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Potassic and nitrogen fertilization in a modern hybrid of sorghum for biomass production cultivated in an Oxisol

Franciele de Freitas Silva, Thomas Jefferson Cavalcante, Kassia de Paula Barbosa, Gustavo Castoldi*, Mariângela Brito Freiberger, Fabiano Guimarães Silva

Goiano Federal Institute. Rio Verde, GO, Brazil

***Corresponding author: gustavo.castoldi@ifgoiano.edu.br**

Abstract

Biomass sorghum [*Sorghum bicolor* (L.)] is a promising option for the supply of dedicated biomass for energy cogeneration in Brazil. However, it is still necessary to better understand gaps around the nutrient requirement and fertilization management, especially for modern materials. The aim of this study was to evaluate the effect of nitrogen (N) and potassium (K) doses on dry matter (DM) and nutrient accumulation in a modern hybrid of biomass sorghum cultivated in an Oxisol. For that, two separate trials were carried out with the hybrid Palo Alto 2562, grown in 2015/16 summer season in the central-western region of Brazil. Both trials were carried out in a randomized block design with four replicates and five doses: 0, 70, 140, 210 and 280 kg ha^{-1} (of N or K). The hybrid Palo Alto 2562 responded positively to N fertilization. The DM production and N accumulation hybrid of Palo Alto 2562 was increased as N fertilization added, reaching, respectively, values of 24.6 Mg ha^{-1} and 206 kg ha^{-1} at dose of 280 kg ha^{-1} N. Also, in order to avoid depletion of N levels in the soil we required a fertilization of at least 140 kg ha^{-1} N. The Palo Alto 2562 hybrid has a high absorption capacity of K, which is the most absorbed nutrient by the plant, reaching values of 316 kg ha^{-1}. However, in this study due to high levels of K in the soil and high K saturation in CEC, the K fertilization may be not necessary to produce sorghum biomass.

Keywords: Bioenergy, dedicated biomass, plant nutrition, nutrient export**.**

Introduction

The interest in obtaining energy through the production of dedicated biomass has increased in several countries, such as the United States, China, Italy and Brazil (Pannacci and Bartolini, 2016; Heitman et al., 2017; Meki et al., 2017; Tang et al., 2018). These countries share the interest of cultivating biomass sorghum (*Sorghum bicolor* L.) due to its great potential to produce raw material, as well as the fact that biomass sorghum presents interesting cultivation characteristics such as high water use efficiency and drought tolerance besides a chemical composition with high energy efficiency (Rooney et al., 2007).

New cultivation technologies and genotypes that are more productive and adapted to the edaphoclimatic conditions have favored the cultivation of sorghum in Brazil (Silva et al., 2018; Almeida et al., 2019). However, there is no well-established nutrient recommendation for it to express its full productive potential, with some gaps for adequate nutrient management (Rego et al., 2003; Rooney et al., 2007; Wight et al., 2012). Among the nutritional aspects, nitrogen (N) and potassium (K) are the most demanded nutrients for the production of biomass sorghum (Santos et al., 2014). This requirement may be even greater in more modern hybrids, mainly due to the greater potential for biomass production. A fertilization experiment of two biomass sorghum varieties (CMSXS 7020 and CMSXS 652) was performed in Sete Lagoas, MG, Brazil. The average extraction of N, phosphorus (P), K, calcium (Ca) and magnesium (Mg) was 7.6, 0.8, 10.8, 3.6 and 2.5 kg, respectively, for each tone of biomass produced (Santos et al., 2015). In the same trial, the maximum dry matter yield (DM) was 33.94 Mg ha^{-1}, obtained by CMSXS 652 variety fertilized with 80 kg ha^{-1} of N and 180 kg ha^{-1} of K_2O, representing an extraction of 242 kg ha^{-1} of N, 32 kg ha^{-1} of P and 298 kg ha^{-1} of K (Santos et al., 2015). In an absorption accumulation curve experiment, the hybrid Palo Alto 2562 (fertilized with 198 kg ha^{-1} of N and 285 kg ha^{-1} of K_2O) has uptaken 289 kg ha^{-1} of N, 38 kg ha^{-1} of P and 447 kg ha^{-1} of K to produce 24.43 Mg ha^{-1} of DM (Cavalcante et al., 2018).

