EVIDENCE OF NITROGEN AND POTASSIUM LOSSES IN SOIL COLUMNS CULTIVATED WITH MAIZE UNDER SALT STRESS

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SUMMARY: The aim of this work was to evaluate the accumulation of salts in the soil from irrigation water and N and K from fertilization. The experiment was conducted in PVC columns (20 cm in diameter and 100 cm high), filled with sand, non-saline soil, grown with maize. The experiment was conducted in randomized block design in a 4 x 4 factorial, four salinity levels (0.5, 2.5, 5.0 and 7.5 dS m^{-1}) and four N rates, with five replicates. The four N rates, applied as urea and potassium nitrate, were as follows: N1: N recommendation for maize (2.6 g $column^{-1}$); N2: 0.3 times of recommendation N1 (0.78 g $column^{-1}$); N3 and N4: Reduced rate of N1 and N2, respectively, based on the evapotranspiration reduction caused by salinity. At 74 DAS the roots and soil samples were collected in different layers. The EC_e and the ions concentrations from irrigation water (Ca, Na and Cl) increased as a function of salinity and soil depth. The opposite was observed for the root system. The increase in salinity also resulted in K and NO_3^- accumulation in the soil column, mainly in higher N rates (N1 and N3). For the treatment of higher salinity (7.5 dS m^{-1}) and higher N rate (N1), it was observed that 88% of the NO_3^- was below 20 cm of the soil at the end of the experiment, evidencing a loss process by leaching.

KEYWORDS: salinity, nitrate, nutrients leaching

EVIDÊNCIAS DE PERDAS DE NITROGÊNIO E POTÁSSIO EM COLUNAS DE SOLO CULTIVADAS COM MILHO SOB ESTRESSE SALINO

RESUMO: Objetivou-se com o trabalho avaliar o acúmulo no solo de sais provenientes da água de irrigação e de N e K provenientes da adubação. O experimento foi conduzido em colunas de PVC (20 cm de diâmetro e 100 cm de altura), cheias de solo arenoso, não salino, cultivado com milho. Utilizou-se DBC com fatorial 4 x 4, quatro níveis de salinidade (0,5, 2,5, 5,0 e 7,5 dS m^{-1}) e quatro doses de N, com cinco repetições. As quatro doses de N, aplicadas como ureia e nitrato de potássio, foram as seguintes: N1: seguindo a recomendação N para o

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milho (2,6 g coluna-^{1}); N2: 0,3 vezes N1 (0,78 g coluna-^{1}); N3 e N4: Taxa reduzida de N1 e N2, respectivamente, com base na redução da evapotranspiração causada pela salinidade. Aos 74 dias após o plantio foram coletadas as raízes e amostras de diferentes camadas do solo. A CE_{es} e as concentrações íons provenientes da água de irrigação (Ca, Na e Cl) aumentaram em função da salinidade e da profundidade. O contrário foi observado no sistema radicular. O aumento da salinidade provocou o acúmulo de K e NO_3^- nas colunas de solo, principalmente nas maiores doses de N (N1 e N3). Para o tratamento de maior salinidade (7,5 dS m^{-1}) e maior dose de N (N1) verificou-se que 88% do NO_3^- encontrava-se abaixo de 20 cm do solo ao final do experimento, mostrando perda por lixiviação.

PALAVRAS-CHAVE: salinidade, nitrato, lixiviação de nutrientes

INTRODUCTION

The salt-stress affects in the plants development is mainly due to their osmotic and toxic effects, causing reduction in stomata opening, nutrient uptake, transpiration and plant growth (Azevedo & Tabosa, 2000; Munns & Tester, 2008; Prisco & Gomes Filho, 2010; Willadino & Camara, 2010;). Water uptake reduction and plant growth (root and shoot), caused by salinity, culminates in the reduction of capacity of the vegetable to extract nutrients from the soil, especially those required in larger quantities by plants (Shenker et al. 2003; Neves et al. 2009; Segal et al. 2010; Ramos et al. 2012; Lacerda et al., 2016).

Although, positive responses to nutrient supplementation have been observed in plants under salt-stress (Hu & Schmidhalter, 2005), especially under conditions of low soil fertility (Grattan & Grieve, 1999), these responses are not present at the same intensity as in non-saline conditions (Irshad et al. 2008; Lacerda et al., 2010; Lacerda et al., 2016), resulting in nutrient losses and reduced use efficiency. As a consequence, a large part of the added nutrients can be lost mainly by leaching, causing the contamination of the water table (Shenker et al., 2003; Neves et al., 2009; Segal et al., 2010; Ramos et al., 2012). This problem can be aggravated in the case of nutrients with high soil mobility, such as nitrate.

