

# Effect of Salinization by NaCl on the Growth of African Palm (*Elaeis guineensis* Jacq)

LUIS ALEMAN<sup>1</sup>, ENRIQUE COMBATT<sup>1\*</sup>, ALVARO ARRIETA<sup>2</sup>

<sup>1</sup> Faculty of Agricultural Science, University of Cordoba, Road 6 No. 76-103, Monteria, Colombia

<sup>2</sup> Department of Biology and Chemistry, University of Sucre, Red Door neighborhood, Sincelejo, Colombia

**Abstract:** It is necessary to know the effect of excessive salinity in the soil on the growth of the African palm crop. The objective of the work was to evaluate the effect of salinity caused by NaCl on the growth and absorption of nutrients in the oil palm crop in early growth stage. The research was carried out in the laboratories of the University of Córdoba, where the 16 kg experimental units were made up of a mixture of alluvium and rice husk in a ratio of 4: 1. A complete randomized design was used with six treatments and a control (0.0, 0.5, 1.0, 1.5, 2.5, 3.6, and 6.1 cmolc kg<sup>-1</sup> Na) and four repetitions. The data were statistically analyzed by analysis of variance and regression. The results report that the salinity in the soil that originates with the application of 2.5 cmolc kg<sup>-1</sup> of Na produces in the soil an electrical conductivity (EC) of 1.96 dS m<sup>-1</sup>. Consequently, a drastic reduction in the quantified biomass of dry mass of stem, leaf, roots, rachis and leaf area originates, and the models that express this trend were adjusted to decreasing linear regressions with their highly significant parameters. Salinity interferes with the absorption of nutritional elements, such as N, K<sup>+</sup> and Mg<sup>2+</sup>, and foliar nitrogen is the nutrient with the highest sensitivity to variations in EC in the soil. Foliar phosphorus (P) and calcium (Ca) concentrations were not affected by salinity levels.

**Keywords:** chemical elements, cultivation, deficiency, physiological stress, toxicity

## 1. Introduction

The chemical degradation of the soil is an important factor that affects the demand and production of food in the world. Currently, 20% of arable land and 50% of irrigated land in the world have been affected to varying degrees by soil salinization [1]. According to the FAO, is estimated that over 400 million hectares on the planet are affected by salts [2].

This increase is caused by both natural phenomena such as low precipitation and high evapo-transpiration, and among the anthropic ones there are those caused by the improper use of agricultural practices with high application of chemical fertilization, irrigation with water that has excess salts, poor drainage and cutting of tree vegetation [3]. Bartels and Sunkar estimate by the 2050, that 50% of the world's arable land will be affected by salinity as a consequence of these phenomena [4]. Saline stress is capable of causing significant decreases in the growth and development of the cultivation of African palms, and in seedlings of *Elaeis guineensis* Jacq subjected to increases in salinity levels [5].

The saline soils solution is made up of a range of dissolved salts, but NaCl is the most prevalent salt and has been the focus of much work on salinity [6, 7] The increase in NaCl induces an increase in Na<sup>+</sup> and Cl<sup>-</sup> and a decrease in the leaves of Ca<sup>2+</sup>, K<sup>+</sup> and Mg<sup>2+</sup> in several plants [8]. The accumulation of salt in the root zone causes the development of osmotic stress and interrupts the homeostasis of cell ions by inducing both the inhibition in the uptake of essential elements such as K<sup>+</sup>, Ca<sup>2+</sup> and NO<sub>3</sub><sup>-</sup> and the accumulation of Na<sup>+</sup> and Cl<sup>-</sup>, down to potentially toxic levels within cells [9].

The saline-alkaline stress can affect the synthesis of chlorophyll and the photosynthetic capacity of plants, which results in decreased cell turgor, as well as affecting root and leaf growth rates [10, 11]. The inefficient economy of water in plants grown in saline conditions occurs due to the appearance of a state of physiological drought, which is due to high concentrations of salts in the soil [12]. Therefore, the objective was to evaluate the effect of salinity on the growth and absorption of nutrients in the oil palm crop in the early growth stage.

\*email:emcombatt@correo.unicordoba.edu.co

## 2. Materials and methods

The study was carried out in the vegetation house of the Faculty of Agricultural Sciences of the University of Cordoba. A substrate sample was collected from the substrate used, alluvium and rice husk in a 1:1 ratio, and a chemical analysis was carried out according to the analytical methods (I.G.A.C., 2006) [13] described below: pH by the potentiometric method; organic matter (M.O.) by the Walkley-Black method. Phosphorus (P) by Bray II and quantified by colorimetry, sulphur (S) extracted with monobasic calcium phosphate and determination by turbidimetry in a Perkin Elmer Lambda XLS.

Interchangeable bases such as Ca, Mg, Na and K by extraction with ammonium acetate, pH 7.0. Calcium and magnesium were quantified by atomic absorption, but the Na and K by atomic emission spectrophotometry. The Cu, Fe, Zn and Mn elements determined by the dilute double acid method and quantified by atomic absorption in Perkin Elmer 3110 equipment. The electrical conductivity (EC) was carried out in saturation paste. In Table 1 are shown the initial chemical characteristics of the substrate used before applying the treatments. The study was developed with seeds of the *Elaeis guineensis* Jacq material (Djongo: Mongana X Ekona), which was acquired by Fedepalma [14]. Initially, the seeds were pre-germinated and then the nursery phase was carried out for 2.5 months, to rule out seedlings with genetic problems. Parallel to the nursery phase, plastic bags with a capacity of 16 kg of the substrate (EU) were filled.

**Table 1.** Initial chemical characteristics of the substrate used before applying the treatments

pH	M.O	S	P	Ca	Mg	K	Na	CIC	Cu	Fe	Zn	Mn	EC
1:1	%	mg kg <sup>-1</sup>		cmolc kg <sup>-1</sup>					mg kg <sup>-1</sup>				dS m <sup>-1</sup>
6.90	0.9	32.2	1.61	5.5	10.3	0.21	0.49	16.5	3.2	75.2	0.9	78.3	0.80

pH: soil-water ratio 1:1, MO: Walkley-Black, S: monobasic calcium phosphate 0.008 mol L<sup>-1</sup>, P: Bray II, Ca-Mg-K-Na: Ammonium acetate 1.0 mol L<sup>-1</sup> at pH 7.0, CICE: sum of bases, Cu-Fe-Zn-Mn: double acid.

In these bags, the treatments equivalent to different doses of sodium were applied as NaCl: 0.5; 1.0; 1.5; 2.5; 3.6 and 6.1 cmolc kg<sup>-1</sup> Na<sup>+</sup>. These treatments plus a control without Na (0), were incubated for a period of 25 days, to allow chemical reactions between the treatments and the substrate. Later and after this time, the plants were transplanted to each experimental unit.

