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Interactive effect of lime and vegetation on the reclamation of saline soil

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Abstract The results showed significant effects of using $CaCO_3$ in desalination in saline soil. There was a significant reduction in electrical conductivity in the saturated soil paste extract (ECe) from 20.00 to 11.47 dS/m. $CaCO_3$ also helped to reduce exchangeable Na_{ex}, percentage exchange sodium (ESP), sodium adsorption rate (SAR) and increased exchangeable cations K_{ex}, Ca_{ex} and Mg_{ex}. The saline soil after desalination was used to grow sedge plants, cattail (*Typha orientalis*), grey sedge (*Lepironia articulata*) and bulrush (*Scirpus littoralis*), for the 2nd experiment. The results indicated that the sedge plants also contributed to salinity reduction, particular EC_e=8.71-11.29 dS/m, Na_{ex}=3.50-3.90 g/kg and ESP=17.02-22.69% in soil soaking with $CaCO_3$ were lower than that in the soil without $CaCO_3$ application (EC_e=10.67-13.13 dS/m; Na_{ex}=3.99-4.48 g/kg and ESP=17.68-23.91%). The results suggested that the combined use sedge plants and lime was effectively reduced soil salinity and improved soil chemical properties than using lime alone.

Keywords: Desalination, Lime, Phytoremediation, Salt-affected soil, Soil reclamation

Introduction

Salinity is one of the most brutal environmental factors limiting the productivity of crop plants because most of the crop plants are sensitive to high concentrations of salts in the soil, and the area of land affected by it is increasing day by day (Shrivastava and Kumar, 2015). The presence of about 1000 M ha or 6% of the world's total land area is salt-affected land (Mahmood *et al.*, 2016) which show the intensity of problem of lossing of fertile land and threats for agricultural sustainability (Munns and Tester, 2008). Vietnam is one of the five countries most affected by climate change, about 971 thousand ha of land is affected by salinity, in which, the Vietnamese Mekong Delta (VMD) covers 77% of the total area, covering about 744 thousand ha (Nguyen and

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Tran, 2020). Reclamation of saline soil has been receiving increasing attention to explore its economic potentials for agriculture.

Saline soil is being classified based on electrical conductivity in the saturated soil extracts (ECe) with at least 4 dS/m, and exchangeable-sodium percentage (ESP) greater than 15. The soil having high concentration of soluble salts (saline soil), or exchangeable sodium (sodic soil) or both (saline-sodic soil) are collectively called salt-affected soil (Saifullah *et al.*, 2018). Normal soil can become salt-affected due to few basic processes bringing salt to soil layers, including a rise of salt-affected, seawater intrusion, saline-water irrigation, excessive fertilizer application, and rock weathering (Rengasamy, 2010). Moreover, the anthropogenic salinity has primarily been the result of inadequate irrigation and drainage practices (Yurtseven *et al.*, 2014). In the present study, the anthropogenic cause is shrimp aquaculture shifting from rice cultivation in the coastal regions of the VMD result in saline accumulation in the soil, so called salt-affected soil. In this context, the farmers shifted to planting sedges instead of rice in the rice-shrimp farming system to cope with the more complex climate change situation, especially those land that had severe salinity and failed in rice cultivation. The farmers believed that some wetlands grass particular *Scirpus littoralis*, *Typha orientalis*, *Eleocharis ochrostachys*, and *Eleocharis dulcis* could be tolerant in the soil with high salinity higher than 4 dS/m, where rice could not survive (Thanh *et al.*, 2019).

