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Research Paper

Mombaça grass development with partial replacement of potassium fertilizer by sodium chloride and the effects of adding calcium

Desarrollo del pasto Mombaça con reemplazo parcial de potasio fertilizado por sodio y efecto de la adición de calcio

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Abstract

The objective of this greenhouse study was to evaluate the effects on development parameters in *Megathyrsus maximus* cv. Mombaça of partially replacing the potassium (K) in fertilizer by sodium (Na) and the impacts of applying calcium (Ca). The experimental design was completely randomized with 4 replicates, in a 3 × 4 + 3 factorial arrangement. Three Ca sources ($CaCO_3$, $CaSO_4$ and $CaCl_2$) were applied at 4 Ca doses (10, 20, 30 and 40 mg Ca/kg of soil) to the grass where 25% of the K fertilizer was replaced by NaCl. The 3 additional treatments were: application of standard fertilizer (N:P:K) with 100% of K recommendation; application of fertilizer with 25% of K replaced by Na but no Ca applied; and grass with no fertilizer of any kind as Control. The variables analyzed were: leaf area, leaf area ratio, net assimilation rate, relative growth rate and photosynthetic rate. Partial replacement of K by Na up to 25% of the K fertilizer recommendation did not cause significant change in the development of Mombaça grass or to any of the measured parameters. Addition of Ca had minimal impact on the analyzed variables regardless of level or source. These measurements helped to explain why dry matter yields of Mombaça grass were not significantly affected by partial replacement of K by Na up to 25% of the K fertilizer recommendation.

Keywords: Abiotic stress, *Megathyrsus maximus,* salinity.

Resumen

En un estudio de invernadero, realizado en la Universidad Federal de Tocantins, Gurupi, Brasil, se evaluaron los efectos de reemplazar parcialmente el potasio (K) en fertilizante por sodio (Na) y el efecto de aplicar calcio (Ca), sobre los parámetros de desarrollo del pasto *Megathyrsus maximus* cv. Mombaça. El diseño experimental fue completamente al azar con 4 repeticiones, en un arreglo factorial 3 × 4 + 3. Se usaron 3 fuentes de Ca ($CaCO_3$, $CaSO_4$ y $CaCl_2$) para 4 niveles de Ca (10, 20, 30 y 40 mg Ca/kg de suelo) aplicado al pasto, donde 25% del K en el fertilizante fue reemplazado por NaCl. Los 3 tratamientos adicionales consistieron en: la aplicación de fertilizante estándar (N:P:K) con 100% de K recomendado; aplicación de fertilizante con 25% de K reemplazado por Na pero sin aplicación de Ca; y sin fertilización (testigo). Las variables evaluadas fueron: área foliar, tasa de área foliar, tasa de asimilación neta, tasa de crecimiento relativa y tasa fotosintética. El reemplazo parcial de K por Na hasta 25% de la dosis de K recomendada no causó cambios significativos en el desarrollo del pasto ni en los parámetros medidos. La adición de calcio tuvo un efecto mínimo en las variables analizadas, independientemente del nivel o la fuente utilizada. Estas mediciones ayudaron a explicar por qué los rendimientos de materia seca del pasto Mombaça no fueron afectados (P>0.05) por el reemplazo parcial de K por Na hasta el 25% de la fertilización de K recomendada.

Palabras clave: Estrés abiótico, *Megathyrsus maximus,* salinidad.

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Introduction

Brazil is among the world's leading fertilizer consumers. A total of 5,854 megatons of K_2O was applied in 2017, and 95% of this fertilizer was imported (ANDA 2018). The need to import potassium (K) fertilizer for applying to crops and pastures in most Brazilian soils (Silva et al. 2014) considerably increases production costs, directly affecting agribusiness.