The research was carried out in a complete randomized design with six treatments plus one control and four replications, for a total of 28 experimental units, which were organized inside a greenhouse in 0.3 x 0.3 m squares between bags. Soil moisture was maintained by applying the amount of water lost, initially every three days and subsequently, it was applied daily based on evapotranspiration, achieving humidity close to 80% of field capacity. After 225 days of applying the treatments, samples of the substrate of 1 kg were collected for each treatment to determine the reaction of the soil (pH), the EC and the sodium content. In addition, the physiological variables of plant height, basal bulb diameter and dry matter of stem, roots, leaves and rachis were quantified, which were separated by organ and dried in a Binder ED-53 stove, for 72 h with forced air circulation at 70±5°C. Likewise, the total leaf area for each experimental unit was evaluated through digital processing with DDA software, coupled to the HP ScanJet 3400 C scanner.

Finally, to evaluate the nutrient concentration, samples were collected in leaf tissue of level 3, which were dried, ground and sieved through a 0.5 mm mesh. For nitrogen (N) 0.5 g of sample were subjected to the Kjeldahl method, with a digestion in sulfuric acid (10 mL of H<sub>2</sub>SO<sub>4</sub>). For the rest of the nutritional elements, 0.3 g of sample was digested wet with 10 mL of HNO<sub>3</sub>. S and P were quantified on a molecular absorption spectrophotometry team, Perkin Elmer Lambda XLS. Ca<sup>2+</sup>, K<sup>+</sup>, Mg<sup>2+</sup> and Na<sup>+</sup> were made using an atomic absorption and emission spectrophotometer Perkin Elmer 3110 [13]. The data obtained from each variable were subjected to an analysis of variance (ANOVA) and the treatment averages were compared using the Tukey test ( $P \leq 0.05$ ). In addition, regressions were performed to calculate the maximum resistance salinity doses using the R Project for Statistical Computing statistical package. The adjustment coefficient R<sup>2</sup>, the coefficient of variation and the statistical significance of the coefficients

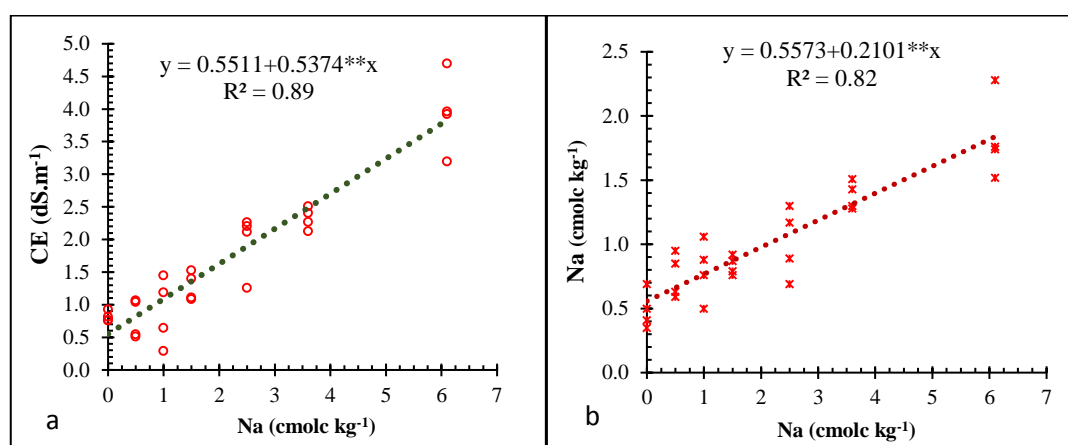
( $\beta_0$  and  $\beta_1$ ) of the models were taken as the adjustment parameter.

### 3. Results and discussions

#### 3.1. Soluble sodium and final electrical conductivity in the substrate of the experimental units

By increasing the concentration of NaCl in the treatments, it was found that in the soil solution, sodium and electrical conductivity increased in response to the applied NaCl. Likewise, and due to the increase in the concentration of the treatments, it was found that the mathematical models that explain the treatment trends were increasing linearly for  $\text{Na}^+$  and EC ( $P \leq 0.05$ ). These models predict that when one  $\text{cmolc kg}^{-1}$  of Na is applied to the substrate, there is an increase of 0.21  $\text{cmolc kg}^{-1}$  Na and 0.537  $\text{dS m}^{-1}$  in the soil EC (Figure 1).

These results that are explained by the gain of ions such as  $\text{Na}^+$  and  $\text{Cl}^-$  in the soil solution, caused by the dissociation of NaCl and the permanence of these ions in solution. Bosch and Slabu found a positive correlation ( $r = 0.61$ ) between the  $\text{Na}^+$  and EC contents and the increase in  $\text{Na}^+$  and  $\text{Cl}^-$  when NaCl is applied to the soil [8, 15].



\*\* and \*, indicate the significance of the coefficients with probability of 1 and 5% respectively. ns, not significant.

**Figure 1.** Response of the NaCl application in the  $\text{Na}^+$  and EC concentrations of the soil planted with African palm seedlings in early stages of development