Leaching with water, chemical amendment, and phytoremediation are among the methods being used to ameliorate saline soils (Qadir *et al.*, 2000). The first step involves the replacement of exchangeable sodium (Na_{ex}) with calcium (Ca_{ex}) and the second step is to leach the resulting sodium salt from the soil (USDA, 1954). The remediation of saline soil using $CaSO_4.2H_2O$, $CaCO_3$ and $CaCl_2.2H_2O$ (Makoi and Verplancke, 2010; Cha-um and Kirdmanee, 2011; Zhao *et al.*, 2016) are able to reduce soil salinity and sodicity. In Vietnam, most widely used Ca^{2+} source is lime (usually in the commercial forms of $CaSO_4.2H_2O$, $CaCO_3$, and CaO), which incorporates enough soluble Ca^{2+} to replace the excess Na^+ effectively. Gypsum/lime provided soluble Ca^{2+} replaces excessive Na^+ from soil exchange sites, which subsequently leaches by irrigation water (Oster and Frenkel, 1980). This is the common practice, the local farmers in the VMD applied in the rice-shrimp farming (Thanh *et al.*, 2019). However, the synergistic effect of the lime application and plantation on ameliorating salinity concentration in the saline soil is still poorly known. The present study was conducted to evaluate the effect of the addition of lime in the rehabilitation of saline soil in the shrimp-sedge farming, under controlled laboratory conditions, using as indicators of changes in ECe and ESP, and to identify interaction effects of plant and lime on saline soil reclamation.

Materials and methods

Experimental setup

The experiment was conducted at the College of Environment and Natural Resources of Can Tho University, Vietnam (10.03 ° N latitude and 105.76 ° E longitude). The study was conducted to reduce salts in saline soil of the shrimp-grass pond by using $CaCO_3$ and combining it with phytoremediation. Before planting, the 1st experiment was conducted to evaluate the ability of reducing salts in soil using $CaCO_3$ (2.06 tons $CaCO_3$/ha). Desalination treatment in soil with tap water without $CaCO_3$ was the control treatment. The saline soil after desalination was used to grow plants for the 2nd experiment with cattail (*Typha orientalis*), grey sedge (*Lepironia articulata*) and bulrush (*Scirpus littoralis*). The experiment was arranged in a factorial completely randomized design in the net house with light intensity in the range of 31.2-35,7 kLux at the 12:00 to 15:00.

Soil and plant preparation

The soil was collected from the shrimp-sedge ponds previously planted with *S. littoralis* in Bac Lieu province (9 ° N latitude and 105 ° E longitude) of the VMD. The cultured species was extensive farmed with tiger shrimp, white-leg shrimp and tilapia. The area remains waterlogged in most of the time of the year. The soil cores were collected at 0-20 cm layer soil using a Ø20 cm PVC pipe that having 7.97±0.09 kg of soil fresh weight of each core. The soil core was placed in the plastic pot with top diameter of 0.23 m^2 and height of 0.21 m.

The young plants of the three studied species were collected from the fields. *Scirpus littoralis* and *T. orientalis* were collected at the shrimp-sedge ponds in Bac Lieu province (9 ° N latitude and 105 ° E longitude) while *L. articulata* was collected in Kien Giang province (10 ° N latitude and 104 ° E longitude) of the VMD. The selected plants were washed to remove particle/soils before planting in the pots.

Soil reclamation

The 1st experiment called soil reclamation using tap water combined with $CaCO_3$ involed three stages of soil soaking. The soil core was soaked with 2.5 L of tap water for 28 days and soil and water samples were collected, called stage 1. The water was drained and 2.5 L of tap water was replenished and added with $CaCO_3$ and without $CaCO_3$ (control treatment), then the soil was continuously soaked for 14 days, called stage 2. A 8.21±0.09 g $CaCO_3$/pot (equal to 2.06 tons/ha) was used based on the calculated exchangeable Na^+ content in the soil (USDA, 1954). The $CaCO_3$ was dissolved in 2.5 L of tap water and then used to soak the soil for 28 days, then soil samples were collected. A 2.5 L of tap water was renewed and the soil was continuously soaked for 28 days in stage 3. At the end of the 1st experiment (total 70 days of soaking period) soil samples were collected for the measurement of soil chemical properties.

The 2nd experiment so called soil reclamation using the desalinized soils from the 1st experiment combined with three wetlands sedge species. Three culms of each species were planted in each pot making up a density of 15 plants/m^2 (Trang *et al.*, 2018). The 2nd experiment was conducted for 90 days and soil samples were collected to analyse soil chemical properties.

