Removal of salts by *Atriplex nummularia* depending on soil moisture

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Abstract
The degradation of soils by the salinity and sodicity has been an important subject in the handling and use of soils, and its reclamation contributes with the improvement of the productivity and sustainability of the environments. Studying the phytoremediation of salt- affected soils with *Atriplex nummularia*, this study aims to determine the extraction of salts by plants grown in saline-sodic soil under conditions of water stress. The experiment was conducted in a greenhouse for 134 days cultivating *Atriplex nummularia* in pots containing 20 kg of saline-sodic soil at four moisture levels (35, 55, 75 and 95% of field capacity) , designed on blocks with eight replications, collecting plant and dividing it into leaf, stem and roots to determine the extraction of salts. The values of extraction of sodium by leaves + stem were 251.63, 277.84, 394,92 and 440,36 kg/ha 134 days^{-1} to 35, 55, 75 and 95% of FC respectively. Removal of Ca, Mg, Na, K and Cl by leaf + stem were 644.25, 757.81, 1058.55 and 1182.00 kg/ha at 35; 55; 75 and 95% of field capacity, making it an alternative for the phytoremediation of salt-affected soils in the semi-arid region of Brazil.

Key Words
Phytoextraction, salt-affected soils, halophytes, field capacity.

Introduction
Salinity and the sodicity are among the main causes of degradation of the soil in semi-arid environments, because they damage soil properties, plant development and the society, which culminates in serious social and environmental impacts. Recovery of these soils contributes to the improvement of productivity and sustainability of the ecosystems. Reclamation practices and efficient handling should be adopted, since these soils are a valuable resource for agriculture and cannot be neglected (Qadir *et al.* 2007). The use of halophyte vegetation is based on phytoextraction, that is a phytoremediation technique that uses species of plants that absorb and accumulate the sodium in the shoot, which can be removed and used for other purposes. Qadir *et al.* (2007) claim that the phytoextraction is an efficient strategy of recovery of saline-sodic soils, with performance comparable to the use of alleviation chemical. One of the factors that should influence the extraction of salts by plants is soil moisture, by increasing the vegetative growth and, consequently, the absorption of salts. This work determined the extraction of elements by *Atriplex nummularia* grown on saline-sodic soil under conditions of water stress (35, 55, 75 and 95% of field capacity).

Methods
The experiment was carried out in a greenhouse. We used sodic-saline soil collected from 0-30 cm depth, dried in air, homogenized and passed through a sieve of 4 mm before filling the pots. For physical and chemical characterization a -2mm subsample had 229 g/kg of coarse sand, 363 g/kg of fine sand, 327 g/kg of silt and 81 g/kg of clay, with soil bulk density of 1,40 kg/dm^3 ; soil pH(1:2,5) = 8,66; pH of the saturation extract = 7,45; electrical conductivity (EC) of the saturation extract = 42,56 dS/m; Exchangeable Na^+ = 3,31 $cmol_c$/kg; cation exchange capacity = 4,69 $cmol_c$/kg; exchangeable sodium percentage = 71,20%.
Polyethylene pots were used with capacity of 20 kg of dry soil. Seedlings of *Atriplex nummularia* were used of 120 days age. The soil had a field capacity of 0.152 g/g. Pots were maintained at four moisture levels (35, 55, 75 and 95% FC). The treatments were disposed in randomized blocks with eight replications. The water used in the irrigation had EC of 0.75 dS/m. 134 days after the seedlings (DAS) the plants were collected and divided in leaf, stem and root, that were oven dried at 65 ºC for 48 h. The dried matter was ground subjected to nitricperchloric digestion to determine sodium, potassium, calcium, magnesium, zinc and copper. Chloride was determined by extraction in water and titration with silver nitrate (Malavolta *et al.* 1989). The results were analyzed through variance analysis and Tukey test ($P < 0.05$) using the Software SAEG 9.1 (UFV 2007).

Results

The dry matter of the leaves increased as a function of the soil moisture, with increment of 81% for the treatment with 95% of FC in relation to 35% FC, however, a decrease occued in the production of dry mass of stem and root for the soil at 95% FC, in relation to the treatment a 75% of FC (Figure 1).