#### 3.2. Effect of salinity on crop growth variables

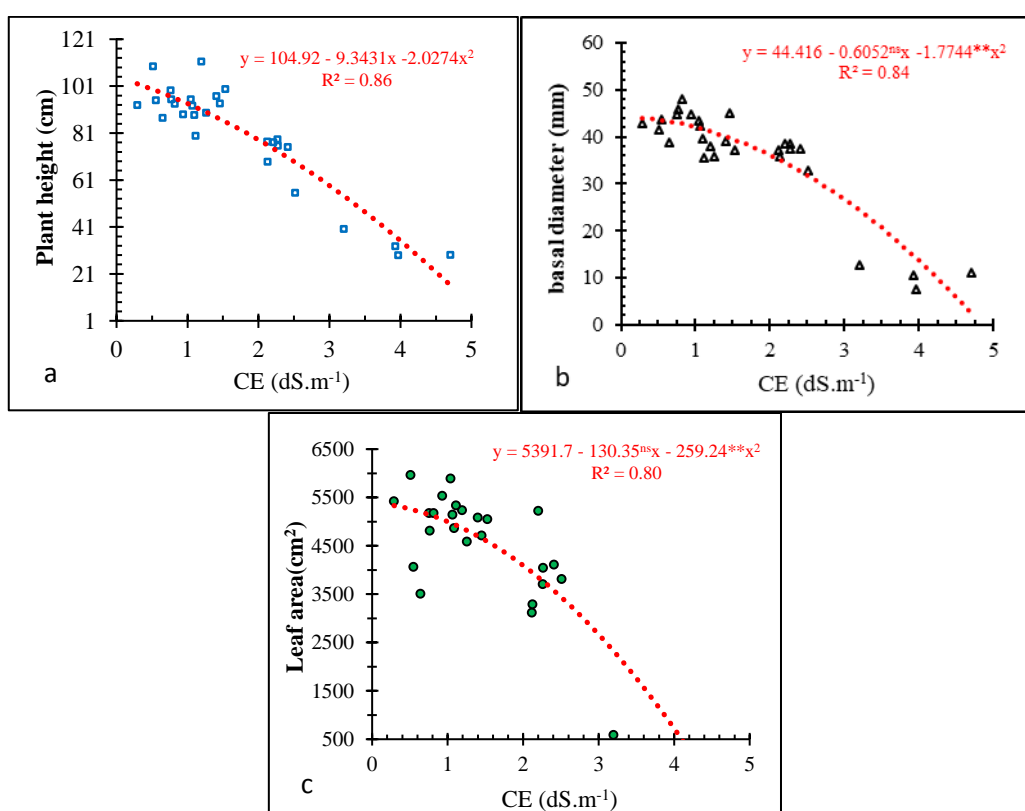
According to Table 2, there are significant statistical differences ( $P \leq 0.05$ ) when salinity (EC) was increased in the development of plant height, basal bulb diameter and leaf area. These are results that were a consequence of the addition of NaCl treatments that provides an excess of Na and Cl, and an increase in EC in the soil. Likewise, the greatest reductions in the development of these variables were presented, when doses greater than 2.5  $\text{cmolc kg}^{-1}$  of Na were applied. A high concentration of salts causes an ionic imbalance in the cytosol and reduces the osmotic potential at the plant cell level, which causes an inadequate assimilation of nutrients such as  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{NO}_3^-$  and as a consequence a reduction in growth parameters [16, 17].

Furthermore, when performing the regressions to determine the effect of NaCl on the EC, it was found that when there was an increase between 1.96 and 3.95  $\text{dS m}^{-1}$ , the seedlings had a 59.4% reduction in plant height. For basal bulb diameter, there was a reduction of 71% when EC levels reached 3.2  $\text{dS m}^{-1}$ . However, the data also shows that this variable was affected from 2  $\text{dS m}^{-1}$ . Likewise, for the leaf area, when 2  $\text{dS m}^{-1}$  appear in the soil, there is a reduction of 1297  $\text{cm}^2$ , which represents 24% of the total leaf area of the *Elaeis guineensis* Jacq palm crop (Djongo: Mongana X Ekona) in early stages of growth (Figure 2).

**Table 2.** Effect of sodium treatments on growth parameters in oil palm crop in early growth stages

Treatments		CE	Ap	Db	Af
Na cmolc kg <sup>-1</sup>		dS m <sup>-1</sup>	----- (cm)-----		----- g -----
T1	0	0.81 ± 0.08 a	94.3 ± 4.3 a	45.9 ± 1.6 a	5176 ± 294 ab
T2	0,5	0.79 ± 0.30 a	98.2 ± 7.6 a	42.8 ± 1.0 ab	5266 ± 883 a
T3	1,0	0.89 ± 0.52 a	96.5 ± 10.4 a	41.2 ± 3.4 cb	4720 ± 861ab
T4	1,5	1.28 ± 0.21 ab	91.3 ± 8.9 a	37.8 ± 1.9 cd	5085 ± 191 ab
T5	2,5	1.96 ± 0.47 bc	80.7 ± 6.0 ab	37.6 ± 1.3 cd	4159 ± 931 ab
T6	3,6	2.32 ± 0.16 c	68.8 ± 9.3 b	35.9 ± 2.1 d	3815 ± 374 d
T7	6,1	3.94 ± 0.61 d	32.8 ± 5.3 c	10.4 ± 2.2 e	334 ± 182 e
ANOVA (F probability)					
MSE		0.15	59.3	4.2	3.839.42
MSTTO		5.286	2193,7	554,9	12.088,569
pr(>F)		6.51e-10 ***	4.19e-10 ***	1.39e-15 ***	1.89e-09***

EC: electrical conductivity, Ap: plant height, Db: package diameter, Af: leaf area. **MSE**: mean square of the error, **MSTTO**: mean square of the treatments. Lowercase letters vertically indicate significant differences according to Tukey P <0.05



\*\* and \*, indicate the significance of the coefficients with probability of 1 and 5% respectively. ns, not significant

**Figure 2.** Effect of salinization on growth parameters in African palm crop subjected to an increase in the electrical conductivity of the soil

The significant reductions of these variables are the result of the effect of NaCl on the hydric dynamics of the soil, by influencing the decrease in the osmotic potential that causes a detriment in the water absorption capacity (Figure 2). In addition, the absorption of essential nutrients that are necessary for metabolic and physiological functions for the growth and development of this crop is affected. Ovie demonstrated that the increase in salinity levels causes significant reductions ( $p < 0.05$ ) in height, leaf area, number of leaves and stem thickness in seedlings of *Elaeis guineensis* Jacq [18]. Also, Mohamed and Glenn found in palm date (*Phoenix dactylifera* L.), significant decreases in seedling growth after 5.0 meq.100 g<sup>-1</sup> of Na<sup>+</sup> in the soil [19].

Similarly, in these conditions there is an excessive concentration of specific ions, such as Na and Cl,

which are absorbed through the transpiration current and cause phytotoxicity when the levels are excessive. This can cause blockage of vital cellular metabolic processes, such as respiration, stomatal conductance, and photosynthesis. In NaCl, Na is the primary toxic ion, since it interferes with the absorption of K and disrupts efficient stomatal regulation, leading to water loss and necrosis [8]. Also, Cl<sup>-</sup> induces chlorotic toxicity due to degradation of chlorophyll. African palm is susceptible to salinity, due to biochemical processes that lead to the loss of ionic selectivity [12]. Therefore, there is permeability of Na<sup>+</sup> and Cl<sup>-</sup> ions towards the interior of the cell and the absorption of other osmoregulatory ions. Furthermore, Parihar and Sanjib found that high Na<sup>+</sup> content in the soil influences carbon fixation, exposing chloroplasts to excessive excitation energy, which in turn increases the generation of reactive oxygen species [12, 20, 21].

### 3.3. Effect of treatments on biomass dry parameters

According to table 3, there are significant statistical differences ( $P \leq 0.05$ ) on the biomass gain of the plant organs, root dry mass (RDM), stem dry mass (SDM), leaf dry mass (LDM) and dry rachis mass (DRM). When applying the NaCl treatments, it was found that since the T5 treatment with 2.5 cmolc kg<sup>-1</sup> of Na and which corresponds to an EC of 1.96 dS m<sup>-1</sup> of the substrate, a drastic reduction in the biomass of the plant organs occurred in study. According to Tester and Devenport a high concentration of salts causes an inadequate assimilation of nutrients such as K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and NO<sub>3</sub><sup>-</sup> and as a consequence there is an imbalance in cell turgor, reduction in cell expansion, decrease in cell wall synthesis and protein synthesis reduction [22, 23].