Soil properties analyses

The soil samples were dried at room temperature, ground, and passed through 0.5 mm sieve to determine physical and chemical properties of the soils. Saturated pastes were prepared by adding deionized water to approximately 25 g of soil sample as received until it reached a condition of complete saturation, as described by guidelines in USDA Handbook 60 (USDA, 1954). Saturated pastes were allowed to equilibrate for 24 h. An extract from the saturated pastes was used to measured EC and pH using portable meters. $BaCl_2$ (0.1M) was used to extract soil to determine CEC by titration with EDTA 0.01M, and the extract was used to measure exchangeable Na, K, Ca, and Mg (Na_{ex}, K_{ex}, Ca_{ex}, Mg_{ex}) by using the iCE 3000 Series Atomic Absorption Spectrometers (AAS). The soil organic matter (OM), N and P contents were determined followed Walkley-Black, Kjeldahl and colorimetric methods. Soil salinity was classified based om ECe of the soil, and soluble Na^+ concentration relative to soluble divalent cation concentration in soil solution, that is sodium adsorption ratio (SAR) or as exchangeable sodium percentage (ESP). The SAR and ESP calculations as described by Qadir *et al.* (2007).

Statistical analysis

Data were tested for normal distribution and variance homogeneity (Levene's test) and logarithmically transformed if necessary. Differences in soil properties were identified using two-way ANOVA (plant species x lime treatments) using Type III sum of squares. Plant species effects within lime treatments and lime effects within plant species were analysed by one-way

ANOVA. Tukey Honestly Significant Differences (HSD) was used to identify significant differences between plant species and lime treatments at the 5% probability level. The software Statgraphics Centurion XV (StatPoint, Inc., USA) was used for all statistical analyses.

Results

The effect of lime on soil chemical properties

The soil was classified as clay soil with a proportion of clay, silt, and sand at 66.7, 32.65, and 0.65%, respectively (Table 1) and was classified as saline soil with EC = 20 dS/m, and exchangeable-sodium percentage (ESP) = 39.76%. The soil pH of the initial soil used in the study was low (4.23) and was increased in the treatment with $CaCO_3$. The presence of $CaCO_3$ helped to reduce Na_{ex}, Na_{ex}/Ca_{ex} ratio, ESP and SAR leading to a significantly reduction of 42.7% ECe level in the initial soil ($p<0.05$). In contrast, K_{ex} and Ca_{ex} contents in the soil was inceased after 70-day soil incubation ($p<0.05$). Although nitrogen content in the soil did not change with the presence of $CaCO_3$ over incubation period, the C/N ratio was the lowest in the treatment with $CaCO_3$.

Table 1. Some soil physico-chemical properties of the initial soil used in the study and after 70-day soaking

Properties	Unit	Initial	After 70 days		F-values
			Without $CaCO_3$	With $CaCO_3$	
Clay:silt:sand	%		66.70:32.65:0.65		
pHe	-	4.23 ± 0.001^b	4.12 ± 0.005^b	5.04 ± 0.06^a	294.5^{***}
ECe	dS/m	20.00 ± 0.14^a	13.15 ± 0.1^b	11.47 ± 0.39^c	609.5^{***}
CEC	meq/100g	17.08 ± 0.07^a	15.38 ± 0.04^c	16.39 ± 0.02^b	73.13^{**}
K_{ex}	g/kg	0.52 ± 0.005^b	0.67 ± 0.005^a	0.66 ± 0.005^a	438.5^{***}
Na_{ex}	g/kg	6.79 ± 0.04^a	6.33 ± 0.005^b	4.57 ± 0.02^c	2233.6^{***}
Ca_{ex}	g/kg	0.73 ± 0.00^c	1.11 ± 0.02^b	1.26 ± 0.01^a	685.5^{***}
Mg_{ex}	g/kg	2.96 ± 0.005	3.00 ± 0.03	3.06 ± 0.02	8.69^{ns}
Na_{ex}/Ca_{ex} ratio		9.29 ± 0.06^a	5.74 ± 0.07^b	3.62 ± 0.02^c	3213.6^{***}
SAR	$(g/kg)^{1/2}$	5.01 ± 0.03^a	4.42 ± 0.02^b	3.11 ± 0.00^c	3318.9^{***}
ESP	%	39.76 ± 0.56^a	41.12 ± 0.005^a	27.85 ± 0.06^b	816.8^{***}
Organic matter	g/kg	134.5 ± 0.5^a	129.1 ± 0.2^b	117.8 ± 0.4^c	946.8^{***}
TP	g/kg	0.28 ± 0.00^a	0.24 ± 0.01^b	0.29 ± 0.007^a	14.60^{*}
TKN	g/kg	1.88 ± 0.005	1.84 ± 0.02	1.9 ± 0.01	9.21^{ns}
C/N ratio		41.62 ± 0.3^a	41.21 ± 0.6^a	35.49 ± 0.4^b	56.08^{**}

Note: Values are the means ± standard deviation (S.D.). Different letter superscripts between columns indicates significant difference. *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$; ^{ns}: $p>0.05$.

