.21, 120% water retention capacity (WRC), sodium adsorption ratio (SAR) of 42.39 $(mmol_c \cdot L^{-1})^{1/2}$, total nitrogen of 0.23%, available phosphorus of 26.65 $mg \cdot kg^{-1}$, 156 of Na^+ $mmol_c \cdot L^{-1}$, 9.37 of K^+ $mmol_c \cdot L^{-1}$, 16.37 of Ca^{2+} $mmol_c \cdot L^{-1}$, 24.69 of Mg^{2+} $mmol_c \cdot L^{-1}$, 4.13 of HCO_3^- $mmol_c \cdot L^{-1}$, 308.7 of $Cl^{-1} mmol_c \cdot L^{-1}$, Sulfates of 67.5 $mmol_c \cdot L^{-1}$, Cation-Exchange Capacity (CEC) of 34.87 $cmol_c \cdot kg^{-1}$, 13.79 of Na^+ $cmol_c \cdot kg^{-1}$, 4.28 of K^+ $cmol_c \cdot kg^{-1}$, 9.47 of Ca^{2+} $cmol_c \cdot kg^{-1}$, 12.58 of Mg^{2+} $cmol_c \cdot kg^{-1}$ and Exchangeable Sodium Percentage (ESP) of 39.54.

Greenhouse experiments under non-leaching conditions

Approximately 500 kg of soil were collected at 0-30 cm depth of a parcel in Villamar, Michoacán, México (20° 03' 6.725" N lat and -102° 36' 19.515" W long), at a 1540 m a.s.l. altitude (SMN 2017). They were dried under shade and, at room temperature, transferred to polyvinyl chloride (PVC) pipes of 50-cm length and 16-cm internal diameter. The pipes were not perforated and were filled with 8 kg of soil each. A completely randomized design was used with 10 experimental units per treatment; therefore, four treatments and ten repetitions were considered for a total of 40 PVC pipes. The evaluated treatments were: T1 (soil), T2 (soil + *S. verrucosum*), T3 (soil + *S. verrucosum* + Polisul C),

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T4 (soil + *S. verrucosum* + $CaSO_4 \cdot 2H_2O$). Temperature and relative humidity conditions in the greenhouse were in average, 38/10 °C (day/night) and 60% (± 10%), respectively. The greenhouse experiment under nonleaching conditions was repeated three times.

Plant material

One hundred plants of *Sesuvium verrucosum* were collected from a location known as Los Negritos, a geothermal zone belonging to the municipality of Villamar, Michoacán, México (20° 03' 46.267" N lat and -102° 36' 46.569" W long). One plant (50 ± 0.59 g FW) was transplanted in each PVC pipe, which were watered with tap water up to 70% of the container's capacity (1.4 liters applied every 12 days in each PVC pipe). Following the protocol of Rahbi et al. (2009), the experiment was completed 170 days after the transplantation of the plant material. Table 1 shows the content of cations of the halophyte species *S. verrucosum* at the beginning of the experiment.

Table 1. The content of Na^+, K^+, Ca^{2+} and Mg^{2+} at the beginning of the experiment in the root (R) and aerial parts (TH) of the halophyte species *S. verrucosum*.

Organ	$Mg.g^{-1}$ DW			
	Na^+	K^+	Ca^{2+}	Mg^{2+}
R	6.84 ± 0.25^b	2.63 ± 0.13^b	3.51 ± 0.27^b	1.87 ± 0.16^b
TH	19.37 ± 1.52^a	7.67 ± 0.33^a	8.42 ± 0.48^a	5.59 ± 0.37^a

In each column, different letters mean significant differences according to Tukey's test ($p \leq 0.05$), values indicated as Mean ± SE (n=30); (R: roots; TH: leaves and stems).

Chemical proportions of Polisul-C

Polisul-C contains: 4.6% calcium, 16% colloidal sulfur, 13% sulfur as sulfide, 2% sulfur as thiosulfate, 1% sulfur as sulfate, 5% nitrogen, 53.4% intermediates and inert ingredients.

Fifteen days prior to the experiment, 0.4 mL of Polisul-C were applied to the soil transferred to the PVC pipes, in accordance with the manufacturer specifications, and one watering was conducted up to container's capacity.