**Table 3.** Dry matter yield of biomass in oil palm subjected to different doses of Na in early stages of growth

Treatments		EC	RDM	SDM	LDM	DRM
Na cmolc kg <sup>-1</sup>		dS m <sup>-1</sup>	g			
T1	0	0.81 ± 0.08 a	31.0 ± 2.6 ab	41.8 ± 2.8 a	43.4 ± 1.6 a	17.7 ± 2.7 a
T2	0.5	0.79 ± 0.30 a	39.5 ± 1.0 a	38.0 ± 3.4 ab	38.2 ± 1.3 ab	13.7 ± 3.5 ab
T3	1.0	0.89 ± 0.52 a	27.5 ± 6.7 bc	31.9 ± 4.9 bc	34.9 ± 6.2 ab	13.3 ± 2.5 ac
T4	1.5	1.28 ± 0.21 ab	31.1 ± 3.5 ab	28.2 ± 4.6 cd	33.1 ± 3.7 bc	11.2 ± 1.8 bcd
T5	2.5	1.96 ± 0.47 bc	20.2 ± 6.7 cd	23.6 ± 1.9 de	25.8 ± 4.1 cd	8.6 ± 1.0 cd
T6	3.6	2.32 ± 0.16 c	13.4 ± 6.4 d	18.0 ± 3.6 e	21.0 ± 5.4 d	7.5 ± 0.8 d
T7	6.1	3.94 ± 0.61 d	1.1 ± 0.2 e	0.5 ± 0.1 f	2.2 ± 1.2 e	0.3 ± 0.1 a
			ANOVA (F probability)			
MSE		0.15	21.6	11.7	14.7	4.4
MSTTO		5.286	453	769.2	753.9	124.6
pr(>F)		6.51e-10 ***	2.18e-09 ***	1.54e-12 ***	1.81e-11 ***	5.04e-09 ***

EC: electrical conductivity, RDM: root dry mass, DSM: stem dry mass, LDM: leaf dry mas, DRM: dry rachis mass, MSE: mean square of the error, MSTTO: mean square of the treatments. Lowercase letters vertically indicate significant differences according to Tukey P < 0.05.

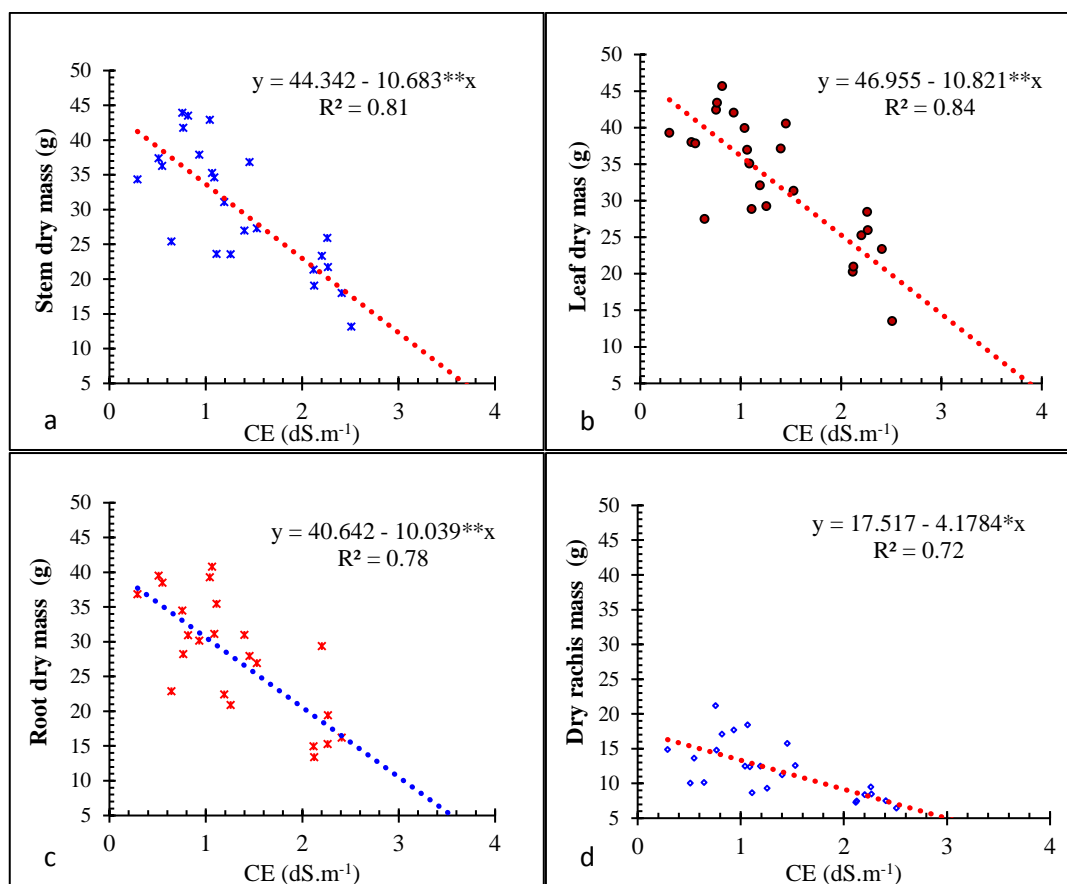
The salinity caused by NaCl reduced the biomass production in dry mass of stem, leaves, root and rachis ( $p < 0.01$ ). Under these conditions, by increasing 1 dS m<sup>-1</sup> the EC reduced the gain in dry matter of these organs (Figure 3 a, b, c y d). For the dry masses of stem, leaves and root, reductions of 25, and 26% were found. Likewise, if the electrical conductivity is increased in soils by 3 dS m<sup>-1</sup>, the reduction in dry mass gain of these organs would be reduced by 73, 70, 75 and 72%. The Figure 3 shows the results obtained using the best fit equations ( $p < 0.05$ ): stem  $\hat{Y} = 44.342 - 10.683^{**}X$ , leaves,  $\hat{Y} = 46.955 - 10.821^{**}X$ , roots  $\hat{Y} = 40.642 - 10.039^{**}X$ , and  $\hat{Y} = 17.517 - 4.178^{**}X$  for rachis.