Potassium is the second most important mineral nutrient required by plants, being vital for photosynthesis, activation of various enzymatic systems and increasing resistance to adverse environmental conditions, and in situations of deficiency photosynthetic rate is reduced and respiration increased, resulting in decrease of carbohydrate accumulation (Ernani et al. 2007; Novais et al. 2007). Despite K being essential for plants, studies show that sodium (Na) and K share some physiological functions, being chemically and structurally similar monovalent cations (Marschner 1995). Thus, some plants are able to benefit from this close similarity between K and Na, and Na is considered a beneficial element and may contribute to plant growth in or resistance to unfavorable conditions (Malavolta 2006).

In studies carried out by Andrade et al. (2014) to examine the partial substitution of Na for K in Mombaça grass (*Megathyrsus maximus* cv. Mombaça), forage production was reduced when Na replaced K at levels higher than 28 mg Na/kg, which represented a 35% replacement of K by Na. However, substitution up to this rate failed to depress production significantly.

An alternative to increase plant tolerance of the added Na would be to apply calcium (Ca) to the soil. Calcium decreases saline stress through an unknown function that preserves K/Na selectivity and inhibits K absorption sites, which can reduce the Na influx mediated by the low affinity K absorption component (Melloni et al. 2000). Since substituting Na for K at low percentages did not significantly reduce forage yield, we hypothesized that adding Ca to soil could increase forage production or allow an even greater substitution of Na for K.

In a work complementary to this using the same experiment, Carneiro et al. (2017) evaluated the effect of substituting K for Na and the addition of Ca doses as a possible reliever of salt stress that could be caused by this substitution in the production and nutrition of Mombaça grass plants. These authors verified that the substitution of K for Na did not cause salinity to the soil. In addition, the application of Ca doses favored the greater development of plants and promoted a reduction in the accumulation of Na in plants. Consequently, based on these results, we sought to evaluate the effects of these treatments on biometric and physiological parameters of plants.

Thus the objective of this study was to evaluate the effects on development parameters in Mombaça grass of partially replacing the K in fertilizer by Na and the impact of applying Ca from different sources and at a range of doses on the outcomes.

Materials and Methods

The work was conducted in a greenhouse in the experimental area of the Federal University of Tocantins in Gurupi, southern region of the state of Tocantins, Brazil. The regional climate is of type ‘Aw’ with distinct wet and dry seasons (Alvares et al. 2013). The greenhouse was 4 m wide and 20 m long, covered with transparent plastic of 150 microns and sombrite on the sides, with retention capacity of 50% of incident radiation.

The experimental design was completely randomized with 4 replicates. The 15 treatments were arranged in a 3 × 4 + 3 factorial. Three Ca sources (calcium carbonate - $CaCO_3$, gypsum - $CaSO_4$ and calcium chloride - $CaCl_2$) were applied at 4 Ca doses (10, 20, 30 and 40 mg Ca/kg of soil). These treatments (rates) were applied in the fertilizer where Na replaced 25% of the standard K application. The 3 additional treatments were: standard fertilizer application with 100% of recommended K fertilizer level; standard fertilizer application but with 25% of K replaced by Na without any Ca added; and grass with no added fertilizer as a Control. All fertilizer (Ca, Na and K) was applied at the same time. Nitrogen fertilizer (50 kg N/ha) was applied after each harvest of the grass.

The experimental units were plastic pots filled with 4.0 kg of soil, which was drawn from the 0–200 cm horizon of an Oxisol (USDA soil taxonomy), with sandy clay texture (Table 1). Holes were made in the sides of the pots to allow drainage of surplus water and to maintain the soil at field capacity.

The K level in the soil (Table 1) was considered low and P very low for plant growth (Alvarez et al. 1999), as was Na level (Sobral et al. 2015), which was too low to negatively influence development of plants.

Fertilizer levels used were based on the chemical analysis of the soil (Table 1) and the manual with recommendations for fertilizing Cerrado plants at medium levels (Sousa and Lobato 2004), i.e. 50 kg N/ha as urea, 120 kg P_2O_5/ha as single superphosphate and 60 kg K_2O/ha as potassium chloride (standard fertilizer). To treatments with partial replacement of K by Na at 25% rate, 45 kg K_2O/ha as KCl and 15 kg Na/ha as NaCl were applied.