Agricultural gypsum requirements ($CaSO_4 \cdot 2H_2O$) (GR)

The agricultural gypsum requirement (GR) to decrease the soil initial ESP from 39.54% to 20% at 30-cm depth was calculated as follows (Lebron et al. 2002):

$$GR = [0.00086\, F\, Ds\, Pb\, (CEC)] \left[\frac{ESPi - ESPf}{100}\right]$$

where GR = is the agricultural gypsum requirement ($kg \cdot m^{-2}$), F = The efficiency of Ca^{2+} to be exchanged for Na^+. In this case, it is assumed as 0.97 (in accordance with the product quality specifications). Pb = soil apparent density, Ds = depth of soil to reclaim, ESPi = soil's initial exchangeable sodium percentage, ESPf = soil's final exchangeable sodium percentage (target), CEC = soil's cation-exchange capacity.

The agricultural gypsum requirement obtained per m^2 was extrapolated to the surface of each PVC pipe ($0.02\ m^{-2}$), so that, 58 g of gypsum were mixed with the soil before filling each of the PVC tubes. Fifteen days prior to the experiment started, a watering was carried out up to the container's capacity.

Physicochemical characteristics of the water

Watering was manual; the physical and chemical characteristics of the irrigation water were: ECe 0.5 $dS \cdot m^{-1}$, 8.81 pH, sodium adsorption ratio (SAR) 1.93, Total Dissolved Solids (TDS) 155 $mg \cdot L^{-1}$, Ca^{2+} 0.42 $mmol_c \cdot L^{-1}$, Mg^{2+} 3.61 $mmol_c \cdot L^{-1}$, Na^+ 2.75 $mmol_c \cdot L^{-1}$, K^+ 0.26 $mmol_c \cdot L^{-1}$, CO_3^{-2} 1.47 $mmol_c \cdot L^{-1}$, HCO_3^- 5.01 $mmol_c \cdot L^{-1}$, SO_4^{-2} 0.153 $mmol_c \cdot L^{-1}$.

Physicochemical analysis of soil and plants

Soil particle size analysis was performed in accordance with the Gee and Bauder (1996) method and the organic matter was analyzed following the Walkley-Black (1934) method. Soil samples were randomly taken, dried, grounded and passed through a 2-mm mesh sieve before the addition of distilled water until saturation. Saturated pastes were covered with aluminum paper and left over night at room temperature. After this period, a vacuum extraction was performed on them. Finally, electrical conductivity (ECe), pH and Na^+, Ca^{2+} and Mg^{2+} concentration was measured in the extracts. Sodium adsorption ratio (SAR), cation exchange capacity (CEC) and interchangeable sodium percentage (ESP) were calculated using the following formulas:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

where SAR = Sodium adsorption ratio [$(mmol_c \cdot L^{-1})^{1/2}$].

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$$CEC = 200 \; x \; V \; x \; N$$

where CEC = Cation-exchange capacity ($cmol_c \cdot kg^{-1}$), V = volume (ml) of HCl, N = normality of HCl

$$ESP = \frac{Nai^+}{CEC} \, x \; 100$$

where ESP = Exchangeable sodium percentage, Nai^+ = Sodium exchangeable ($mmol_c \cdot L^{-1}$).

For the chemical analysis of plant material, the plants were washed with distilled water; roots and aerial parts (stems and leaves) were separated and fresh and dry weight were measured (g). The samples were dried in an oven at 70 °C during 48 h before crushing. An Anton Paar's Multiwave GO was used for the acid digestion of the samples. Extracts were filtered through filter paper and the Na^+, K^+, Mg^{2+} and Ca^{2+} concentrations were analyzed through atomic absorption spectroscopy (Allen 1989), using a SensAA GBC spectrometer, both for soil and plant samples.

Phytodesalination capacity (PHC)

Phytodesalination capacity of the halophyte evaluated in the different treatments was calculated from the amount of sodium accumulated in the aerial part and the dry weight achieved after 170 days of being transplanted in the PVC pipes. Phytodesalination Capacity (CPH) was calculated using the following equation (Rabhi et al. 2010):

$$CPH = [(Na_f^+ \text{-} Na_i^+)_{\text{Leaves and Stems}} \; \text{x} \; (DW_f \text{ - } DW_i)_{\text{Leaves and Stems}}]$$

where Na_f^+-Na_i^+ = Difference between the amount of sodium accumulated at the beginning and the end of the experiment ($mg \cdot g^{-1}$), DWf - DWi = Difference between the dry weight at the beginning and at the end of the experiment (g).