These results are explained by the high concentration of Na<sup>+</sup> and Cl<sup>-</sup> in the soil, which produce a decrease in the osmotic and water potentials, generating an effect similar to a lack of water in the soil. Stomatal closure resulting from a water deficit can lead to a reduction in CO<sub>2</sub> acquisition and photo-



synthesis that directly influences plant growth [24, 25]. Understanding the mechanisms of stress injury, adaptation, and acclimatization of plants is essential for future agricultural development.

According to Gong the concentration of salts in the soil negatively affects the biomass production in plants sensitive to salinity [10]. Likewise, Ovie and Sperling were able to demonstrate that saline stress is capable of causing significant reductions in the growth of oil palm seedlings [18, 26].



\*\* and \*, indicate the significance of the coefficients with probability of 1 and 5% respectively. ns, not significant.

**Figure 3.** Effect of salinization on the dry matter of the stem, leaves, root and rachis, in African palm seedlings in early stages of growth

### 3.4. Effect of sodium on the nutritional content of the crop leaf

The percentage of nutritional elements in the oil palm leaves (Table 4) was different between the applied treatments, finding that there are significant statistical differences ( $P \leq 0.05$ ) in the N, K and Na. However, the accumulated amounts of P, Ca and Mg in the leaf tissue were not affected. The treatments that most affected the assimilation of N, K and Na were when 3.6 and 2.5 cmolc kg<sup>-1</sup> of Na was applied, which are equivalent in this investigation to 2.32 and 1.96 dS m<sup>-1</sup>. According to Tester under conditions of severe salinity that provide Na<sup>+</sup> and Mg<sup>2+</sup>, the absorption of essential nutrients is unbalanced. Therefore, there are nutritional deficiencies in Ca<sup>2+</sup> and K<sup>+</sup> that cause alterations in the metabolism of the crops [22].

**Table 4.** Nutritional content of oil palm leaves subjected to different doses of Na in early stages of growth

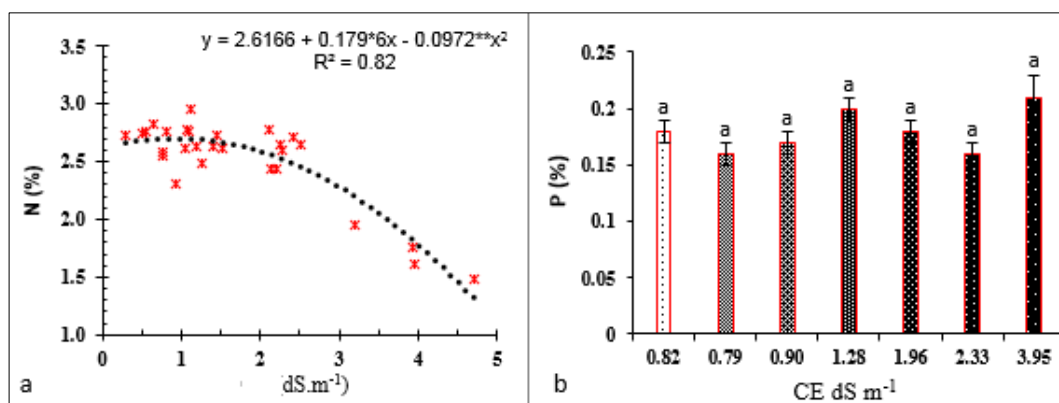
Treatments		CE	N	P	K	Ca	Mg	Na
Na cmole kg <sup>-1</sup>		dS m <sup>-1</sup>	----- % -----					
<b>T1</b>	0	0.81 ± 0.08 a	2.6 ± 0.18 a	0.18 ± 0.01 a	1.43 ± 0.03 a	0.73 ± 0.09 a	0.47 ± 0.04 a	0.021 ± 0.01bc
<b>T2</b>	0.5	0.79 ± 0.30 a	2.7 ± 0.08 a	0.16 ± 0.01 a	1.26 ± 0.07 ab	0.68 ± 0.11 a	0.50 ± 0.03 a	0.023 ± 0.01 c
<b>T3</b>	1.0	0.89 ± 0.52 a	2.6 ± 0.08 a	0.17 ± 0.01 a	1.20 ± 0.07 ab	0.75 ± 0.07 a	0.52 ± 0.03 a	0.031 ± 0.01 ac
<b>T4</b>	1.5	1.28 ± 0.21 ab	2.7 ± 0.15a	0.20 ± 0.01 a	1.17 ± 0.02 b	0.73 ± 0.14 a	0.54 ± 0.03 a	0.035 ± 0.01 ac
<b>T5</b>	2.5	1.96 ± 0.47 bc	2.5 ± 0.15a	0.18 ± 0.01 a	1.19 ± 0.08 b	0.58 ± 0.05 a	0.54 ± 0.07 a	0.053 ± 0.01 a
<b>T6</b>	3.6	2.32 ± 0.16 c	2.4 ± 0.11 a	0.16 ± 0.01 a	1.20 ± 0.08 ab	0.49 ± 0.18 a	0.65 ± 0.03 a	0.048 ± 0.01 ab
<b>T7</b>	6.1	3.94 ± 0.61 d	1.4 ± 0.2 b	0.14 ± 0.02 a	1.14 ± 0.08 b	0.48 ± 0.07 a	0.59 ± 0.1 a	0.035 ± 0.01 ac
<b>ANOVA (F probability)</b>								
<b>MSE</b>		0.15	0.0996	0.0008762	0.01018	0.01719	0.01084	0.0001286
<b>MSTTO</b>		5.286	0.7794	0.0016071	0.03807	0.0548	0.01418	0.0007571
<b>pr(&gt;F)</b>		6.51e-10 ***	0.00016 ***	0.141 ns	0.0109 *	0.022 ns	0.297 ns	0.000992 ***

EC: electrical conductivity, MSE: mean square of the error, MSTTO: mean square of the treatments. Lowercase letters vertically indicate significant differences according to Tukey P < 0.05. \*\*\*: Indicate highly significant differences. ns: indicates that there are no statistical differences.

The nitrogen concentration in the leaf tissue decreased, as a consequence of the exposure time and increased electrical conductivity (Figure 4a). This figure shows that the decreasing quadratic model,  $\hat{Y} = 2.5955 + 0.2037^{ns}x - 0.1129x^2$  predicts that the N levels do not exceed 2.84% when the electrical conductivity is greater than 0.5 dS m<sup>-1</sup> and by increasing the EC to 1.2 dS m<sup>-1</sup> the content of N is reduced to 2.3%, which is considered adequate when compared with the results of foliar N in oil palm of 2.63 to 2.85%, 2.24 to 2.97% and 2.24 to 2.97% obtained by others authors [27, 28].