Table 1. Characterization[1] of the soil (DM basis) used in the experimental pots, Gurupi, Tocantins.

Parameter	Value
pH($CaCl_2$)	5.3
Organic matter (g/kg)	1.1
Phosphorus (mg/kg)	0.5
Potassium (mg/kg)	23.0
Calcium ($cmol_c$/kg)	0.4
Magnesium ($cmol_c$/kg)	0.2
Aluminum ($cmol_c$/kg)	0.0
Potential acidity (H+Al) ($cmol_c$/kg)	1.8
Sum of bases (Ca+Mg+K+Na) ($cmol_c$/kg)	0.7
CEC (Ca+Mg+K+Na+H+Al) ($cmol_c$/kg)	2.5
Sodium ($cmol_c$/kg)	0.017
Sand (%)	46.5
Silt (%)	6.3
Clay (%)	47.2

[1]According to Embrapa's methodology (Embrapa 1997): P and K extracted by Mehlich-1; Ca, Mg and Na extracted by KCl 1 mol/L.

At 10 days after plant emergence (DAE) of Mombaça, seedlings were thinned to leave 7 plants per pot. Stands of seedlings were thinned further to 5 plants/pot at 20 DAE. At 48 DAE all plants were cut at 20 cm from the soil surface. In addition to this uniformity cut, 3 further harvests at 20 cm were made at 21-day intervals, giving a total growth period of 111 days.

At each harvest Mombaça forage (leaf and tillers) was packed into paper bags before drying in a ventilated oven at 60 ºC for 72 hours to determine total dry weight (TDW). TDW was reported in a separate publication (Carneiro et al. 2017) and values were used to calculate the parameters indicated below.

Leaf area (LA) was calculated using measurements of length and width of 3 representative leaves per pot according to Benincasa (1988). Leaf area ratio (LAR), net assimilation rate (NAR), relative growth rate (RGR) and photosynthetic rate (PR) were calculated according to Benincasa (1988) and Perez and Fanti (1999).

Leaf area - LA (cm^2) was calculated using the formula:

$$LA = L \times W \times 0.905$$

where:
L = average length (cm); and
W = average width (cm).

Leaf area ratio - LAR (cm^2/g) was calculated by the formula:

$$LAR = LA/TDW$$

where:
LA = leaf area (cm^2); and
TDW = total dry weight (g).

Net assimilation rate - NAR (g/cm^2) was calculated as follows:

$$NAR = \frac{TDW(n) - TDW(n-1)}{t(n) - t(n-1)} \times \frac{LnLA(n) - LnLA(n-1)}{LA(n) - LA(n-1)}$$

where:
n = number of collections;
TDW = total dry weight;
Ln = Napierian log;
t = time in days; and
LA = leaf area (cm^2).

Relative growth rate - RGR (g/day) was calculated as follows:

$$RGR = \frac{NAR \times LAR(n) + LAR(n-1)}{2}$$

where:
n = number of collections;
NAR = net assimilation rate; and
LAR = leaf area ratio.

Photosynthetic rate - PR ($g/cm^2/day$) was calculated as follows:

$$PR = NAR \times K/h$$

where:
NAR = net assimilation rate;
K = 1.65; and
h = 12 hours.

K is a conversion factor of dry matter quantity in amount of absorbed carbonic gas, and h is hours of photoperiod considered, according to Paulilo et al. (1993).

The data were verified for the homoscedasticity of variances and normality and subsequently were submitted to analysis of variance and regression analysis through the Sisvar program (Ferreira 2011). When significant by analysis of variance, the Tukey test was applied at 5% probability ($P<0.05$). Regression models were chosen based on the significance of the coefficients of the regression equation (β), adopting 5% probability ($P<0.05$).

Results

The partial replacement of K by Na in fertilizer application (75K:25Na) did not affect any of the variables, i.e. LA, LAR, NAR, RGR and PR (Table 2). Applying Ca to the 75K:25Na treatment had no significant effects on any of the parameters, compared with no Ca application. When K was replaced by Na and Ca added as $CaCO_3$ and $CaSO_4$, the LAR was higher than for 100% K fertilizer application.