Nitrogen has a key role in the chlorophyll molecule, as well as it is one of the responsible for the production of leaf area and regulation of the photosynthetic rate, being fundamental for the photosynthetic apparatus of the plant, which may reflect on the biomass production (Olson et al., 2013; Ameen et al., 2017; Tang et al., 2018). Potassium can be related to the increase of resistance to lodging in plants due to its importance for the stem stiffness (Castoldi et al., 2011; Júlio et al., 2016). So, a better understanding of biomass sorghum response to N and K, particularly for new materials with a high demand for nutrients, is a key factor for the success and expansion of its cultivation in Brazil. In this context, the aim of this study was to evaluate the biometric parameters, dry matter production and the accumulation of nutrients by a modern hybrid of biomass sorghum cultivated in an Oxisol and as affected by N and K fertilization.

Results

Nutrients accumulation, biometric parameters and dry matter production in Nitrogen trial

Only the accumulation of manganese (Mn) in the shoot part of the biomass sorghum was not influenced by the N doses (Table 2). On the other hand, the accumulation of P, Ca, sulfur (S), copper (Cu) and zinc (Zn) linearly increased with increasing N doses. In the particular case of DM and N (Figure 1), the highest accumulation also occurred at the highest dose of N (280 kg ha^{-1}). Other nutrients, such as K, Mg, iron (Fe) and boron (B), presented a quadratic behavior forming a parabola with the vertex facing downward, with its minimum accumulation occurring at the calculated doses of 133.9; 72.5; 85.2 and 121.4 kg ha^{-1} of N, respectively.

The accumulation of N in the shoot part of the biomass sorghum was linearly increased as the dose of N provided in the fertilization increased from 62.1 kg ha^{-1} to 206.5 kg ha^{-1} at doses 0 and 280 kg ha^{-1}, respectively (Figure 1A), showing an increase of 3.3 times. Following accumulation of N, the DM accumulation rose from 14.5 Mg ha^{-1} to 24.6 Mg ha^{-1} at at dose of 0 and 280 kg ha^{-1} N, respectively (Figure 1B), an increase of 69.4 %. In the maximum DM production, the accumulation (in the shoot) of P, K, Ca, Mg and S was 34.5, 273.2, 233.6, 105.8 and 9.1 kg ha^{-1}, respectively (Table 2). For Cu, Fe, Mn, Zn and B the values were 208, 3,942, 283, 862 and 179 g ha^{-1}, respectively (Table 2).

Nitrogen doses did not interfere with the height and stem diameter of the biomass sorghum plants, which at the time of harvest showed means of 4.87 m and 1.98 cm, respectively. In the simplified balance of N in the system, doses 0 and 70 kg ha^{-1} of N resulted in a negative balance (Figure 2), which means that under these conditions the plant has uptaken (only in the shoot part) more N than those supplied via fertilization. In this study, it was evident that N doses from 140 kg ha^{-1} are required to meet the crops need.

Nutrients accumulation, biometric parameters and dry matter production in Potassium trial

The analysis of variance revealed significant effects of K doses on DM production and nutrient accumulation, except for the accumulation of Mg and B (Table 3). The nutrients P, Ca and S showed a linear decreasing behavior, with lower values of accumulation as K doses increased. The other nutrients responded quadratically, with K and Fe presenting the maximum accumulation point estimated at the doses of 134.8 and 76.2 kg ha^{-1} of K, respectively.

The absorption of K had the maximum estimated accumulation of 316.2 kg ha^{-1} at the dose of 134.8 kg ha^{-1} K (Figure 3A). On the other hand, the accumulation of DM presented a linear decreasing behavior (Figure 3B), unlike the N trial, in which the behavior was linearly increased (Figure 1B). Thus, for the K trial, the highest accumulation of DM (21.47 Mg ha^{-1}) was occurred in the absence of K fertilization. In this condition, the accumulation (in the shoot) of N, P, Ca, Mg and S was 149.5, 25.5, 190.5, 56.9 and 14.7 kg ha^{-1}, respectively (Table 3). For Cu, Fe, Mn, Zn and B this value was, respectively, 195, 2,427, 395, 618 and 249 g ha^{-1} (Table 3).

The K fertilization did not significantly affect the height and stem diameter of the biomass sorghum plants, which at the time of harvest presented 4.84 m and 1.96 cm, respectively. The simplified balance of K in the system (Figure 4) indicates that only the dose of 280 kg ha^{-1} presented a positive balance of K, with a surplus of approximately 104 kg ha^{-1}. In all the other doses (0, 70, 140 and 210 kg ha^{-1} – Figure 4), the amount of K accumulated in the shoot of plants was higher than the amount of K provided by K fertilization, so that the K balance was negative (Figure 4).