Data analysis

An analysis of variance was performed to examine the effects of the factors studied in each of the variables evaluated. Then a Tukey test, with a significant threshold of $p \leq 0.05$, was used to determine whether the mean values of each variable analyzed significantly vary among the treatments. All analyses were performed with the SAS 9.1 software (SAS Institute 2004).

RESULTS AND DISCUSSION

Cations determination in plants

When halophytic species grow in soils with high levels of salinity, concentration of sodium (Na^+) in their tissues increases (Jlassi et al. 2013). This phenomenon was observed in the root and in the aerial parts of the plants grown under the treatments evaluated, being the combination of soil + *S. verrucosum* + $CaSO_4 \cdot 2H_2O$ (T4) the one that accumulated, in the aerial part, the highest concentrations of all monitored cations (Table 2). Rabhi et al. (2010) and Zorrig et al. (2012) reported that *Sesuvium portulacastrum*, *Tecticornia indica* (Willd.) subsp. *indica* and *Suaeda fruticosa* (Forssk.) are able to accumulate high amount of Na^+, which confirm the capacity of halophytic species to regulate the sodium inflowing in the xylem stream reported by Flowers & Colmer (2008). On the other side, *Distichlis spicata*, *Suaeda aegyptiaca* and *Suaeda vermiculata* were able to adsorb K^+, Ca^{2+} and Mg^{2+} cations (Sefidanzadeh et al. 2015; Sabzalian et al. 2018). According to Shabala and Munns (2017), these cations exert a positive function in the energy metabolism of halophytic species, because they allow to carry out photosynthesis and maintain the cellular turgor, the osmotic adjustment and the cellular expansion in saline stress.

Table 2. Content of Na^+, K^+, Ca^{2+} and Mg^{2+} in the root (R) and aerial part (TH) of the halophyte species *S. verrucosum*.

Treatments ($dS \cdot m^{-1}$)	Organ	Mg.g^{-1} DW			
		Na^+	K^+	Ca^{2+}	Mg^{2+}
T2	R	15.13 ± 0.87^f	5.59 ± 0.38^e	7.34 ± 0.51^f	4.45 ± 0.43^e
	TH	57.36 ±2.04^c	14.46 ± 0.47^c	18.19 ± 0.70^c	9.76 ± 0.77^c
T3	R	19.96 ± 1.36^e	11.95 ± 0.71^d	10.36 ± 0.68^e	5.87 ± 0.56^e
	TH	72.26 ±2.38^b	22.48 ± 1.93^b	26.01 ± 2.17^b	17.65 ± 1.64^b
T4	R	28.35 ±1.49^d	14.37 ± 0.68^c	14.37 ± 0.97^d	7.81 ± 0.61^d
	TH	83.04 ± 3.31^a	24.39 ± 1.70^a	29.65 ± 1.43^a	22.11 ± 2.08^a

In each column, different letters mean significant differences according to Tukey's test ($p \leq 0.05$): values indicate mean ± SE (n=10); (R: roots; TH: leaves and stems).

Soil remediation

Concerning the soil, evaluated treatments at depths of 0-10 and 11-30 cm showed a large capacity to reduce the pH, ECe, SAR and ESP with respect to the initial soil (T1). Efficienty of evaluated treatments can be resumed as follows: T4>T3>T2>T1. The results showed that T4 was the most efficient even at depths of 31-40 cm (Table 3). These results are consistent with the findings of Abdel-Fattah (2015), where the application of agricultural gypsum in combination with various halophytic species, such as *Atriplex halimus, Atriplex lentiformis* and *Atriplex amnicola*, was more effective for improving the soil characteristics (pH, ECe, SAR and ESP) as in an isolated manner. According to Ahmad et al. (2003), Kharel et al. (2018) and López Aguilar et al. (2012), the process of exchanging Ca^{2+}/Na^{+} during phytodesalination is driven by the ability and the architecture of the roots to: i) increase the dissolution rate of calcium, ii) enhance changes in the structure of the soil, iii) modify the ionic and osmotic balance in the rhizosphere and iv) extract sodium from the soil and take it to the shoots. In the case of treatment T3, the reductions could be explained by the fact that large part of the sulfur of Polisul-C tends to oxidize, due to the action of soil bacteria and the reaction that comes up with the irrigation water to form sulfuric acid, which, in turn, reacts with carbonates and bicarbonates in the soil to become leachable sodium sulfate (Brady and Weil 1999), where the roots absorb and translocate it towards the harvestable parts (Rahbi et al. 2010). These results are consistent with the statements made by Cifuentes and Lindemann (1993) and Chapman (1990), who affirm that sulfur is an acid former that allows the decreasing of pH and ECe of the soil in a fast way, under humidity conditions and favorable temperatures (Table 3).