The aim of this study is to find evidence of the loss of N and K in corn cultivation under salt-stress, using soil columns.

MATERIAL AND METHODS

The experiment was conducted at the US Salinity Laboratory (ARS – USDA), Riverside, CA (33^{o}59' N; 117^{o}21'W), from September 13th to November 26th. During the experiment the mean maximum, minimum, and average air temperature were 26.7, 12.8 and 20 ^{o}C, respectively. Maize plants were grown in columns of polyvinyl chloride (PVC) with 20 cm in diameter and 100 cm in length. Columns were filled by a sieved (5-mm mesh) sandy loam soil, pH 6.8, non-saline soil (EC_e of 1.6 dS m^{-1}), collected near the experimental area. A nylon mesh and a cap adapted with a drainage pipe were used at the bottom of each PVC tube to retain the soil, but allowing the drainage water to be collected into 1-L glass bottles with wide mouths set below the drainage pipes (Lacerda et al., 2016).

The experiment was conducted in a complete randomized block design following a 4 x 4 factorial arrangement, composed of four levels of salinity (S1 = 0.5; S2 = 2.5; S3 = 5.0; and S4 = 7.5 dS m^{-1}) and four N rates, with five replications. Saline treatments were obtained by adding NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6.H_2O$ salts in a 7:2:1 equivalent ratio, according to relationship between EC_w and concentration ($mmol_c$ L^{-1}=EC_w x 10). Irrigation was performed every other day and during the experiment, two rain events were observed (13 and 25 mm). The average leaching fraction for treatments S1, S2, S3 and S4 were respectively, 0.16, 0.17, 0.19, and 0.23, considering both irrigation and rainfall events.

The four N rates, applied as urea and potassium nitrate, were as follows: N1: N recommendation for maize in California (206 kg ha^{-1}); N2: 0.3 times the N recommendation for maize in California (62 kg ha^{-1}); N3: Reduction in N1 based on the decrease in evapotranspiration caused by salinity in the previous stage; N4: Reduction in N2 based on the decrease in evapotranspiration caused by salinity in the previous stage. The values of N for all treatments were described by Lacerda et al. (2016).

The application of N and K (120 kg ha^{-1} of K_2O) in each treatment was distributed during the vegetative growth stage, as follows: 15% at sowing; 25% 20 days after sowing (DAS); 30% 35 DAS, and 30% 50 DAS. The other nutrients were applied following technical recommendations for maize in California (Lacerda et al., 2016).

Five seeds of maize (*Zea mays* L.) cv Nothstine Dent OG Lot # 41629 (Johnny's Selected Seeds, Winslow, ME, USA) were sown per column. Thinning was done seven DAS, leaving only one plant per column. The treatments with saline waters were initiated eight DAS.

Four soil samples per column, of different layers (0-20, 20-40, 40-60, and 60-80 cm), were collected the end of the experiment (74 DAS). The electrical conductivity (EC_e) and nitrate, K, Na, Ca and Cl concentrations were determined in the saturation extract. The root biomass of each soil column was also measured.

Differences among salt treatments, N application, and the interaction salt x N were tested using a two-way analysis of variance (F test). The regression analysis and Tukey's test were used to evaluate the effects of salinity and N application, respectively.

RESULTS AND DISCUSSION

The effects of irrigation with saline water can be verified through the results observed in the development of the plant root system. We observed that the root dry mass decreases with increasing soil depth and with the increase of the salt concentration in the water applied in each treatment (Figure 1).

In fact, the plant root system, especially grasses, concentrates in the first 30 cm of depth in the soil, decreasing with the distance of the surface. However, the decrease in the root dry mass was accentuated by the increase in the salts concentration in irrigation water. This effect becomes more evident in the first 10 cm of the soil where the treatments that received salt low concentration water (0.5 dS m^{-1}) presented 4.5 g of roots while the treatment with the highest concentration of salts presented a mean of 1.2 g.

Salinity is one of the main factors that reduce crop productivity. Inhibition of plant growth (root and shoot) due to salt-stress may be caused by the reduction of osmotic potential and / or excessive ions accumulation, which may induce ionic toxicity, nutritional imbalance or both (Munns & Tester, 2008; Lacerda et al. 2016). The effects of salinity (osmotic, toxic and nutritional) affect the net assimilation of CO_2, inhibit leaf expansion and accelerate the senescence of mature leaves, reducing, consequently, the area destined to the photosynthetic process (Lacerda et al., 2003; Munns & Tester, 2008).

