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Sweet potato yield in response to different potassium sources and splitting of fertilization[1]

Produção de batata-doce em resposta a diferentes fontes de potássio e parcelamento da adubação

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HIGHLIGHTS:

All sources and splitting of the potassium fertilization resulted in a yield higher than the national marketable yield for sweet potatoes.
Potassium sulfate promoted a greater marketable yield when split by 50% at planting and 50% at 60 days after planting.
The highest foliar potassium concentration was with potassium sulfate at 100% at planting.

ABSTRACT: Sweet potatoes are an important staple food for human consumption. This study evaluated sweet potato yield in response to potassium fertilization using different sources and splitting. It was conducted at the Universidade Federal da Paraíba, Areia-PB. A complete randomized block experimental design was used in a 7 × 2 factorial arrangement. The fertilization was split into seven treatments (100% after planting; 100% at 30 days after planting (DAP); 100% at 60 DAP; 50% after planting and 50% at 30 DAP; 50% after planting and 50% at 60 DAP; 50% at 30 DAP and 50% 60 at DAP; 33% after planting, 33% at 30 DAP, and 33% at 60 DAP). Two fertilization sources were used, namely potassium chloride and potassium sulfate, with three replicates. Plant fresh mass, mass of marketable roots, production of marketable roots per plant, leaf K concentration, total and marketable root yields were evaluated. Chloride and sulfate potassium efficiently increased the fresh mass of the plant and the mass of marketable roots, respectively. The marketable yield of the roots (25.16 and 22.28 Mg ha^{-1}) was higher than the national average (14.07 Mg ha^{-1}) when K_2O was supplied in the sulfate and potassium chloride sources, respectively. The leaf K concentration remained within the standard levels for the crops under chloride and potassium sulfate fertilization. Potassium sulfate application results in higher sweet potato yields. When supplied in a single application, chloride and sulfate potassium increase the total and commercial yield only when the plants are at 60 DAP.

Key words: *Ipomoea batatas*; chloride; mineral nutrition; sulfate

RESUMO: A batata-doce é uma hortaliça alimentar básica para a população. Este trabalho objetivou-se avaliar o rendimento da batata-doce em resposta à adubação potássica com diferentes fontes e parcelamento. O trabalho foi conduzido na Universidade Federal da Paraíba, em Areia-PB. O delineamento experimental foi de blocos casualizados em arranjo fatorial 7 × 2, com sete épocas de aplicação (100% no plantio; 100% aos 30 dias após o plantio (DAP); 100% aos 60 DAP; 50% no plantio e 50% aos 30 DAP; 50% no plantio e 50% aos 60 DAP; 50% aos 30 e 50% aos 60 DAP; 33% no plantio 33% aos 30 e 33% aos 60 DAP) e duas fontes, cloreto e sulfato de potássio, com três repetições. As variáveis analisadas foram à massa fresca por planta, massa média de raízes comerciais, produção de raízes comerciais por planta, teor de K foliar, produtividades total e comercial de raízes. O cloreto e sulfato de potássio incrementaram a massa fresca da planta e a massa de raízes comerciais, respectivamente. As produtividades comerciais de raízes (25,16 e 22,28 Mg ha^{-1}) foram superiores à média nacional (14,07 Mg ha^{-1}), quando se forneceu K_2O nas fontes sulfato e cloreto de potássio, respectivamente. O teor de K foliar ficou dentro do padrão para a cultura, sob adubação de cloreto e sulfato de potássio. A aplicação de sulfato de potássio proporciona maior rendimento de batata-doce. O cloreto e o sulfato de potássio, quando fornecidos em uma única aplicação, aumentam a produtividade total e comercial somente quando as plantas estão aos 60 DAP.

Palavras-chave: *Ipomoea batatas*, cloreto, nutrição mineral, sulfato

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INTRODUCTION

Sweet potatoes (*Ipomoea batatas* [L.] Lam.) are a staple food used for human consumption. This crop is of high socioeconomic importance because of its nutritional properties, adaptability to different edaphoclimatic conditions, and high yield within a short period (Amaro et al., 2017; Glato et al., 2017).