On the other hand, the reductions of treatment T2 could be explained, both due to the activity of the roots to absorb Na^{+} cations of the soil (Qadir et al. 2004), and the morphology, the volume and the depth of penetration from the same roots (Torres-Guerrero et al. 2013).

According to Abdel-Fattah (2018), another factor that could explain the reductions in treatment T2 is due to the ability of Na^{+} to form NaOH when it reacts with irrigation water, since, when combined with free CO_2 in the soil, it tends to transform into sodium carbonate, a compound that can be diluted between the less mobile layers of the soil (Table 3) (Abdel-Fattah 2018).

On the other hand, halophytes with large biomass production, along with the ability to withstand high levels of salinity and periodic flooding, are suitable species to improve the physicochemical conditions of saline soils (Qadir et al. 2002). Such process is observed with the halophytic species *S. verrucosum* in the evaluated different treatments, showing significant differences ($p \leq 0.05$) in their phytodesalination capacity (Table 4). The greater gain in biomass content

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Table 3. Physicochemical properties of the soil at the beginning (I) and at the end (F) of phytodesalination.

Parameters	Depths (cm)	T1		T2	T3	T4
		I	F	F	F	F
pH	0 – 10	8.15 ± 0.02^{a}	8.08 ± 0.02^{b}	7.75 ± 0.03^{c}	7.56 ± 0.03^{d}	7.47 ± 0.04^{e}
	11 – 30	8.18 ± 0.03^{b}	8.26 ± 0.02^{a}	7.87 ± 0.02^{c}	7.81 ± 0.02^{d}	7.64 ± 0.03^{e}
	31 – 40	8.21 ± 0.01^{b}	8.32 ± 0.04^{a}	8.13 ± 0.05^{c}	7.95 ± 0.04^{d}	7.82 ± 0.03^{e}
	Mean	8.18 ± 0.02^{b}	8.22 ± 0.02^{a}	7.91 ± 0.02^{c}	7.78± 0.03^{d}	7.64 ± 0.04^{e}
ECe ($dS \cdot m^{-1}$)	0 – 10	6.21± 0.01^{a}	5.87± 0.04^{b}	2.77 ± 0.14^{c}	1.93 ± 0.07^{d}	1.21 ± 0.11^{e}
	11 – 30	6.24± 0.03^{b}	6.51± 0.07^{a}	3.06 ± 0.08^{c}	2.75 ± 0.08^{d}	2.18 ± 0.09^{e}
	31 – 40	6.19± 0.05^{b}	6.76± 0.04^{a}	6.12 ± 0.06^{b}	4.84 ± 0.12^{c}	3.78 ± 0.23^{d}
	Mean	6.21± 0.04^{a}	6.38± 0.03^{b}	3.93 ± 0.04^{c}	2.87 ± 0.05^{d}	2.39 ± 0.06^{e}
SAR $(mmol_c \cdot L^{-1})^{1/2}$	0 – 10	33.83± 0.72^{a}	33.40± 0.42^{a}	16.48± 0.57^{b}	6.17± 0.47^{c}	4.85± 0.35^{d}
	11 – 30	34.6± 0.90^{a}	35.09± 0.63^{a}	20.31± 0.72^{b}	14.05± 0.53^{c}	9.39± 0.44^{d}
	31 – 40	34.96± 0.82^{a}	35.78± 0.51^{a}	26.67± 0.88^{b}	16.74± 0.71^{c}	15.46± 0.54^{d}
	Mean	34.46± 0.65^{a}	34.75± 0.37^{a}	21.15± 0.28^{b}	12.65± 0.36^{c}	9.90± 0.44^{d}
ESP	0 – 10	38.96± 0.52^{a}	38.13± 0.62^{a}	15.71± 0.53^{b}	5.28± 0.44^{c}	3.45± 0.61^{d}
	11 – 30	40.16± 0.57^{a}	39.93± 0.82^{a}	23.30± 0.75^{b}	13.95± 0.53^{c}	10.12± 0.37^{d}
	31 – 40	39.53± 0.41^{a}	41.66± 0.59^{a}	32.64± 0.64^{b}	22.61± 0.86^{c}	18.76± 0.78^{d}
	Mean	39.55± 0.39^{a}	39.91± 0.41^{a}	23.88± 0.45^{b}	13.94± 0.59^{c}	10.56± 0.42^{d}