Regarding the chemical characteristics of the soil after an application of the treatments, it observes the increase in the electrical conductivity of the saturated extract of the soil as a function of the application of the treatments with saline water, according to the figure 2A. The highest values of EC_e were verified in the treatment with the highest salt concentration (S4 = 7.5 dS m^{-1}), while the lowest values occurred in the treatments with lower salt concentrations, respectively, S1 (0.5 dS m^{-1}) and S2 (2.5 dS m^{-1}). It was also verified, the increase of the EC_e in depth in the ground, motivated mainly by the downward flow of the water that caused the leaching of the salts (Figure 2A). The water that crosses the soil profile is able to solubilize the chemical elements (mainly the chlorides and sulphates) and translocates them to deeper layers (Brady & Weil, 2013). Irrigation water itself (saline water or brackish water) can contribute to the increase of the salt concentration and, consequently, the increase of the soil electrical conductivity (Ayers & Westcot, 1999; Bernardo et al., 2006).

The same tendency is observed in relation to the distribution of sodium, calcium and chlorine in the soil (Figures 2B, 2C e 2D). This behavior is due to the chemical composition of saline water used in irrigation. According to Gheyi et al. (2010) the main elements present in saline water are the cations Na^+, Ca^{2+} and Mg^{2+} and anions Cl^-, SO_4^{2-} e HCO_3^-. Thus, it is common to accumulate the ions Ca^{2+}, Cl^- and especially Na^+ in soils irrigated with saline waters, and the higher the concentration of these elements in the irrigation water, the greater the accumulation of these constituents in the soil (Ayers & Westcot, 1999).

In the treatments with different rates of N and irrigation using fresh water (S1N1, S1N2, S1N3 and S1N4), we observed a low nitrate accumulation (NO_3^-) in the soil (Figure 3A), especially in the treatments with reduced amounts of N (S1N2 and S1N4).

In the treatments with higher levels of nitrogen (N1 and N3), we observed the NO_3^- accumulation in the deeper regions of the soil. This effect became more evident when higher salt concentrations were used (starting at 2.5 dS m^{-1}), according to figures 3B, 3C e 3D. In the treatment with saline water (7.5 dS m^{-1}) and 100 % of level of N recommendation for maize crop (S4N1), 88 % of nitrate was below 20 cm of soil depth.

The results show a high loss of N due to the leaching of NO_3^-, as well as the low N utilization by the crop under saline conditions. Under salt-stress conditions, the processes of absorption and assimilation of nutrients by plants are affected, mainly nitrate, which is the main source of nitrogen in agricultural soils and most frequently limits the growth of plants (Meloni et al., 2004). The intense reduction in root growth in treatments with higher salinity (Figure 1) reduces the possibility of utilization of this nutrient. Moreover, the increase of the electrical conductivity can affect the movement of nutrients in the soil, because it reduces its displacement by mass flow, mainly restricting the nitrogen and potassium uptake (Santos et al., 2010).

The application of K was given along with the application of N-NO_3^- in the form of potassium nitrate. Thus, all treatments received the same amount of potassium. The behavior of potassium in the soil was similar to that of nitrogen (figure 4). We observed that in the treatment with higher content of N and saline water (S4N1), it presented greater accumulation of K in the soil. The K concentration in the soil of the S4N1 treatment was approximately 253% higher than those found in the treatments with lower N levels and lower concentration of salts (S1N2 e S1N4). Root growth under salt-stress is restricted by the osmotic and toxic effects of the ions (Figure 1), which results in lower nutrient uptake and inhibits the translocation of mineral nutrients, especially K (Figure 4). Shabala & Cuin (2008) also attribute the low efficiency potassium use by the plant under salt-stress to the physicochemical similarities between Na^+ and K^+. According to the authors, sodium competes with potassium inside the plant for ionic transport sites and metabolic processes.

Leaching nutrients losses may be more significant in systems where plants are subject to saline stress. In this situation, plants tend to decrease growth and their water demand, mainly due to the osmotic effects and salinity toxicity of sodium and chlorine (Lacerda et al., 2003; Munns & Tester, 2008; Lacerda et al., 2016).