In the state of Paraíba, sweet potatoes are widespread and mainly cultivated in the micro-region of Brejo and along the state coastline. The state of Paraiba is one of the largest sweet potato producers in Brazil. However, the area has a low average productivity of 7.78 Mg ha^{-1} (Landau et al., 2020). This can be attributed to inadequate use of fertilizers by producers, due to a lack of basic or technical information on growing the crop (Leonardo et al., 2014). Furthermore, there is also a lack of technical-scientific information on nutritional management of sources and splitting of fertilizer application recommended for this crop.

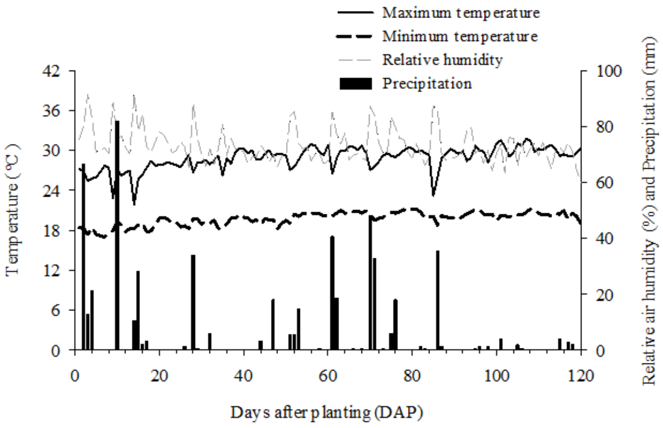
Potassium influences the quality and development of vegetables by increasing biomass production and leaf area and reducing sugar concentration. Meanwhile, potassium deficiency reduces the distribution of assimilates via the phloem (Corrêa et al., 2018; Koch et al., 2020). The demand for this macronutrient can be met by using potassium chloride (KCl) and potassium sulfate (K_2SO_4) (El-Mogy et al., 2019). Owing to the accompanying ions, these fertilizers can generate distinct responses in root production.

The splitting of fertilizer applications is also one of the factors that influences nutrient uptake by plants. This is particularly the case for nutrients that are mobile in the soil, such as potassium (Ribeiro et al., 2014; Guerra et al., 2020). Splitting this nutrient should therefore be considered to avoid losses due to leaching, especially on sandy-textured soils (Nascimento et al., 2017).

Therefore, this study aimed to evaluate sweet potato yield in response to potassium fertilization from different sources, as well as the effects of fertilizer splitting.

MATERIAL AND METHODS

The current study was carried out under field conditions at the Center of Agrarian Sciences at the Universidade Federal da Paraíba (UFPB), Areia, Paraiba, in the microregion of Brejo Paraibano (6°57'26" S and 35°45'30" W; altitude of 620 m). According to Köppen's classification, the climate is As type, characterized as hot and humid, with average annual precipitation of 1.200 mm occurring from March to August (Alvares et al., 2013; Francisco & Santos, 2017). The meteorological conditions during the experimental period are shown in Figure 1.



Source: INMET Automatic Weather Station of Areia, PB, Brazil

Figure 1. Maximum and minimum air temperature, relative air humidity, and precipitation during the period of cultivation for the sweet potato 'Campina' variety

The soil in the experimental area was classified as an Entisol with a sandy loam texture (Santos et al., 2018). Soil samples were collected at a depth of 0-20 cm prior to the start of the experiment to analyze the chemical and physical attributes. The results are shown in Table 1.

A randomized block design was used, in a 7 × 2 factorial scheme, with three replicates. The factors were composed of two sources of potassium fertilizer (potassium chloride and potassium sulfate) and seven application splitting: 100% at planting; 100% at 30 days after planting (DAP); 100% at 60 DAP; 50% at planting and 50% at 30 DAP; 50% at planting and 50% at 60 DAP; 50% at 30 and 50% at 60 DAP; 33% at planting, 33% at 30 and 33% at 60 DAP, in three replicates. The experimental plot comprised 4.8 m^2 area with 40 plants, distributed across four lines, all of which were considered valid for evaluation.

The soil was prepared by plowing, harrowing, and ridging. Planting was then carried out using cuttings of the 'Campina' variety obtained from a young plantation (between 70 and 80 days) near the study area. The cuttings were approximately 40 cm in length and were planted at a depth of 10-12 cm.