Interation effects of lime and plant species on soil desalination

There were significant interactions between the factors in the two-way ANOVA for ECe, CEC, Mg_{ex}, Na/K ratio, SAR, ESP and TP in soils (**Table 2**). Lime significantly affected all measured parameters in soil except for CEC and ESP while plant species affected ESP. The pH values in the soil after 90-day planting were increased in the treatment with lime but soil ECe in the pots planted with *T. orientalis* were reduced remarkably from 11.47 to 8.71 dS/m (Figure 1). There were increments of K_{ex}, Ca_{ex} and Mg_{ex} in the soils after planting for 90 days (Table 1), whereas a reduction of Na_{ex} in the soils was observed. Soil CEC was increased after 90-day planting and Na/K ratio, SAR and ESP were reduced in all treatments (Figure 2).

There was a slight reduction of N content in the soil after planting for 90 days while OM content in the soil was not changed leading to a significantly increase in C/N ratio. Phosphorus content in the soils of all treatments was also increased (Figure 3).

Table 2. Results of two-way ANOVA (F-ratios) shows the effects of plant species and lime treatments on soil chemical properties after 90-day planting

Properties	Factors		Interaction
	Plant species	**Lime treatments**	**Plant species x Lime treatments**
pH	$1,05^{ns}$	$10,28^{**}$	$2,83^{ns}$
ECe (dS/m)	$1,57^{ns}$	$19,71^{***}$	$17,89^{***}$
CEC (meq/100g)	$2,66^{ns}$	$1,00^{ns}$	$11,29^{***}$
K_{ex} (g/kg)	$5,33^{*}$	$35,93^{***}$	$1,78^{ns}$
Na_{ex} (g/kg)	$18,18^{***}$	$71,53^{***}$	$1,64^{ns}$
Ca_{ex} (g/kg)	$9,59^{**}$	$37,18^{***}$	$1,59^{ns}$
Mg_{ex} (g/kg)	$0,49^{ns}$	$14,35^{*}$	$31,10^{***}$
Na_{ex}/Ca_{ex} ratio	$24,03^{***}$	$119,78^{***}$	$5,00^{*}$
SAR $(g/kg)^{1/2}$	$23,04^{***}$	$43,23^{***}$	$26,30^{***}$
ESP (%)	$7,92^{**}$	$3,39^{ns}$	$11,12^{***}$
OM (g/kg)	$21,47^{***}$	$44,32^{***}$	$0,91^{ns}$
TP (g/kg)	$14,18^{***}$	$9,44^{**}$	$16,96^{***}$
TKN (g/kg)	$14,15^{***}$	$151,74^{***}$	$1,47^{ns}$
C/N ratio	$2,66^{ns}$	$209,59^{***}$	$2,37^{ns}$

*: p<0.05; **: p<0.01; ***: p<0.001; ^{ns}: p>0.05.

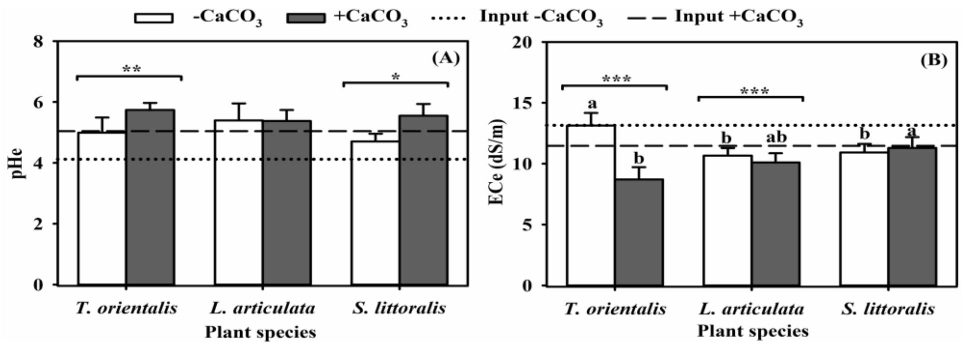

Figure 1. Effects of lime application and plant species on soil pH and ECe

Note: *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$ indicates significant difference within each species; Different letter superscripts between species within lime treatment indicates significant difference. The input data is the results from the 1st experiment.