Discussion

The results regarding the average plant height (4.85 m) in the N trial were close to that obtained in trials with the variety CMSXS 7015 cultivated in four spacing and populations in the 2012/2013 and 2013/2014 crop years, with mean values of plant height of 5.24 and 4.83 m, respectively (May et al., 2015). However, agronomic characteristics of biomass sorghum such as plant height, stem diameter and dry matter can vary due to several factors related to the hybrid, soil nutrient availability, climatic conditions, area history and management practices (May et al., 2015; Santos et al., 2015; Pannacci and Bartolini, 2016).

The increase in DM production due to the increase in N fertilization (Figure 1B) demonstrates the important role that N has in the vegetative growth of biomass sorghum. Synergistic effect of N doses on sorghum production was also reported in Texas, on a clayey Pulman soil, with DM values of 12.1 and 18.2 Mg ha^{-1}, respectively, found for TAMX08001 and TAM09024 under different N doses and irrigation levels (Hao et al., 2014).

Dry matter yield for sorghum biomass was directly related to the increase of N doses (Figure 1B), so the difference between doses 0 and 280 kg ha^{-1} N was 10.1 Mg ha^{-1} corresponding to an increase of 69.4%. In this condition of highest DM production (24,6 Mg ha^{-1} with 280 kg ha^{-1} N), the nutrient accumulation in the shoot occurred the following order: K > Ca > N > Mg > P > S > Fe > Zn > Mn > Cu > B.

The variation in DM yield shows that the production potential (in the higher N doses) is close to that presented by other modern hybrids such as biomass sorghum 133-Syngenta, which produced between 18.1 and 25.0 Mg ha^{-1} of DM when grown under two N doses and two irrigation levels

Table 1. Soil pH, organic matter (OM), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), potential acidity (H + Al), cation exchange capacity (CEC) and base saturation (V), in the layers of 0.0-0.1, 0.1-0.2 and 0.2-0.4 m in the soil at the experimental area. Rio Verde, GO, Brazil.

Depth	pH	OM	P	K	Ca	Mg	H+Al	CEC	V
(m)	$CaCl_2$	g dm^{-3}	mg dm^{-3}	----------------------		cmolc dm^{-3}	---------------------		%
0.0–0.1	5.48	39.8	21.5	0.7	2.6	0.9	4.5	8.7	49
0.1–0.2	4.98	32.7	14.0	0.3	1.6	0.6	5.1	7.7	33
0.2–0.4	5.19	31.4	12.6	0.3	1.5	0.5	4.1	6.4	36