The significant reduction in the absorption of the essential chemical elements is caused by the high osmotic potential that affects the assimilation of water, which reduces the absorption of N by mass flow. Villa state that the reductions are due to an antagonism between Cl<sup>-</sup> and NO<sup>3-</sup>, due to a restriction in the activity of the nitrate transporter [29]. Sanjib found in oil palm, that osmotic stress is capable of causing degradation in photosynthetic pigments (Chlorophyll a and b) [21].

The concentration of P in the leaf tissue did not show significant differences with the increase in the EC of the soil (Figure 4b). According to the results, the P contents ranged from 0.14 to 0.18% at the different ECs that were presented in this investigation. Therefore, in these conditions of high electrical conductivity, there was no antagonism with the assimilation of this essential element. According to Behera, the critical ranges for this species are between 0.08 and 0.14%, and 0.13 and 0.16 respectively [27]. Therefore, the concentrations of P found in this investigation are classified as optimal in seedlings in this stage of development. However, there are many reports that indicate that salinity generates a suppression of P absorption, especially due to the deterioration of the root system [30]. On the other hand, Zribi explains that salinity does not have a substantial impact on P concentrations in plants [31].



\*\* and \*, indicate significance of the coefficients with probability of 1 and 5% respectively. ns, not significant

**Figure 4.** Effect of salinization on nitrogen and phosphorus concentration in African palm seedlings subjected to increased electrical conductivity

In this research, the stress caused by the increase in EC reduced the concentration of Na and K in the tissues of the African palm crop (Figure 5b,c,d). Explained by the increase of the sodium ion in the soil what can cause nutritional imbalances that alter the absorption of essential chemical elements. In these edaphological environments, the equation  $\hat{Y} = 1.302 - 0.0416 * x$  ( $p < 0.05$ ), predicts the absorption of K under these conditions and through this model it was determined that by increasing 1 dS m<sup>-1</sup> the foliar contents of K are reduced at 0.06% (Figure 5). However, the K contents found are considered optimal, regardless of the CE levels that were evaluated in the substrates. Sanjib, in oil palm plantations found levels of 0.48–0.88% for K that was established as optimal [21]. According to Zörb, the K have key functions in physiological processes, enzymatic activation and osmoregulation [32].

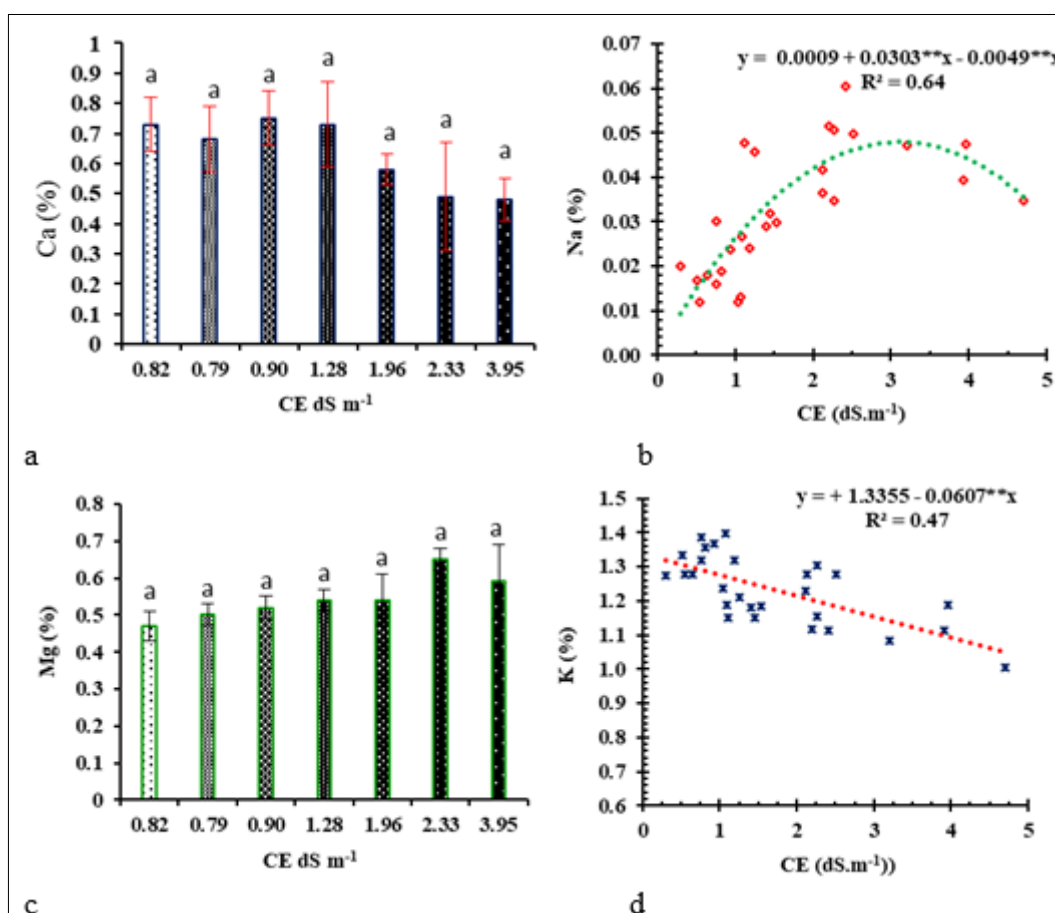
Likewise, for Na the model was  $y = 0.0009 + 0.0303^{**}x - 0.0049^{**}x^2$  and it was established that the maximum absorption of 0.06% was presented at 3.3 dS m<sup>-1</sup>. The significant decrease in essential elements can be attributed to Na toxicity in metabolic processes. These result from the ability of Na to compete with K for binding sites and inactivate essential cellular functions and enzymes, and consequently, crops grown in saline soils can suffer double injury. The first is Na toxicity, in addition to low K concentrations [33].

On the other hand, the contents in the vegetal tissue Ca and Mg (Figure 5a,b,c) did not present differences between the electrical conductivities. According to the results, the Ca contents ranged between 0.48 and 0.73% and for Mg between 0.47 and 0.65% respectively. These contents are generally lower or higher, when compared with the values found by different researchers. According to Behera the contents of Ca and Mg vary between 0.74 to 1.53% and 0.25 to 0.98% [27]. Also, Behera found contents between 1.01 and 1.79 for Ca and Mg from 0.34 to 0.84% [28] and Sanjib in Ca of 0.66–2.66% and Mg of 0.10–1.03% [21]. Therefore, in these conditions of high electrical conductivity, it is necessary to know the information regarding the nutritional status of the leaves in oil palm plantations, as regards foliar diagnosis and management. Results that are due to the Na content in the soil solution, which can alter the Ca/Na and Mg/Na ratios, caused by the probable antagonism by the absorption sites in the roots, which causes the high concentration of Na in the solution from the soil and inside the cell [33]. Mohamed and Glenn argue that the high concentration of Na<sup>+</sup> is capable of displacing the Ca ions from the cell membrane binding sites in the root [19] and Rahman found that salinity decreases the accumulation of Ca<sup>2+</sup> in plants [34]. According to Zheng, the germination, pollen tube growth and root lengthening increases with optimal and higher Ca<sup>2+</sup> contents [35]. Likewise, Mg has important functions in the physiological and biochemical processes in the plant, such as enzymatic activation, photosynthesis and osmoregulation [32].