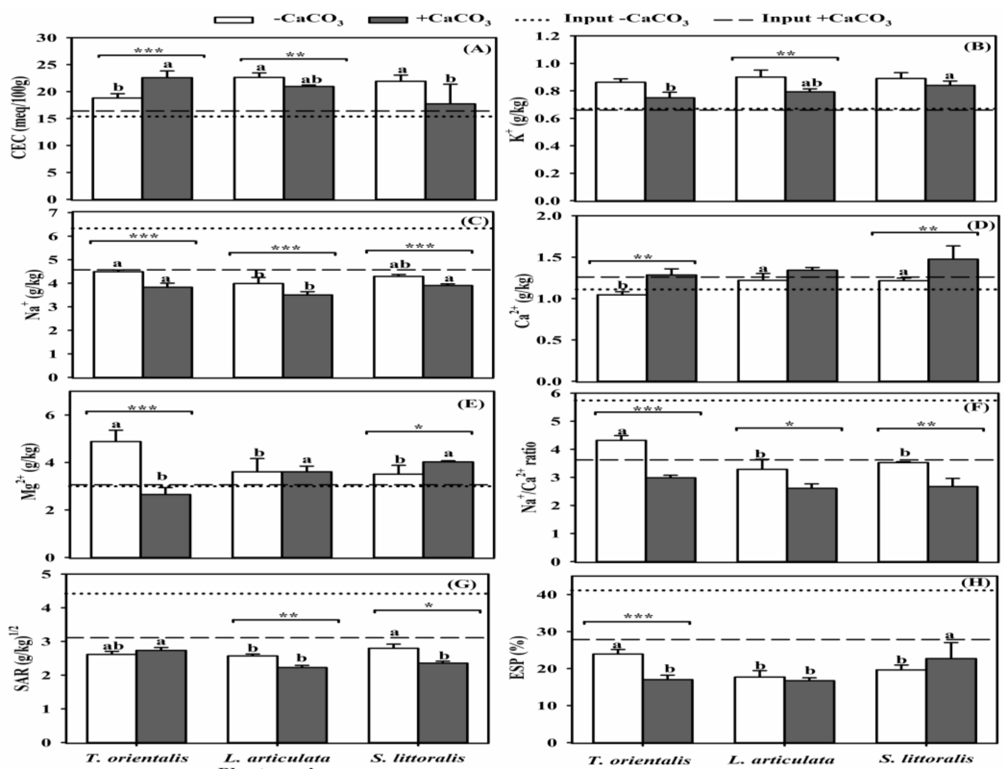

Figure 2. Effects of lime application and plant species on soil minerals contents, CEC, SAR and ESP

Note: *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$ indicates significant difference within each species; Different letter superscripts between species within lime treatment indicates significant difference. The input data is the results from the 1st experiment.