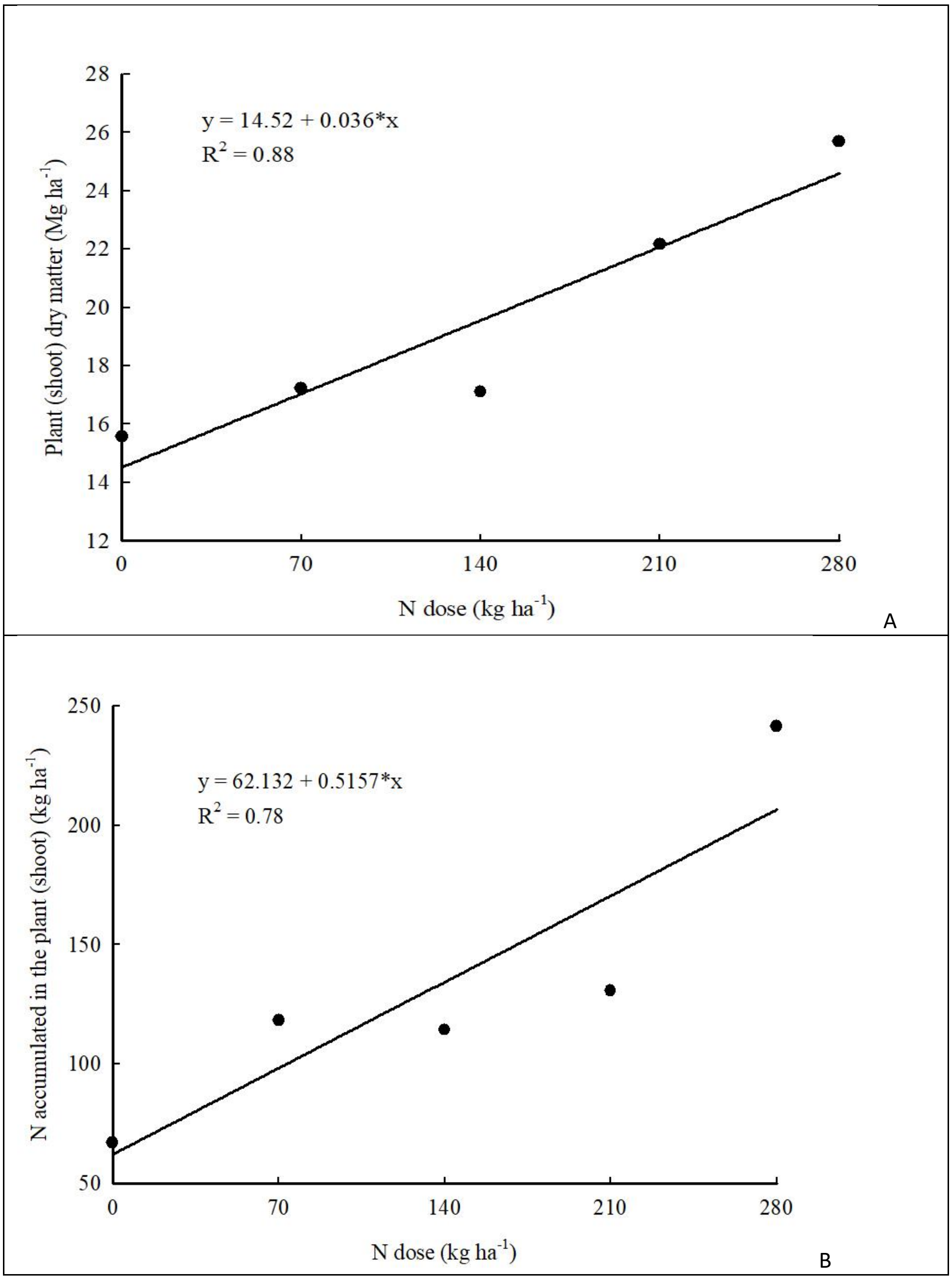

Fig 1. Total shoot dry matter (A) and nitrogen (N) accumulated in the shoot dry matter (B) of biomass sorghum (hybrid Palo Alto 2562) cultivated in an Oxisol and as affected by K doses. Rio Verde, GO, Brazil.

Table 2. Accumulation of dry matter (DM) and macro and micronutrients in the shoot part of the biomass sorghum (hybrid Palo Alto 2562), at the harvest stage and as a function of nitrogen (N) doses. Rio Verde, GO, Brazil.

Variable	N dose (kg ha^{-1})					F	Equation
	0	70	140	210	280		
	--------------------------- Mg ha^{-1} ---------------------------						
DM	15.57	17.23	17.10	22.17	25.70	**	y = 14.513 + 0.0360x
	--------------------------- kg ha^{-1} ---------------------------						
N	67.00	118.3	114.3	130.7	241.3	**	y = 62.133 + 0.5157x
P	15.33	25.33	18.00	34.00	34.00	**	y = 16.133 + 0.0657x
K	277.3	154.7	250.0	183.7	280.0	**	y = 261.74 - 1.079x + 0.0040x^2
Ca	137.7	157.3	156.0	209.3	243.7	**	y = 128.00 + 0.3771x
Mg	50.33	61.00	55.33	62.00	110.67	*	y = 56.152 - 0.1867x + 0.0013x^2
S	8.33	11.00	9.33	11.00	12.33	**	y = 8.800 + 0.0011x
	--------------------------- g ha^{-1} ---------------------------						
Cu	113.7	111.0	113.3	212.3	205.0	*	y = 94.267 + 0.4057x
Fe	1812	2074	1767	2108	4174	*	y = 2042.4 - 10.577x + 0.0620x^2
Mn	213.3	272.3	267.3	316.0	344.3	ns	y = 282.66
Zn	297.0	622.7	402.0	697.3	936.7	**	y = 320.33 + 1.9343x
B	116.7	112.0	65.00	67.00	201.0	**	y = 134.22 - 1.1553x + 0.0047x^2