Fertilization at planting consisted of 15 Mg ha^{-1} of cattle manure (5% moisture), 100 kg ha^{-1} of triple superphosphate (P_2O_5), and potassium fertilization corresponding to 100 kg ha^{-1} of K_2O in sources, with the splitting as described in the experimental design. The fertilizers were applied at a depth of 15 cm in a continuous open furrow at the top of each ridge and under cover fertilization, distributed in a line on the side of each ridge, before being covered with soil. For nitrogen fertilization, 100 kg ha^{-1} of nitrogen (urea) was applied at 30 and 60 DAP (Filgueira et al., 2008).

Table 1. Chemical and physical attributes of the soil in the experimental area

Chemical characteristics										
pH	P	K^+	Na^+	$H^+ + Al^{3+}$	Al^{3+}	Ca^{2+}	Mg^{2+}	BS	CEC	OM
H_2O (1:2.5)	(mg dm^{-3})		(cmol$_c$ dm^{-3})							(g kg^{-1})
6.70	1.95	63.50	0.03	1.90	0.00	0.49	0.23	0.92	2.82	15.60

Physical characteristics						
Coarse sand	Fine sand	Silt	Clay	Soil density	Particle density	Total porosity
(g kg^{-1})				(g cm^{-3})		(m^3 m^{-3})
652	130	87	64	1.61	2.63	0.39

P, K^+, Na^+ - Extractor Mehlich 1; $H^+ + Al^{3+}$ - Extractor calcium acetate (0.5 M) and pH 7.0; Al^{3+}, Ca^{2+}, Mg^{2+} - Extractor KCl 1 Mol L^{-1}; BS - Base saturation; CEC - Cation exchange capacity; and OM - Organic matter (Walkley-Black)

Manual weeding was performed using hoes to keep the area free of weeds. In the absence of precipitation, water was supplied on alternate days via a drip system (drip tape). Phytosanitary control was not performed, due to the absence of pests and diseases capable of causing economic damage.

The plant fresh mass was assessed based on the average weight of two plants taken from each plot at 80 DAP. After weighing, the leaves were removed, placed in paper bags, brought to the laboratory, and dried to constant mass in an oven with forced air circulation at 65 °C. They were then weighed on a precision scale to obtain the leaf dry mass. The dried leaves were then ground to determine the K concentration, following the methodology of Tedesco et al. (1995).

Harvesting took place 120 DAP. The mass of commercial roots was determined by the ratio of plot production to the number of marketable roots. Roots weighing between 200 and 500 g were considered to be marketable (Silveira et al., 1997).

The number of marketable roots per plant was calculated as the ratio of the number of commercial roots to the number of plants in each plot. The yield of marketable roots per plant was calculated as the ratio between the marketable root weight and number of plants in each plot, with the results being expressed in grams. The total yield was obtained from the weight of all the roots that were harvested in the plot, with the marketable yield corresponding to the marketable roots.

Analysis of variance was conducted on the dataset. The means were grouped using the Scott-Knott mean test. All the analyses were performed using R statistical software (R Core Team, 2021).

Results and Discussion

The fresh mass per plant was influenced by the fertilizer source. In addition, interactions between treatments were observed. Potassium sources positively affected the mass and marketable production of roots, with interactions between these factors.

The sources and splitting of the potassium fertilizer application and their interaction influenced the mass and the marketable yield of roots. The yield of marketable roots per plant and the total yield were also affected by the splitting and interaction between fertilizer sources. The leaf K concentration was only affected by the splitting of potassium sources. In contrast, these two factors had no effect on leaf dry mass or the number of marketable roots per plant (Table 2).

When potassium chloride was provided at a proportion of 33% after planting, at 30 DAP, and at 60 DAP, the plants reached a fresh mass of 474.50 g. However, this was not statistically different from the application of 100% at 60 DAP (Table 3). When potassium sulfate was provided, plants had the lowest fresh mass at 190.50 g per plant. However, when this nutrient was provided at 100% at 30 DAP, it promoted a fresh mass of 321.75 g per plant. This result was similar to that obtained on the application of 50% at 30 and 60 DAP (Table 3). The higher level of accumulation of fresh mass per plant, in response to potassium chloride source, can be explained by the combination of K^+ and Cl^- ions directly participating in the cell division of leaves, favoring the production of leaf biomass (Wege et al., 2017; Koch et al., 2020).