CONCLUSION

The increase in the electrical conductivity of the irrigation water caused an intense reduction of the maize root biomass and the accumulation of nitrate and potassium in the soil profile, evidencing the increase in the losses of these nutrients under conditions of high salinity.

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GRAPHICS

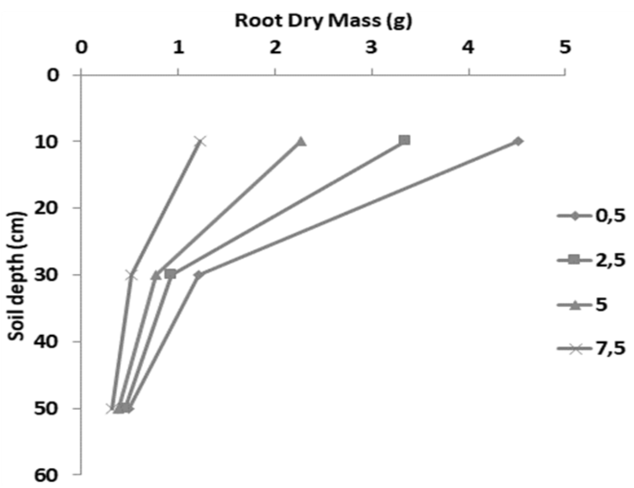

Figure 1. Effect of different irrigation water salinity levels (0.5, 2.5, 5 and 7 dS m^{-1}) and soil depth on root dry mass.

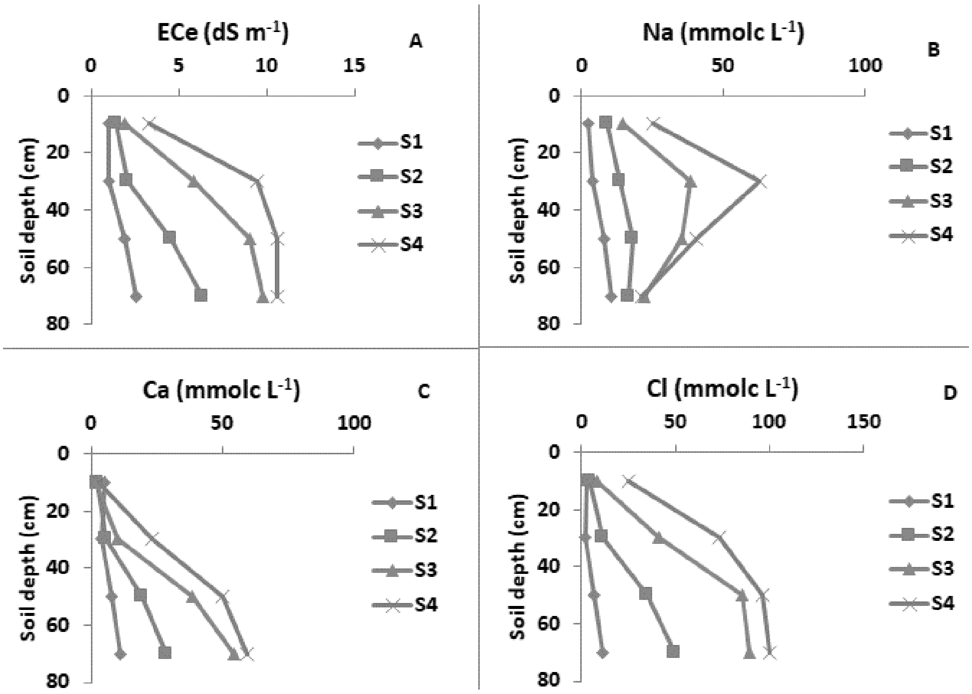

Figure 2. Results of the electrical conductivity values of the saturated soil extract and determination of the soil chemical analysis as a function of the saline concentrations, in dS m^{-1} (S1 = 0.5, S2 = 2.5, S3 = 5.0 and S4 = 7.5). A – Electrical conductivity of the saturated extract (dS m^{-1}); B – Na (mmolc L^{-1}); C – Ca (mmolc L^{-1}); D - Cl (mmolc L^{-1}).