**, * and ^{ns}. Significant at 0.01; 0.05 probability and not significant, respectively.

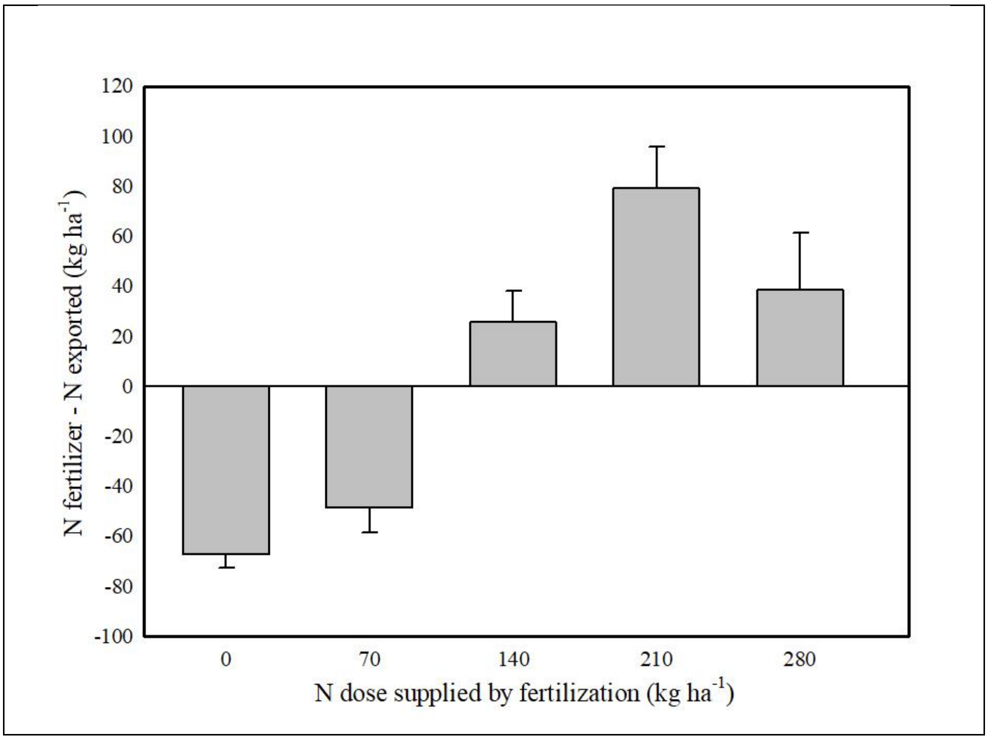

Fig 2. Simple balance between the amount of nitrogen (N) supplied by the fertilizer (N dose) and the amount of N accumulated in the shoot and then exported by biomass sorghum. Rio Verde, GO, Brazil.

Table 3. Accumulation of dry matter (DM) and macro and micronutrients in the shoot part of the biomass sorghum (hybrid Palo Alto 2562), at the harvest stage and as a function of potassium (K) doses. Rio Verde, GO, Brazil.

Variable	K dose (kg ha^{-1})					F	Equation
	0	70	140	210	280		
	-------------------------- Mg ha^{-1} ------------------------						
DM	21.83	21.43	16.30	13.87	17.30	*	y = 21.47 – 0.0237x
	-------------------------- kg ha^{-1} --------------------------						
N	138.7	143.3	101.7	89.67	132.7	**	y = 149.52 - 0.5278x + 0.0015x^2
P	25.67	26.67	19.67	15.33	22.67	*	y = 25.467 - 0.0247x
K	199.7	249.0	368.3	244.7	176.3	*	y = 189.47 + 1.8795x - 0.0069x^2
Ca	181.3	205.7	141.0	114.3	143.7	**	y = 190.53 - 0.2380x
Mg	69.33	74.33	50.67	39.67	50.33	ns	y = 56.87
S	14.00	14.67	9.67	8.00	7.33	**	y = 14.733 - 0.0286x
	--------------------------- g ha^{-1} --------------------------						
Cu	190.7	126.0	74.33	89.33	151.3	**	y = 195.11 - 1.4709x + 0.0047*x^2
Fe	2221	3163	1839	2393	1707	*	y = 2426.9 + 3.0623x - 0.0201x^2
Mn	387.7	307.0	245.0	190.0	246.0	*	y = 395.25 - 1.7161x + 0.0041x^2
Zn	622.0	435.7	326.3	376.3	433.3	*	y = 618.35 - 3.2605x + 0.0094x^2
B	315.3	155.0	281.0	243.7	250.7	ns	y = 249.13