Table 2. Effects of partial replacement of potassium by sodium plus addition of calcium on mean leaf area (LA), leaf area ratio (LAR), net assimilation rate (NAR), relative growth rate (RGR) and photosynthetic rate (PR) of Mombaça grass.

Treatment[1]	LA (cm²)	LAR (cm²/g)	NAR (g/cm²)	RGR (g/day)	PR (g/cm²/day)
Control	33.5 b	72.4 a	0.0023 b	0.077 b	0.00030 b
100% K	129 a	8.95 c	0.0264 a	0.115 a	0.00364 a
75K:25Na	133 a	10.3 bc	0.0230 a	0.116 a	0.00318 a
$CaCO_3$	135 a	10.7 b	0.0223 a	0.116 a	0.00308 a
$CaSO_4$	134 a	10.7 b	0.0227 a	0.116 a	0.00312 a
$CaCl_2$	140 a	10.3 bc	0.0236 a	0.117 a	0.00324 a
Probability	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1]100% K = recommended K level of fertilizer applied; 75K:25Na = 25% of recommended K fertilizer replaced by NaCl; $CaCO_3$, $CaSO_4$ and $CaCl_2$ = addition of Ca in these different forms to 75K:25Na. Means followed by the same letters within columns do not differ from each other according to the Tukey test at P<0.05.

Development of Mombaça grass in unfertilized Control plots was lower than for all other treatments. This indicates that, in order to grow this forage in soil of low fertility, fertilizer application is necessary to increase soil fertility. Mombaça grass plants averaged 134 cm^2 and 116 g/day, respectively, for LA and RGR across all treatments.

Increasing level of Ca fertilizer applied to Mombaça grass as $CaCO_3$ promoted a quadratic response in LAR, NAR and PR (Figure 1). Mean LA measurements were 134, 134 and 138 cm^2, respectively, for $CaCO_3$, $CaSO_4$ and $CaCl_2$, regardless of the dose given (Figure 1A). On the other hand, plants that received 100% of K fertilizer showed an average LA of 128 cm^2, 3% less than that of plants where Na replaced some of the K. Mean LA for plants receiving recommended fertilizer levels with the complete K proportion was significantly greater than that of unfertilized plants in the Control treatment (129 and 33.5 cm^2, respectively).

Responses from adding Ca as $CaSO_4$ and $CaCl_2$ did not fit the model. For LAR, maximum value (11 cm^2/g) was obtained at a Ca application of 22 mg Ca/kg of soil. The high LAR observed for the Control occurred due to the low dry mass production (0.61 g) of these plants (Carneiro et al. 2017), since LAR is a relationship between leaf area and total dry mass produced by plants.

For NAR, responses to applying increasing levels of $CaCO_3$ followed a quadratic model (Figure 1C) with the maximum depression (approx. 19%) in this parameter at 20–22 mg Ca/kg of soil. Responses to the other Ca sources ($CaSO_4$ and $CaCl_2$) did not fit the model. Net assimilation rate for the complete K treatment was significantly greater than that of the unfertilized Control (0.0264 and 0.0023 g/cm^2, respectively; Table 2).

Irrespective of source and level of Ca provided, RGR of plants was 0.11 g/day (Figure 1D), a value similar to that found for plants with 100% K fertilizer. The increase relative to plants that were not fertilized was 57%.

Effects of Ca application on photosynthetic rate (PR) followed a quadratic model for the $CaCO_3$ source (Figure 1E) with maximum depression at about 20–22 mg Ca/kg of soil. Photosynthetic rate on the treatment with full K rate was more than 12 times that on the unfertilized Control.