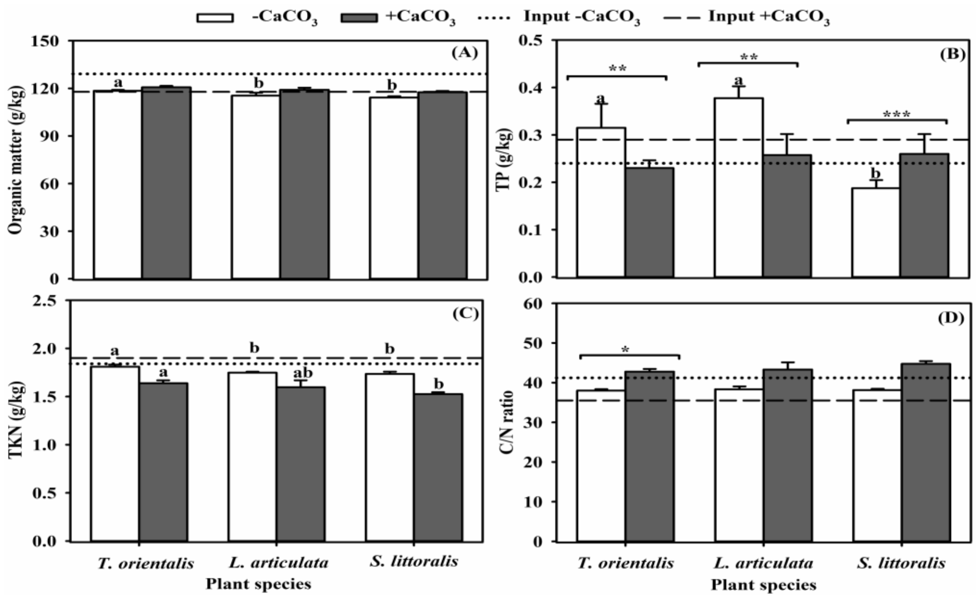

Figure 3. Effects of lime application and plant species on soil nutrients
Note: *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$ indicates significant difference within each species; Different letter superscripts between species within lime treatment indicates significant difference. The input data is the results from the 1st experiment.

Discussion

The soil used in the study is strongly acidic soil (pH=4.23) according to USDA classification (USDA, 1954), using $CaCO_3$ to improve soil pH and reduce toxicity of acidic soil (Ameyu, 2019). The use of lime is suitable and is a good practice that the VMD farmers commonly applies (Thanh *et al.*, 2019). The shrimp-rice/shrimp-grass farms are generally located nearby canals and are engineered to allow effective water exchange. The farmers can take advantage of this to leach the salts from the soils at the beginning of the rainy season using rain water and/or river/canal water having low EC for at least two months. They drained out the soaked-water before planting rice in the next cropping. The farmers apply $CaCO_3$ with purposes of enhancement alkalinity and sterile soil conditions and do not imply for desalination (Thanh *et al.*, 2019).

After 70 days of soaking, the soil pH in the treatment with $CaCO_3$ application was increased higher than that of the control treatment (without $CaCO_3$) and in the initial soil. The application of $CaCO_3$ also helped to reduce soil ECe from 20 to 11.47 dS/m (42.7% reduction). At this soil ECe level only some salt-tolerant species could survive such as forage grass *Cenchrus* species, and *Chloris gayana* which could tolerate with ECe level up to 17.9 dS/m

(Qureshi *et al.*, 2018) and not for rice (Lang *et al.*, 2010). That is also the reason we select the three-sedge species, *T. orientalis*, *L. articulata* and *S. littoralis*, for desalination in the 2nd experiment based on their salt-tolerant ability up to 20‰ (eq. to the EC of 38 dS/m) (Trang *et al.*, 2018; Han *et al.*, 2020). Those sedge are also suggested for crop pattern in the strong saline soil level, later that plant biomass contribute to reclaim soil salinity and rice and other vegetables can be cultivated on that soil in the next cropping (Lang *et al.*, 2010; Thanh *et al.*, 2019). There are also effective amelioration management and usage of coastal saline soils strategies that the nation seeks to do under climate change and sea level rise contexts. In the present study, the three sedge plants contributed to a significant salinity reduction as soil ECe, of which *T. orientalis* associated with $CaCO_3$ (+$CaCO_3$) provided the highest reduction (from 11.47 to 8.7 dS/m, 24.1% reduction). Regarding USDA classification (USDA, 1954), the range of ECe in the soil of 8-16 dS/m was suitable for to salt-tolerant plants only. In practice, the VMD farmers plant *T. orientalis* and *S. littoralis* in the rice-shrimp farming system to cope with more complex climate change situation, especially those lands that have severe salinity effect and failed in rice cultivation (Thanh *et al.*, 2019).