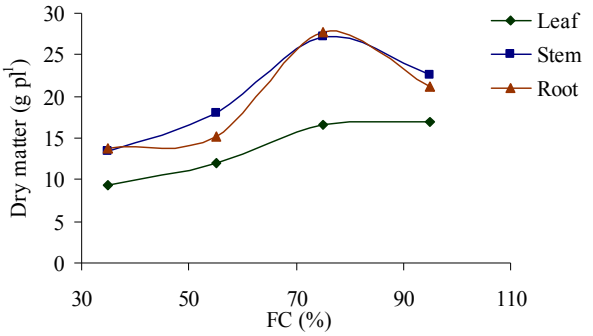

Figure 1. Dry matter production of parts of *Atriplex nummularia* as a function of soil water content.

The production of dry matter of stem + leaves were 3978.93; 5228.35, 7639.82 and 6925.11 kg/ha for 35, 55, 75 and 95% of FC, respectively. This biomass can be used as forage (Masters *et al.* 2007). The element content varied among the parts of the plant, with prevalence of chloride and sodium in the leaf, stem and root, followed by potassium and then calcium and magnesium (Table 1).

Table 1. Leaf, stem and root chemical composition of *Atriplex nummularia* grown in saline sodic soil

Element	Leaf	Stem	Root
Ca (g/kg)	5,24	1,55	3,40
Mg (g/kg)	6,13	1,13	2,50
Na (g/kg)	124,73	13,01	15,29
K (g/kg)	19,33	10,50	7,09
Cl (g/kg)	149,45	26,52	19,96
Cu (mg/kg)	1,03	0,35	7,84
Zn (mg/kg)	40,81	3,74	15,42

The leaf was the organ with the larger concentrations, especially for chloride and sodium, indicating the potentiality of use of the species in the phytoextraction of NaCl in soil-affected salts. The contents of Cu and Zn in the leaves were 1.03 and 40.81 mg/kg of dry matter respectively (Table 1). Norman *et al.* (2008) found values of Cu and Zn to leaves and small stems (< 3 mm) of *Atriplex nummularia* corresponding to 4.1 and 40 mg/kg of dry matter. Underwood and Suttle (1999) suggested that a diet for lambs should contain > 4 mg Cu/kg DM at highest rates of absorption and as much as 17 mg Cu kg DM^{-1} at lowest absorbability (Table 1).

The highest content of sodium and chlorine were removed by the leaves (Figure 2). The treatments 75 and 95% of FC removed more Na than for 35 and 55% FC. The contents of K were similar for the three fractions of the plant and there were not significant differences among the treatments, except for the stem. The same behavior of the sodium was observed for chlorine in the three analyzed fractions, with the largest content in the leaf, reaching 2.92 g/plant for the 95% FC treatment. The ratio of Na:K differed significantly among the treatments, that had larger values in relation to the stem and the root. The sodium removed by the stem + leaves were 251.63, 277.84, 394.92 and 440.36 kg/ha for 35, 55, 75 and 95% of FC. Leal *et al.* (2008), evaluating phytoremediation with Atriplex in the same soil type, cultivated in a greenhouse, found values similar of sodium content in the leaves to 130 DAS. In addition, Ravindram *et al.* (2007), evaluate the reclamation of a saline soil in India, verified that the halophyte species *Saueda* and Sesuvium *portulacastrum* removed 504 to 474 kg/ha of sodium chloride in four months, respectively. Considering removal of total Ca, Mg, Na, K and Cl by leaf + stem were found 644.25, 757.81, 1058.55 and 1182.00 kg/ha for 35; 55; 75 and 95% FC.