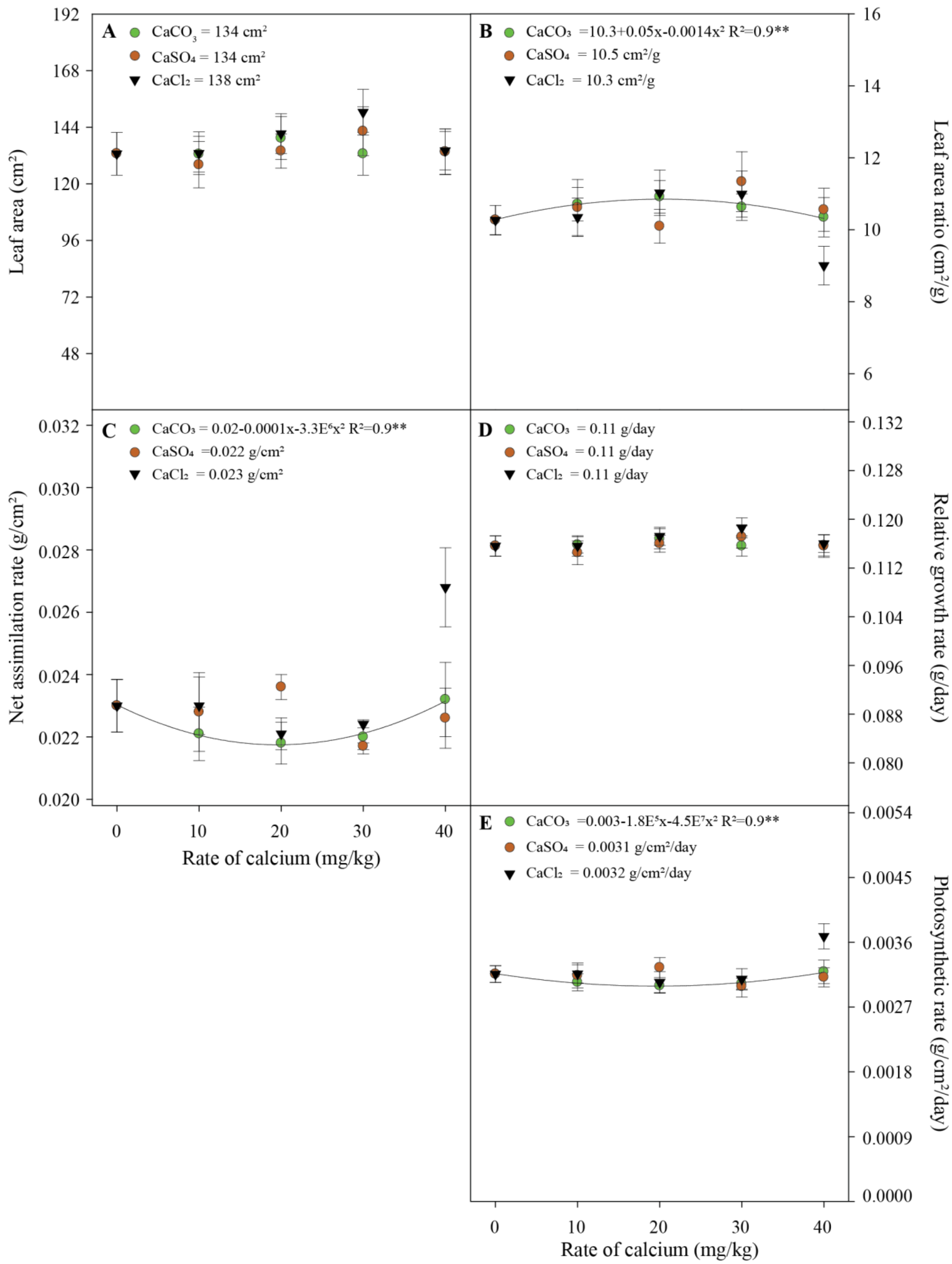

Figure 1. Leaf area - LA (**A**); leaf area ratio - LAR (**B**); net assimilation rate - NAR (**C**); relative growth rate - RGR (**D**); and photosynthetic rate - PR (**E**) of Mombaça grass as a function of dose and source of calcium when added to soil where 25% of the potassium fertilizer was replaced by sodium.