Likewise, the Na ion is not an essential element, but it is observed that increasing the EC to higher contents of 2.9 dS m<sup>-1</sup> decreases the absorption capacity of Na<sup>+</sup> in oil palm plants. Results coincide with those reported by Sperling, who found a positive response between the edaphic and foliar sodium concentration. However, at high amounts there is a blockage of metabolic functions, due to the high salt



concentrations in the soil that induce dehydration of the plant [36].



\*\*and \* indicate the significance of the coefficients with probability of 1 and 5% respectively. ns, not significant.

**Figure 5.** Effect of substrate salinization on the concentration of calcium, potassium, magnesium and sodium in African palm seedlings subjected to an increase in electrical conductivity

## 4. Conclusions

From the above study, it has been concluded that the increase in salinity in the soil by NaCl caused a decrease in the dry mass yields of stem, leaf, roots, rachis and leaf area, due to the phytotoxicity generated by the high concentrations of Na and Cl that are absorbed by the African palm cultivation. Through the use of mathematical models, it was found that the equations that demonstrate the effect of Na and Cl on the evaluated physiological variables were adjusted to decreasing linear regressions, with highly significant coefficients. The evaluation of the effect of salinity on the mineral nutrition of the African palm crop yielded new results, which indicate that Na and Cl can affect the absorption of nutritional elements, such as  $\text{N}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  and nitrogen is the nutrient with the highest sensitivity to variations in EC in the soil. Due to the phytotoxic effect of salinity, foliar concentrations of phosphorus at different degrees of salinity presented adequate levels, with a maximum of 0.20% at conductivities of  $2.5 \text{ dS m}^{-1}$ , however it shows a clear quadratic decrease from  $3.0 \text{ dS m}^{-1}$ .

**Acknowledgments:** The authors Acknowledgment the Cordoba University for financial support.

## References

1. BHATNAGAR-MATHUR, P., VADEZ, V., SHARMA, KK. Transgenic approaches for abiotic stress tolerance in plants: retrospect and prospects. *Plant Cell Reports*, **27**(3), 2008, 411-424.  
<https://doi.org/10.1007/s00299-007-0474-9>.

- 2.\*\*\*FAO. Global network on integrated soil management for sustainable use of salt-affected soils. Rome, Italy: FAO Land and Plant Nutrition Management. 2000.
- 3.MINHAS, PS. Saline water management for irrigation in India. *Agricultural Water Management*, **30(1)**, 1996, 1-24. [https://doi.org/10.1016/0378-3774\(95\)01211-7](https://doi.org/10.1016/0378-3774(95)01211-7).
- 4.BARTELS, D., SUNKAR, R. Drought and salt tolerance in plants. *Crit. Rev. Plant Sci.*, **24**, 2005, 23-58. <https://doi.org/10.1080/07352680590910410>.
- 5.OKOLO, CC., OKOLO, EC. NNADI, AL., OBIKELU, FE., OBALUM, SE., IGWE, CA. The oil palm (*Elaeis guineensis* Jacq): nature's ecological endowment to eastern Nigeria. *Agro-Science*, **18(3)**, 2019, 48-57. <https://doi.org/10.4314/as.v18i3.9>.
- 6.GHOSH, B., ALI, MN., GANTAIT, S. Response of rice under salinity stress: a review update. *J. Res. Rice*, **4(2)**, 2016, 1-8. <https://doi.org/10.4172/2375-4338.1000167>.
- 7.HOANG, TML., WILLIAMS, B., KHANNA, H., DALE, J., MUNDREE, SG. Physiological basis of salt stress tolerance in rice expressing the anti- apoptotic gene SfiAP. *Funct. Plant Biol.*, **41(11)**, 2014, 1168-1177. <https://doi.org/10.1071/fp13308>.
- 8.SLABU, C., ZÖRB, C., STEFFENS, D., SCHUBERT, S. Is salt stress offaba bean (*Vicia faba*) caused by Na<sup>+</sup> or Cl<sup>-</sup> toxicity. *Journal of Plant Nutrition and Soil Science*, **172**, 2009, 644-650. <https://doi.org/10.1002/jpln.200900052>
- 9.MEMON, SA., HOU, X., WANG, LJ. Morphological analysis of salt stress response of pak Choi. *Electron. J. Environ. Agric. Food Chem.*, **9(1)**, 2019, 248-254.
- 10.GONG, B., WEN, D., VANDENLANGENBERG, K., WEI, M., YANG, F., SHI, Q., ET AL. Comparative effects of NaCl and NaHCO<sub>3</sub> stress on photosynthetic parameters, nutrient metabolism, and the antioxidant system in tomato leaves. *Scientia Horticulturae*, **57(3)**, 2013, 1-12. <https://doi.org/10.1016/j.scienta.2013.03.032>
- 11.GUO, R., ZHOU, J., REN, GX., HAO, W. Physiological responses of linseed seedlings to iso-osmotic polyethylene glycol, salt, and alkali stresses. *Agronomy Journal*, **105(3)**, 2013, 764-72. <https://doi.org/10.2134/agronj2012.0442>
- 12.FIRMANSYAH, E. Growth and morphology of palm oil (*elaeis guineensis* jacq.) root under different waterlogging salinity. *Agroista Jurnal Agroteknologi.*, **1(2)**, 2017, 181-191.
- 13.INSTITUTO GEOGRÁFICO AGUSTÍN CODAZZI - IGAC. Métodos analíticos del laboratorio de suelos. Bogotá, Colombia: IGAC. (2006).
- 14.CASTRO J., F., CORLEY, V. Avances en el programa de investigación y desarrollo de semillas Unipalma DxP. *Revista Palmas*, 28(especial),2007, 227-233.
- 15.BOSCH, M., COSTA, JL., CABRIA, FN., APARICIO, VC. Relación entre la variabilidad espacial de la conductividad eléctrica y el contenido de sodio del suelo. *Ciencia del suelo*, **30(2)**, 2012, 95-105.
- 16.ACOSTA-MOTOS, J., ORTUÑO, M., BERNAL, A., DIAZ, P., SANCHEZ, M., HERNANDEZ, J. Plant responses to salt stress: adaptive mechanisms. *Agronomy*, **7(1)**, 2017, 18-56. <https://doi.org/10.3390/agronomy7010018>.
- 17.KHAMZINA, LJ., VLEK, P., Nitrogen fixation by *Elaeagnus angustifolia* in the reclamation of degraded croplands of Central Asia. *Tree Physiology*, **29(6)**, 2009, 799-808. <https://doi.org/10.1093/treephys/tpp017>.
- 18.OVIE, S., OKO-OBOH, E., OKORONKWO, TO., OKERE, RO., EKHORUTOMWEN, OE. Enhancement of Growth of Oil Palm Seedlings as Affected by Composted Oil Palm Bunch Wastes Under. *Nigerian journal of agriculture food and environment*, **11(3)**, 2015, 13-18.
- 19.MOHAMED, SA., GLENN, PE. Effect of Salinity on Growth of Twelve Cultivars of the United Arab Emirates Date Palm. *Communications in Soil Science and Plant Analysis*, **40**, 2009, 2372-2388. <https://doi.org/10.1080/00103620903111293>.
- 20.PARIHAR, P., SINGH, S., SINGH, R. Effect of salinity stress on plants and its tolerance strategies: a review. *Environmental Science and Pollution Research*, **22(6)**, 2014, 4056-4075. <https://doi.org/10.1007/s11356-014-3739-1>.