According to Oster and Frenkel (1980), gypsum/lime provides soluble Ca^{2+} replacing excess Na^+ from soil exchange sites, which is then washed away by water, contributed a 32.7% reduction of Na^+ content in the original soil (6.79 g/kg) after 70-day soaking. Although interaction effect between lime application and plant species was not detected, only single effect was found. The plants additionally contributed 14.6-37.0% reduction in Na^+ content in the soil after 90-day planting. In contrast, the concentration of exchangable K^+ (0.66 g/kg), Ca^{2+} (1.26 g/kg) and Mg^{2+} (3.06 g/kg) in the soil soaking with $CaCO_3$ increased compared to in the initial soil. Liming increases in the availability of Ca^{2+} in soils (Xu *et al.*, 2020) because Ca^{2+} is the main cation in the limestones used, that gave 72.6% concentration of soil Ca_{ex}. A linear increase in soil Ca^{2+}, Mg^{2+} and K^+ concentrations with respect to the amount of lime applied in the soil (Herrera and Pérez, 2020) and the highest concentration of K_{ex} in acidic soils after 90-day lime application was observed by Das and Saha (2014). An increase in cations Ca^{2+}, Mg^{2+} and K^+ is generated during the decomposition of existing organic matter in the soil (Das and Saha, 2014). Beneficial effects of plant roots during soil amelioration including physical action of plant roots improves the soil structure and provides channels for infiltrating water, and an increase in the dissolution of lime ($CaCO_3$) in the presence of CO_2 evolved from root respiration and decomposition of organic matter. We also found the same with a slightly reduction of soil organic matter content and an increase in the concentrations of these cations were observed after planting for 90 days.

Filho *et al.* (2020) also reported the role of Ca^{2+} in soil ECe reduction contributing to improve soil physical properties facilitating excess salt leaching. They confirmed that Ca^{2+} is effective in removing Na^+ from the soil leading to a significant decrease in ECe, SAR and ESP in the soil solution. Organic matter decomposition also reduces ECe, ESP and accelerates Na^+ leaching (Qadir *et al.*, 2001). The combined use of sedge plants and lime also contributed in salinity reduction, particular EC_e=8.71-11.29 dS/m, Na_{ex}=3.50-3.90 g/kg, SAR=2.35-2.73 $(g/kg)^{1/2}$ and ESP=17.02-22.69%, were lower than that in the soil without $CaCO_3$ application (EC_e=10.67-13.13 dS/m; Na_{ex}=3.99-4.48 g/kg, SAR=2.57-2.80 $(g/kg)^{1/2}$ and ESP=17.68-23.91%). The plants additionally contributed to a reduction of 12.0-41.9% SAR and 18.5-57.0% ESP. Compared to the results in the 1st experiment after soaking 70 days with $CaCO_3$ the soil chemical properties after planting for 90 days were better. It indicates that the combined use of sedge plants and lime is better to reduce soil salinity, improve soil chemical properties than lime alone. In addition, a better growth of the sedge plants was visually observed in the soil desalinating with $CaCO_3$. This agrees with Herrera and Pérez (2020) who found that liming improves soil pH, availability of P, Ca, Mg and K, in the same way, the development and yield of tomato crop with doses of up to 3 t/ha of lime on the soil is improved. An added advantage relates to better availability of some macro- and micronutrients after soil amelioration that involved cropping and leaching compared to leaching alone also found by Qadir *et al.* (2007).

In summary, the results showed that using $CaCO_3$, Na^+ exchange in the soil decreased along with some soil salinity characteristics such as ECe, increased Ca^{2+} exchange, decreased ESP and SAR of the soil, which are consistent with that reported by many previous studies (Herrera and Pérez, 2020; Filho *et al.*, 2020; Das and Saha, 2014). Although cropping duration amelioration of saline soils is a common practice, only a few crops can tolerate high ambient salinity levels (Qadir *et al.*, 2007; Mass and Hoffman, 1977; Ameyu, 2019). The three sedge plants used in this study showed good performance in terms of growth, biomass and salinity reduction.

It is concluded that application of $CaCO_3$ in saline soil reclamation, better chemical conditions were achieved, the pH was increased, which resulted in improvement of P, Ca, Mg and K, which were used by the sedge plants. Liming and phytoremediation using in saline soil reclamation were effective combination providing a better reduction of ECe, Na_{ex}, SAR and ESP in the soil. Leaching efficiency was variable among the three sedge plants being in the order: *L. articulata* > *T. orientalis* > *S. littoralis*.

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