Discussion

Growth of higher plants is based on the conversion of light energy into chemical energy, the intensity of which is proportional to the interception and capture of light by the crop canopy (Gomide and Gomide 1999). Evaluating variables like leaf area, leaf area ratio, net assimilation rate, relative growth rate and photosynthetic rate, which are directly related to plant growth, can help in understanding the behavior of plants in relation to their adaptation to the environments in which they are grown.

Since leaf area values in plants with partial replacement of K in fertilizer by Na were similar to plants with 100% K fertilizer levels, partial replacement of K by Na obviously did not cause any marked change in this variable. These data are promising, since leaf area is of great importance in pasture productivity, having a direct influence on ability of plants to absorb incident light and photosynthesize as well as the nutritional value of the plant (Lavres Júnior and Monteiro 2003; Pedreira and Pedreira 2007). Therefore, we can infer that there was no negative effect on nutrient uptake by plants with partial replacement of K by Na. Not surprisingly application of Ca did not have any significant effect on leaf area.

Leaf area ratio indicates the relative size of the photosynthetic apparatus, also expressed as the foliar area useful for photosynthesis, being a morphophysiological component of growth analysis (Benincasa 1988). The high leaf area ratio observed for the Control treatment results from low dry mass production in this treatment, which increases the ratio. The data regarding plant production can be seen in Carneiro et al. (2017), which were on average 12.15 (75K:25Na with no Ca addition), 13.39 (+ calcium carbonate), 12.75 (+ gypsum), 14.25 (+ calcium chloride), 14.73 (100% K) and 0.61 g of dry mass/pot (Control). Since photosynthetic rate for plants with partial replacement of K by Na was similar to that for plants with 100% of K fertilizer, one could not expect differences in plant development between these treatments.

Values found for relative growth rate show that plants subjected to partial replacement of K by Na had a similar growth rate to plants receiving 100% of the recommended K fertilizer dosage, while adding Ca, regardless of source or dose, had little influence on this variable. We are unaware of any published reports of studies in which the effects of partial replacement of K by Na in fertilizer and interactions with applied Ca were examined.

The effects of high salinity on plants occur through a 2-stage process; initially there is a rapid response to high osmotic pressure at the root-soil interface and this is followed by a slower response caused by Na accumulation in the leaves. These processes directly affect growth of the aerial parts of plants, with reduction in leaf expansion, inhibition of tillering, photosynthesis and biosynthetic processes (Taiz et al. 2017). High concentrations of dissolved salts in the soil solution reduce the osmotic potential and consequently water potential of this solution, thus reducing the availability of water and nutrients to plants (Alves et al. 2011). Quantities of Na added in this study were obviously insufficient to cause salinity problems in Mombaça grass.

Studying the benefits of applying Ca to reduce salt stress caused by partial replacement of K by Na in Mombaça grass at a 25% rate, Carneiro et al. (2017) concluded that the addition of Ca to modify the salinity effect enhanced the development of Mombaça grass, mainly for plant height (cm) and growth rate (cm/day). That work was carried out in the same experiment, being therefore complementary to this one. For the production and nutrition variables, the Ca doses affected the response of the plants when K was replaced by Na, unlike the results obtained in this work in which there was no influence on the biometric and physiological parameters.

Although our study showed little benefit in applying Ca in this situation, it did reveal that Na could replace 25% of the K in the fertilizer applied without causing reduction in most of the analyzed variables, particularly leaf area and relative growth rate. K sources, containing significant Na contaminants, require less energy in the purification process, so the final price of fertilizer is reduced (Castro et al. 2017). Our results suggest that these cheaper sources of K could be applied to Mombaça grass without marked impact on the plants, especially without reduction in growth rate, on soils similar to those used in this study.

Photosynthetic rates of plants can be reduced by the partial replacement of K by Na, which is generally associated with a decline in growth as a result of salinity (Chatrath et al. 2000). According to these authors, the reduction in photosynthetic rate can occur for 2 reasons, i.e. reduction in stomatal conductance and reduction in the biochemical photosynthetic capacity of the leaf. While photosynthetic rate in our study was reduced when 25% of the recommended K fertilizer level was replaced by NaCl, the differences were not significant. In more saline soils the results might have been more definite.