**, * and ^{ns}. Significant at 0.01; 0.05 probability and not significant, respectively.

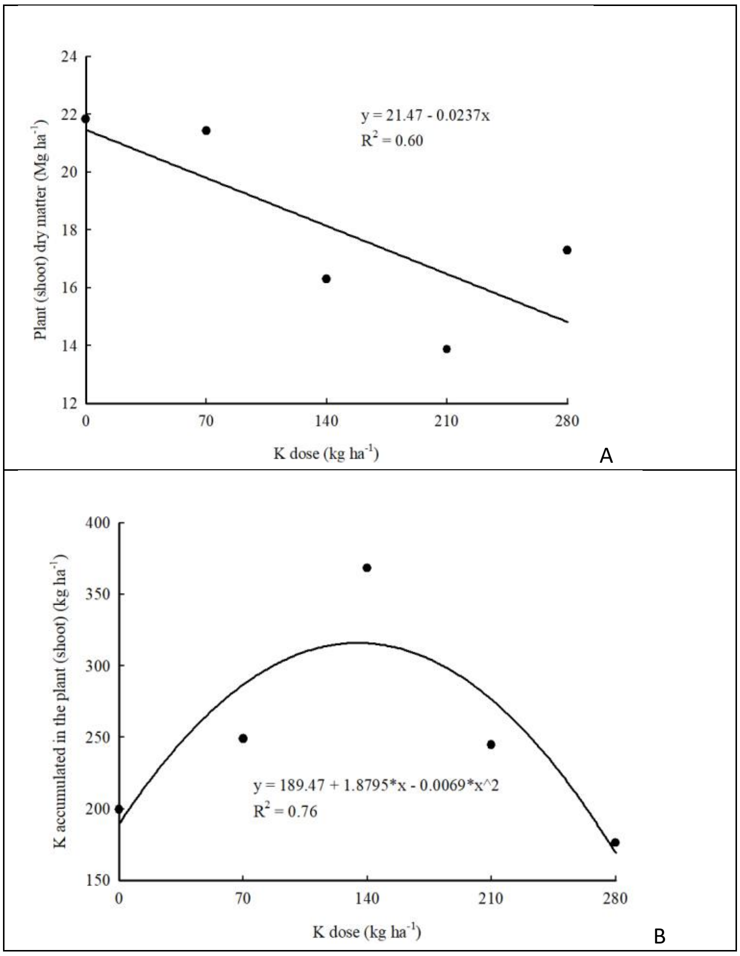

Fig 3. Total shoot dry matter (A) and potassium (K) accumulated in the shoot dry matter (B) of biomass sorghum (hybrid Palo Alto 2562) cultivated in an Oxisol and as affected by K doses. Rio Verde, GO, Brazil.

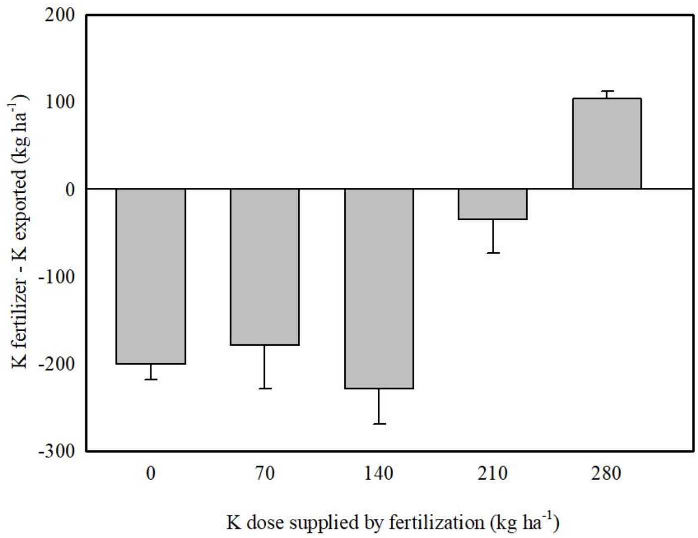

Fig 4. Simple balance between the amount of potassium (K) supplied by the fertilizer (K dose) and the amount of N accumulated in the shoot and then exported by biomass sorghum. Rio Verde, GO, Brazil.

(Amaducci et al., 2016). The relationship between fertilization need and N uptake suggests that biomass sorghum requires fertilization above 70 kg ha^{-1} N (starting from 140 kg ha^{-1}) (Figure 2) to avoid depletion of soil N levels. This is evident when that the amount of N accumulated in the shoot part of the plant, even at dose 0 was 67 kg ha^{-1} of N (Figure 1A), possibly resulting from the mineralization of the organic matter present in the soil, which was 31 to 40 g dm^{-3} (Table 1).

To avoid limitation in biomass production, it is important to provide the total amount of nutrients that plant extracts. This is done mainly through fertilization to avoid withdrawing nutrients from the soil reserves. Besides absorbing nutrients from the fertilizer, the plant can also uptake mineralized N from the organic matter and occasionally, from the N biological fixation (Fageria and Baligar, 2005). Thus, fertilization with 140 kg ha^{-1} of N can prevent soil degradation and maintain the sustainability of raw material production for bioenergy production.