In each row, different letters mean significant differences according to Tukey's test ($p \leq 0.05$): values indicate mean ± SE ($n = 10$).

Table 4. Biomass content and phytodesalination capacity of the halophytic species *S. verrucosum* (CPH).

Parameters	Treatments		
	T2	T3	T4
Final FW per plant (g)	325.09 ±15.85^{c}	496.44 ± 21.85^{b}	562.79 ± 17.43^{a}
Final DW per plant (g)	58.19 ± 2.31^{c}	72.48 ± 3.25^{b}	78.92 ± 1.89^{a}
Biomass FW / DW	5.58 ± 0.47^{b}	6.84 ± 0.19^{a}	7.13 ± 0.24^{a}
CPH (g.plant $^{-1}$)	2.02 ± 0.07^{c}	3.56 ± 0.21^{b}	4.70 ± 0.27^{a}

In each row, different letters mean significant differences according to Tukey's test ($p \leq 0.05$): values indicate mean ± SE ($n = 10$)

and accumulation of sodium (Na^+) in the harvestable part were obtained in the treatment T4; possibly, the adaptation mechanisms that this species has developed, as is the case of the formation of successive changes in its ontogenetic system, allows it to have greater mechanical resistance, flexibility and compartmentalization of ions in the vacuole and organic solutes in the cytoplasm (Elbar 2015). Hence, among its main structural modifications, there are patterns of secondary thickening and formation of the internal phloem (Rajput et al. 2008).

Although, the phytodesalination capacity of the species *S. verrucosum* was lower than other reported species, such as *Mesambryanthemum crystallinum* (179.08 mg·g^{-1} DM) (Atzori et al. 2017), it was higher than *Suaeda paradoxa* (44.27 mg·g^{-1} DM) (Hidri et al. 2016) or *Atriplex lentiformi* (46.2 mg·g^{-1} DM) (Diaz et al. 2013) to mention just a few; however, the duration of the process, the properties of the soil (salinity, sodicity and porosity), the number and the initial weight of the species per experimental unit could explain such discrepancy (Rahbi et al. 2010).

CONCLUSION

S. verrucosum has the ability to improve the physicochemical properties of a moderately saline and clay-textured soil, mainly at a depth of 0-30 cm. This desalinization capacity is increased when *S. verrucosum* is used in combination with the chemical amendments $CaSO_4 \cdot 2H_2O$ and Polisul-C. In addition, it was confirmed that the $CaSO_4 \cdot 2H_2O$ was more efficient than Polisul-C (as acid forming substance) to remedy a heavy textured saline soil.

Also, *S. verrucosum* showed an enormous adaptation potential and a high growth rate under conditions of moderate salinity, which could contribute to rehabilitation of degraded lands and safeguard food security inthe most vulnerable sectors, specifically in regions with low production systems because of salinity conditions.

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AUTHORS' CONTRIBUTION

Conceptualization, Alvarez-Bernal D. and Lastiri-Hernández M.; Methodology, Lastiri-Hernández M. and Bermudez-Torres K.; Investigation, Alvarez-Bernal D.and Lastiri-Hernández M.; Writing – Original Draft, Alvarez-Bernal D. and Lastiri-Hernández M.; Writing – Review and Editing, Alvarez-Bernal D., Lastiri-Hernández M., Cruz-Cárdenas G. and Ceja-Torres L.; Funding Acquisition, Alvarez-Bernal D.; Resources, Alvarez-Bernal D. and Lastiri-Hernández, M.; Supervision, Alvarez-Bernal D.

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