In studies with partial replacement of K by Na when fertilizing pasture, Andrade et al. (2014) found that partial substitution of up to 35% of K by Na increased forage yield, in the second cultivation cycle. According to the authors, this response is related to the reduction of the effect of Na due to its extraction by plants in the previous cycle, and also due to the greater supply of energy for root development in the second cycle. In contrast, Carneiro et al. (2017) showed that substitution of Na for up to 25% of K in fertilizer for

Mombaça grass had no affect on either absorption of nutrients or productivity of the crop. Our results provide an explanation for the results of Carneiro et al. (2017), allowing us to conclude that up to 25% of K fertilizer applied to Mombaça grass can be replaced by NaCl without detriment to production on the soils we studied because the parameters contributing to DM production were not affected.

As our study demonstrated, there is little influence on plant growth of the partial replacement of K by Na on these types of soils. It is possible that benefits from applying Ca to soil could be more evident with higher levels of substitution by Na, where there would be greater stress on plants due to the increase in Na absorption. More detailed plant evaluations, such as foliar and root nutrient accumulation, are recommended in later studies. In addition the use of levels higher than 25% in the partial replacement of K by Na could be examined in order to explore the benefits of saline stress minimizer, as well as similar levels on more saline soils.

Conclusions

Partial substitution of K fertilizer by Na up to 25% of the recommended K fertilizer level did not cause damage to the development of Mombaça grass plants in this study. Results might be different if basic Na levels in soil were higher and this warrants investigation.

While the addition of Ca to counteract any effects of increasing salt levels in soil with the partial substitution of K by Na showed no beneficial effects, in soils with higher salt levels results may differ.

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References

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Alvares CA; Stape JL; Sentelhas PC; Gonçalves JLM; Sparovek G. 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 22:711–728. doi: 10.1127/0941-2948/2013/0507

Alvarez VH; Novais RF; Barros NF; Cantarutti RB; Lopes AS. 1999. Interpretação dos resultados das analises de solos. In: Ribeiro AC; Guimarães PTG; Alvarez VVH, eds. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais - 5ª Aproximação. Comissão de Fertilidade do Solo do Estado de Minas Gerais, Viçosa, MG, Brazil. p. 25–32.

Alves FAL; Ferreira-Silva SL; Silveira JAG da; Pereira VLA. 2011. Efeito do Ca^{2+} externo no conteúdo de Na^{+} e K^{+} em cajueiros expostos a salinidade. Revista Brasileira de Ciências Agrárias 6:602–608. doi: 10.5039/agraria.v6i4a1257

ANDA (Associação Nacional para Difusão de Adubos). 2018. Anuário estatístico do setor de fertilizantes, 2018. ANDA, São Paulo, SP, Brazil. anda.org.br/arquivos

Andrade CAO de; Fidelis RR; Santos AC dos; Santos ACM dos; Silva RR da. 2014. Substituição parcial do potássio por sódio na adubação do capim Mombaça em ciclos de pastejo. Revista Verde de Agroecologia e Desenvolvimento Sustentável 9:95–101. doi: 10.18378/rvads.v9i5.2974

Benincasa MMP. 1988. Análise de crescimento de plantas: Noções básicas. Fundação de Apoio a Pesquisa, Ensino e Extensão (FUNEP), Jaboticabal, SP, Brazil.

Carneiro JSS; Silva PSS; Santos ACM; Freitas GA; Santos AC; Silva RR. 2017. Mombaça grass responds to partial replacement of K^{+} by Na^{+} with supplemental Ca^{2+} addition in low fertility soil. Journal of Agricultural Science 9:209–219. doi: 10.5539/jas.v9n11p209

Castro VR; Surdi PG; Sette Junior CR; Tomazello Filho M; Chaix G; Laclau JP. 2017. Application effect of potassium, sodium and water availability in the apparent density at 12% humidity of juvenile wood of *Eucalyptus grandis* trees. Ciência Florestal 27:1017–1027. (In Portuguese). doi: 10.5902/1980509828675

Chatrath A; Mandal PK; Anuradha M. 2000. Effect of secondary salinization on photosynthesis in fodder oat (*Avena sativa* L.) genotypes. Journal of Agronomy and Crop Science 184:13–16. doi: 10.1046/j.1439-037x.2000.00333.x

EMBRAPA. 1997. Manual de métodos de análise de solo. 2nd Edn. EMBRAPA, Centro Nacional de Pesquisa de Solos, Rio de Janeiro, RJ, Brazil.