Fertilization higher than 70 kg ha^{-1} of N for modern hybrids of biomass sorghum was reported in two-year plantations on typically sandy soil in northern China, where GN-11 biomass sorghum was cultivated under four levels of N fertilization. It was found that to avoid soil degradation on marginal lands, it was necessary to provide at least one fertilization of 120 kg ha^{-1} of N (Tang et al., 2018). Another study reports that fertilization between 60 and 120 kg ha^{-1} of N could satisfy crop demand since high amounts of N were extracted from the soil in the control treatment (0) and with 60 kg ha^{-1} of N, when sorghum was cultivated in sandy soil with low natural fertility and organic matter content (Ameen et al., 2017). In the South of the USA, to avoid N depletion in the soil, N fertilization was 183 kg ha^{-1} (Hao et al., 2014). Thus, it is evident that the amount of N required for a satisfactory production of DM from biomass sorghum can vary as a function of cultivated varieties, soil type, and production environment.

In the K trial, the reduction of DM production with increasing levels of K (Figure 3B) has already been reported by other authors (Santos et al., 2014), when the variety CMSXS 65, cultivated in Minas Gerais, Brazil, under K doses of 0, 60, 120 and 180 kg ha^{-1} produced the highest amount of DM at 0 dose. One of the hypotheses for the present study may be related to the amount of K present in the soil of the experimental area, which at the time of sowing, corresponded to 625.6 kg ha^{-1} (Table 1) at 0.0–0.4 m soil layer.

We observed that the highest estimated K accumulation in shoot biomass was 316.1 kg ha^{-1}, at the estimated dose of 134.8 kg ha^{-1} K, so the amount of K present in the soil was sufficient to nourish the plant. In this context, the high content of K in the soil may have covered the effect of K fertilization, even for biomass sorghum, which presents a very high capacity of K accumulation (Cavalcante et al., 2018). It is important to point out that the maximum accumulation of K in this study has not produced highest DM production, presenting that the biomass sorghum has a luxury characteristic for K consumption.

The amount of K available in the soil, and the possible luxury consumption of K by biomass sorghum, might justifies the absence of crop response to the increase of the K fertilization. However as observed in the present study, the reduction of DM as a function of fertilization with K may be related to the relation of bases in the soil.

The effect of K fertilization on the accumulation of Ca in the shoot part of the biomass sorghum was similar to the accumulation of DM, because as the dose of K increased, there was a proportional reduction of Ca accumulation (Table 3). This behavior may be the evidence of the probable competition between Ca and K by exchange sites at the time

of absorption (Diem and Godbold, 1993), since K absorption is favored in comparison to other cationic species such as Ca and Mg (Oliveira et al., 2001). The saturation of K in the CEC of the soil when we increased the dose from 0 to 280 kg ha^{-1} K varied from 8.04 to 12.15%, 3.95 to 8.65% and 4.65 to 7.48% at 00–0.1, 0.1–0.2 and 0.2–0.4 m layers, respectively.
The high K levels in the soil and the K saturation in the CEC (> 3%) (Sousa and Lobato, 2004) of the soil in the present study (even for a condition of acidity and low level of base saturation (< 50%) may have impaired the absorption of Ca and, consequently, the production of DM, justifying the deleterious effect of the K doses on DM production of biomass sorghum. The importance of the Ca/K and also Mg/K ratio in the soil has already been reported for sweet sorghum. So, the Ca/K and also Mg/K ratios lower than 7.4 and 0.6, respectively, may result in yield losses (Rosolem et al., 1984).
The simple balance of K in the system shows that the biomass sorghum needs both the presence of K in the soil and the K provided by the fertilization, because a quantity of less than 210 kg ha^{-1} would not be enough to meet up the crop needs (Figure 4). The high demand of K for the biomass sorghum has been reported also by other authors. In a 4–year experiment in North Carolina, USA, variation in removal of K by variety Blade ES5200 from 187 to 205 kg ha^{-1} of K was reported (Heitman et al., 2017). In Goiás, Brazil, an absorption accumulation curve experiment with the hybrid Palo Alto 2562 found an accumulation of 447 kg K ha^{-1} for a DM production of 24.4 Mg ha^{-1} (Cavalcante et al., 2018). For the other nutrients, in the condition of highest DM productin (21,5 Mg ha^{-1} with 0 kg ha^{-1} K) the accumulation in the shoot followed the order of: K ~ Ca > N > Mg > P > S > Fe > Zn > Mn > B > Cu.