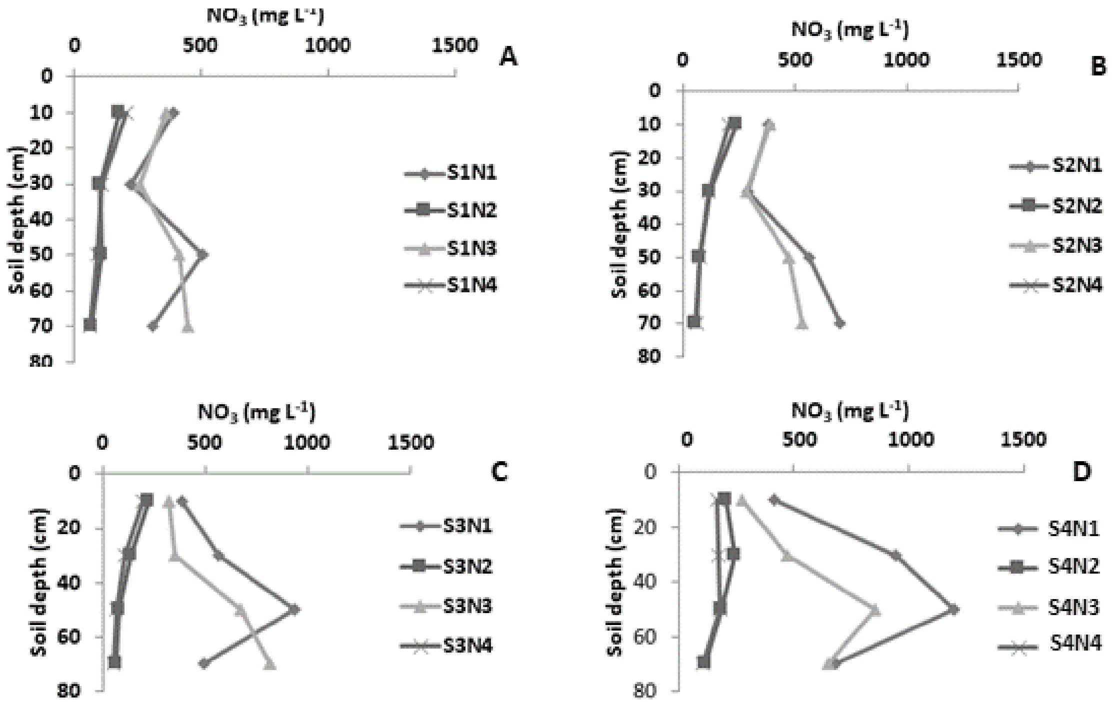

Figure 3. Soil nitrate accumulation according to the combination of four salinity levels, from S1 to S4 (0,5, 2,5, 5,0 and 7,5 dS m^{-1}) and four rates of N, N1 to N4 (N1: N recommendation for maize (2.6 g column-1); N2: 0.3 times of recommendation N1 (0.78 g column-1); N3 and N4: Reduced rate of N1 and N2, respectively, based on the evapotranspiration reduction caused by salinity).

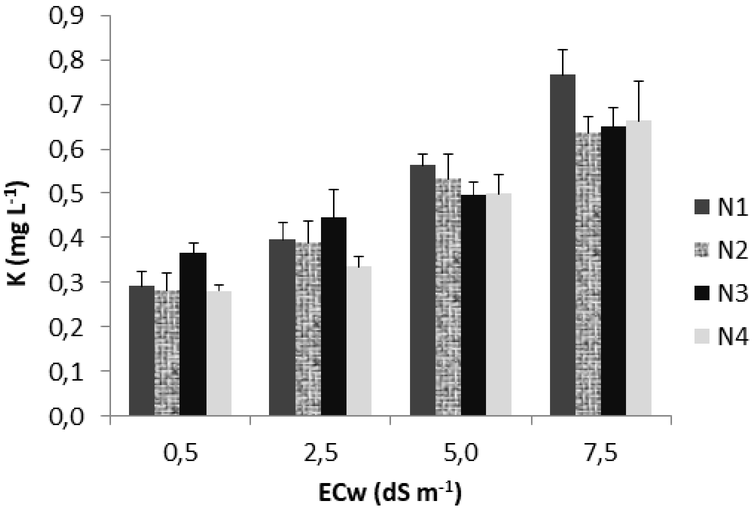

Figure 4. Soil potassium accumulation according to the combination of four salinity levels, from S1 to S4 (0.5, 2.5, 5.0 and 7.5 dS m-1) and four rates of N, from N1 to N4 (N1: N recommendation for maize (2.6 g column-1); N2: 0.3 times of recommendation N1 (0.78 g column-1); N3 and N4: Reduced rate of N1 and N2, respectively, based on the evapotranspiration reduction caused by salinity).