Ernani PR; Almeida JA; Santos FC. 2007. Potássio. In: Novais RF de; Viegas VHA; Barros NF de; Fontes RL; Cantarutti RB; Neves JCL, eds. Fertilidade do solo. Editora UFV, Viçosa, MG, Brazil. p. 551–594.

Ferreira DF. 2011. Sisvar: A computer statistical analysis system. Ciência e Agrotecnologia 35:1039–1042. doi: 10.1590/S1413-70542011000600001

Gomide CAM; Gomide JA. 1999. Growth analysis of *Panicum maximum* Jacq. cultivars. Revista Brasileira de Zootecnia 28:675–680. (In Portuguese). doi: 10.1590/S1516-35981999000400003

Lavres Junior J; Monteiro FA. 2003. Tillering, leaf area and Mombaçagrass root system in response to nitrogen and potassium combinations. Revista Brasileira de Zootecnia 32:1068–1075. (In Portuguese) doi: 10.1590/S1516-35982003000500006

Malavolta E. 2006. Manual de nutrição mineral de plantas. Agronômica Ceres, São Paulo, SP, Brazil.

Marschner H. 1995. Mineral nutrition of higher plants. Academic Press, London, UK. doi: 10.1016/B978-0-12-473542-2.X5000-7

Melloni R; Silva FAM; Carvalho JG de. 2000. The use of calcium, magnesium and potassium for reducing salinity effects on mineral nutrition and growth of aroeira

(*Myracrodruon urundeuva*). Cerne 6(2):35–40. (In Portuguese). bit.ly/2XGQjf2

Novais RF de; Viegas VHA; Barros NF de; Fontes RL; Cantarutti RB; Neves JCL, eds. 2007. Fertilidade do solo. Editora UFV, Viçosa, MG, Brazil.

Paulilo MTS; Felippe GM; Dale JE. 1993. Crescimento inicial de *Qualea grandiflora*. Revista Brasileira de Botânica 16:37–46.

Pedreira BC; Pedreira CGS. 2007. Leaf photosynthesis in Xaraés palisadegrass [*Brachiaria brizantha* (A. Rich.) Stapf. cv. Xaraés] and modeling canopy assimilatory potential under rotational stocking strategies. Revista Brasileira de Zootecnia 36:773–779. (In Portuguese). doi: 10.1590/S1516-35982007000400004

Perez SCJA; Fanti SC. 1999. Growth and drought resistence of leucaena in "cerrado" soil. Pesquisa Agropecuária Brasileira 34:933–944. (In Portuguese). doi: 10.1590/S0100-204X1999000600003

Silva IP da; Rodas CL; Ferreira ED; Carvalho JG de. 2014. Growth and nutrition of physic nut seedlings influenced by the replacement of potassium by sodium. (In Portuguese). Revista Caatinga 27:194–199. bit.ly/379j0V4

Sobral LF; Barretto MCV; Silva AJ da; Anjos JL dos. 2015. Guia prático para interpretação de resultados de análises de solo. Embrapa Documentos 206. Embrapa Tabuleiros Costeiros, Aracajú, SE, Brazil. bit.ly/2XISE99

Sousa DMG de; Lobato E. 2004. Cerrado: Correção do solo e adubação. Embrapa Informação Tecnológica, Brasília, DF, Brazil.

Taiz L; Zeiger E; Møller M; Murphy A. 2017. Fisiologia e desenvolvimento vegetal. 6th Edn. Artmed Editora, Porto Alegre, RS, Brazil.

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