Materials and Methods

Characteristics of experimental area

The study was conducted at the experimental station of the company *Nexsteppe Sementes do Brasil*, located in the municipality of Rio Verde, GO, Brazil. According to the classification of Köppen-Geiger, the climate of the region is tropical, with dry season in winter (Aw), average annual rainfall of 1400-1600 mm and average temperature around 23–24ºC.
The soil of the experimental area was classified as a Dystrophic Red Latosol (Oxisol) (WRB, 2015) of medium texture (45% of clay). Before the implementation of the trials, the soil was sampled at depths of 0.0–0.1; 0.1–0.2 and 0.2–0.4 m and analyzed for its main chemical characteristics (Table 1). All analyzes were performed according to the methodologies described by Silva (2009).

Experimental design and treatments

Two separate experiments were carried out, both in the summer crop year 2015/16, using the hybrid Palo Alto 2562, a modern photoperiod sensitive material from *Nexsteppe*.
The N trial was conducted in a randomized block design with four replicates and five N doses: 0, 70, 140, 210 and 280 kg ha^{-1}. N–urea (45% N) was applied in two steps: 20% on the furrow after sowing, and 80% as top dressing, when the plants had 3 fully expanded leaves (V3 – approximately 3 weeks after sowing). A 120 kg ha^{-1} of P, as triple superphosphate (41% P_2O_5 and 12% Ca) was also used in the fertilization and distributed in the sowing furrow, and 140 kg ha^{-1} of K was applied as top dressing as potassium chloride (KCl, 60% K_2O).
Similarly, the K trial was conducted in a randomized block design with four replicates and five doses of K: 0, 70, 140, 210 and 280 kg ha^{-1}. Potassium was applied manually as KCl and in two steps: 40% on the furrow after sowing and 60% as top dressing, at the same time of N fertilization (V3). In the fertilization, there was also 120 kg ha^{-1} of P, as triple superphosphate and distributed in the sowing furrow, and 140 kg ha^{-1} of N–urea applied as top dressing.
The experimental plots consisted of four rows 5 m long and 0.50 m apart. The adoption of the spacing of 0.50 m considered the results obtained by May et al. (2015). The useful plot was composed by the two central lines, excluding 1 m from each end. Sowing was carried out on November 04, 2015 with a mechanical seeder for no-till, equipped with a vacuum system, aiming a population of 110 to 120 thousand plants ha^{-1}. For insect control, triflumurom, flubendiamide and lambda-cyhalothrin were applied at 10, 26 and 28 days after planting (DAP), and the herbicide atrazine at 26 DAP for weed control.

Evaluations

The evaluations were carried out at the same time of the harvest, which took place on March 08, 2016, considering only the plants from the useful plot. In the field, plant height (measured, in meters, from the soil surface to the tip of the grain panicle with the aid of a ruler) and the diameter of the stem (diameter, in mm, measured with the aid of a digital caliper in the third node of the plant) was measured in five plants per plot.
Five plants of each plot were then cut close to the surface of the soil, crushed in a forage harvester and then weighed. From the resulting material, a sample of approximately 200 g was collected, weighed and taken to a drying oven with forced air circulation at 65 °C until constant mass. The samples were weighed again for moisture correction and then the values were converted to kg ha^{-1} to obtain the dry matter.
The samples were analyzed for N, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn and B, according to the methodologies described by Silva (2009). With the content of these nutrients and the shoot dry matter, the export of nutrients was calculated in kg ha^{-1}.

Statistical analysis

Data were submitted to analysis of variance. Once the treatment effect was detected by the F test, the results were submitted to polynomial multiple regression analysis (Ferreira, 2011). The simplified balance of nutrients N and K was calculated by subtracting the quantity exported by the plant from the applied doses of the element.

Conclusions

The hybrid of biomass sorghum Palo Alto 2562, cultivated in an Oxisol, positively responds (in terms of dry matter production) to N fertilization up to the dose of 280 kg ha^{-1}, requiring at least 140 kg ha^{-1} N in order to avoid depletion of N levels in the soil. The hybrid of biomass sorghum Palo Alto 2562 has a high absorption capacity of K, which is the most absorbed nutrient by the plant. Part of the accumulated K, however, seems to be associated with a luxurious absorption characteristic of the plant. In conditions of an Oxisol with high level of K and high K saturation in the CEC, the K fertilization may negatively affect the dry matter production of biomass sorghum hybrid Palo Alto 2562, so the best option would be to refrain K as fertilizer.

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