- 21.SANJIB, KB., ARVIND, KS., KANCHERLA, S., RAVI, KM. Estimation of soil properties and leaf nutrients status of oil palm plantations in an intensively cultivated region of India. *Current Science*, **117**(3), 2019, 497-502. <https://doi.org/10.18520/cs/v117/i3/498-502>.
- 22.TESTER, M., DAVENPORT, R. Na<sup>+</sup> tolerant and Na<sup>+</sup> transport in higher plants. *Annals of Botany*, **91**(5), 2003, 503-527. <https://doi.org/10.1093/aob/mcg058>.
- 23.GOMES, MAC., SATIKA, M., CUNHA, M., FERRANTE, C. Effect of salt stress on nutrient concentration, photosynthetic pigments, proline and foliar morphology of *Salvinia auriculata* Aubl. *Acta Limnologica Brasiliensia*, **23**(2), 2011, 164-176. <https://doi.org/10.1590/s2179-975x2011000200007>.
- 24.SHI, L., MENG, Z., WANG, Y., XU, M. Growth and photosynthetic characteristics of glycine gracilis seedlings under different types of saline stresses. *Pak. J. Bot.* **47**(3), 2015, 819-828.
- 25.ZOUAOU, R., AMMARI, Y., ABASSI, M., BEN, AHMED, HELA., SMAOUI, A., HILALI, K. Physiological and biochemical responses of rhus tripartita (Ucria) grande under water stress. *Pak. J. Bot.*, **51**(4), 2019, 1215-1221. [https://doi.org/10.30848/pjb2019-4\(22\)](https://doi.org/10.30848/pjb2019-4(22)).
- 26.SPERLING, O., LAZAROVITCH, N., SCHWARTZ, A., SHAPIRA, O. Effects of high salinity irrigation on growth, gas-exchange, and photoprotection in date palms (*Phoenix dactylifera* L., cv. Medjool). *Environmental and Experimental Botany*, **99**, 2013, 100-109. <https://doi.org/10.1016/j.envexpbot.2013.10.014>.
- 27.BEHERA, SK., MANOJA, K., RAO, BN., SURESH, K. Soil Nutrient Status and Leaf Nutrient Norms in Oil Palm (*Elaeis guineensis* Jacq.) Plantations Grown on Southern Plateau of India. *Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.*, **86**(3), 2015, 1-6. <https://doi.org/10.1007/s40011-015-0508-y>.
- 28.BEHERA, SK., RAO, BN., SURESH, K., RAMACHANDRUDU, K., MANORAMA, K. Soil fertility, leaf nutrient concentration and yield limiting nutrients in oil palm (*Elaeis guineensis*) plantations of Surat district of Gujarat. *Indian Journal of Agricultural Sciences*, **86**(3), 2016, 409-413.
- 29.VILLA-CASTORENA, M., CATALÁN, EA., INZUNZA, MA., ULERY, AL. Absorción y traslocación de sodio y cloro en plantas de chile fertilizadas con nitrógeno y crecidas con estrés salino. *Fitotecnica Mexicana*, **29**(1), 2006, 79-88.
- 30.PATIL, VA., CHAVAN, PD. Influence of salt stress on phosphorus metabolism in the roots and leaves of one month old *Prosopis juliflora* (Sw.) DC seedlings. *Pharmacognosy Journal*, **3**(25), 2011, 48-51. <https://doi.org/10.5530/pj.2011.25.9>.
- 31.ZRIBI, OT., SLAMA, I., TRABELSI, N., HAMDI, A., SMAOUI, A., ABDELLY, C. Combined effects of salinity and phosphorus availability on growth, gas exchange, and nutrient status of *Catapodium rigidum*. *Arid Land Research and Management*, **32**(3), 2018, 277-290. <https://doi.org/10.1080/15324982.2018.1427640>
- 32.ZÖRB, C., SENBAYRAM, M., PEITER, E. Potassium in agriculture - status and perspectives. *Journal of Plant Physiology*. **171**(9), 2014, 656-669. <https://doi.org/10.1016/j.jplph.2013.08.008>
- 33.MUNNS, R., TESTER, M. Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, **59**, 2008, 651-681. <https://doi.org/10.1146/annurev.arplant.59.032607.092911>.
- 34.RAHMAN, A., NAHAR, K., HASANUZZAMAN, M., FUJITA, M. Calcium supplementation improves Na<sup>+</sup>/K<sup>+</sup> ratio, antioxidant defense and glyoxalase systems in salt-stressed rice seedlings. *Frontiers in Plant Science*, **7**, 2016, 1-16. <https://doi.org/10.3389/fpls.2016.00609>.
- 35.ZHENG, R., SU, S., XIAO, H., TIAN, HQ. Calcium: A Critical Factor in Pollen Germination and Tube Elongation. *International journal of molecular sciences*, **20**(2), 2019, 1-12. <https://doi.org/10.3390/ijms20020420>.
- 36.SPERLING, O., LAZAROVITCH, N., SCHWARTZ, A., SHAPIRA, O. Effects of high salinity irrigation on growth, gas-exchange, and photoprotection in date palms (*Phoenix dactylifera* L., cv. Medjool). *Environmental and Experimental Botany*, **99**, 2014, 100-109. <https://doi.org/10.1016/j.envexpbot.2013.10.014>.

Manuscript received: 02.02.2021