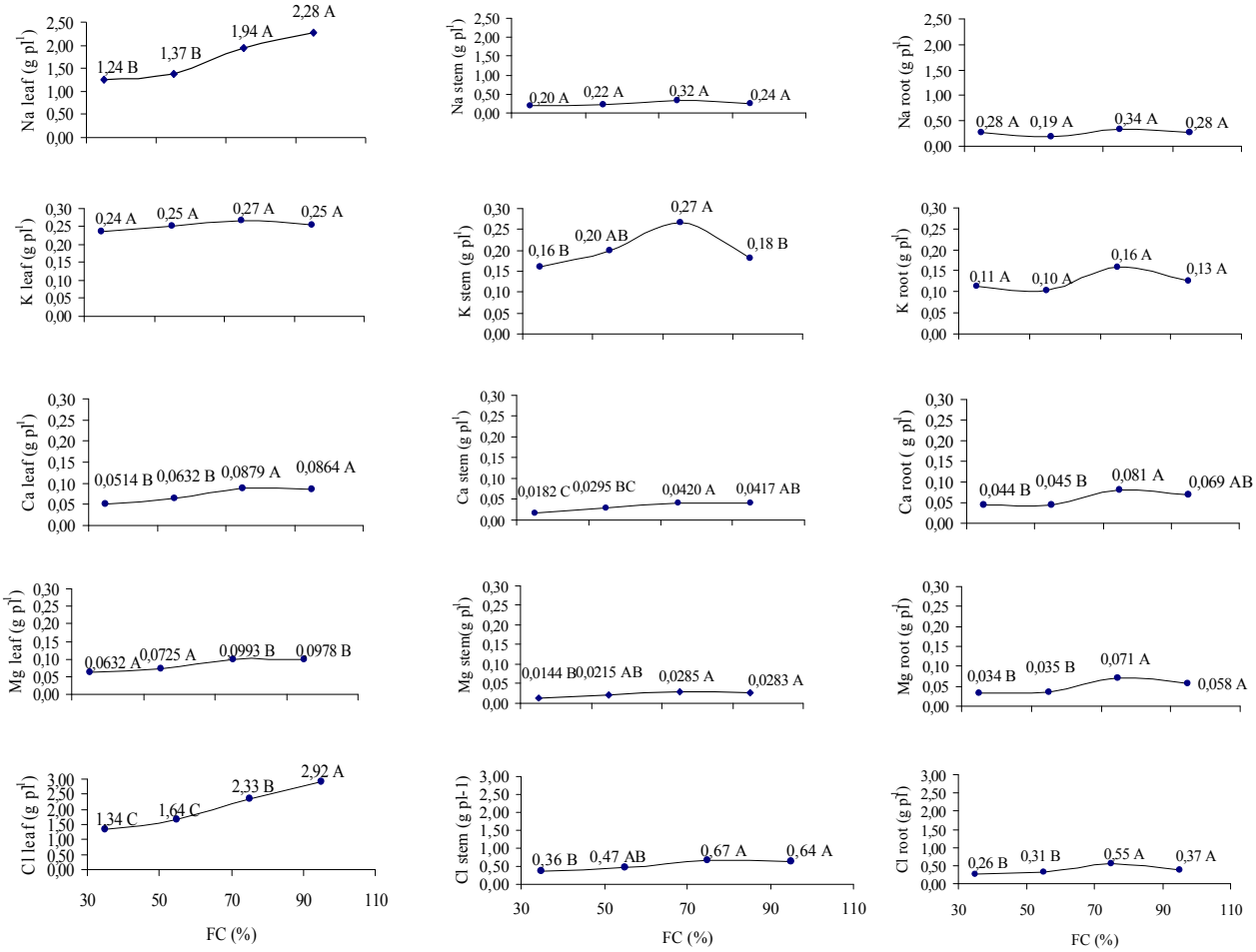

Figure 2. Sodium, potassium, calcium, magnesium and chlorine content in leaf, stem and root of *Atriplex nummularia* grown at salt-affect soil in Pernambuco (Brazil). Medium follow by same letter are no different by Tukey's test at 5% probability.

Conclusion

The production of dry matter by the leaf, stem and root was sensitive to soil moisture; The values of extraction of sodium by leaf + stem were 251.63, 277.84, 394,92 and 440,36 kg/ha 134 days^{-1} to 35, 55, 75 and 95% of FC respectively. Considering the removal of total Ca, Mg, Na, K and Cl by leaf + stem were found 644.25, 757.81, 1058.55 and 1182.00 kg/ha for 35; 55; 75 and 95% of field capacity.

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