The application of potassium chloride reduced the commercial mass of roots by 14.60% compared with that of potassium sulfate (Table 3). Potassium sulfate, applied at 50% after planting and 50% at 30 DAP, resulted in the highest marketable root weight (454.20 g). However, lower values were obtained (368.97 g) when 100% potassium chloride was used at 30 DAP (Table 3).

Regardless of the potassium source and splitting, the marketable root mass of the sweet potatoes was within the standard range for the crop, between 200 and 500 g (Silveira et al., 1997). Given the crop response to K_2O, potassium sulfate should not be entirely supplied post planting before the sweet potatoes start to form an adequate leaf area. Similar results were obtained by Oliveira et al. (2019), when studying the effect of potassium

Table 3. Plant fresh mass (PFM), marketable root mass (MRM), and marketable root production per plant (MRPP) of sweet potato in response to potassium sources and fertilization splitting

Source	Splitting (%)			PFM	MRM	MRPP
	Planting	30 DAP	60 DAP		(g)	
KCl	100	0	0	312.16 bA	256.49 cB	100.78 bB
	0	100	0	318.50 bA	368.97 aA	114.51 bB
	0	0	100	390.00 aA	253.78 cB	115.10 bB
	50	50	0	286.00 bA	320.81 bB	183.30 aA
	50	0	50	273.00 bA	312.75 bB	207.34 aB
	0	50	50	234.00 cB	300.92 bB	126.23 bB
	33	33	33	474.50 aA	273.45 cB	210.34 aA
K_2SO_4	100	0	0	217.75 bB	367.87 cA	149.87 cA
	0	100	0	321.75 aA	253.89 eB	143.32 cA
	0	0	100	218.15 bB	360.08 cA	150.04 cA
	50	50	0	273.00 aA	454.20 aA	135.04 cB
	50	0	50	286.00 aA	425.25 bA	243.32 aA
	0	50	50	309.00 aA	327.87 dA	200.14 bA
	33	33	33	190.50 bB	255.00 eA	100.14 dB

Lowercase letters compare the means of the splitting treatments within each source. Capital letters compare the means between sources within each splitting. Means followed by the same letter do not differ according to the Scott-Knott cluster test ($p \leq 0.05$). DAP: days after planting

Table 2. Summary of the analysis of variance for plant fresh mass (PFM), leaf dry mass (LDM), K leaf concentration (KLC), marketable root mass (MRM), number of marketable roots per plant (NMRP), production of marketable roots per plant (MRPP), total yield (TY) and marketable yield (MY) of sweet potato roots, in response to K_2O sources and application splitting

Source of variation	DF	Mean squares							
		PFM	LDM	KLC	MRM	NMRP	MRPP	TY	MY
Potassium sources (P)	1	56485.0**	17.8^{ns}	15.1^{ns}	22811.2**	0.02^{ns}	1246.5^{ns}	13.1^{ns}	15.70**
Application splitting (A)	6	2773.6^{ns}	6.6^{ns}	27.8**	12292.8**	0.71^{ns}	3353.4**	92.2**	18.72**
Interaction (P x A)	6	28131.6**	34.3^{ns}	7.9^{ns}	13805.9**	0.35^{ns}	11089.1**	89.9**	73.96**
Blocks	2	921.6^{ns}	13.7^{ns}	2.2^{ns}	56.7^{ns}	0.88^{ns}	774.7^{ns}	4.2^{ns}	2.50^{ns}
Residue	26	1907.0	20.36	4.15	178.90	0.32	623.8	3.65	1.51
CV (%)		11.8	27.1	5.0	3.3	18.1	12.9	6.8	7.4

ns, *, **: not significant, significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test; CV: coefficient of variation; DF: degree of freedom sources and splitting on the cultivation of potato cultivar 'Agata'. They found that splitting of K_2O, which is monovalent, must be undertaken to avoid losses due to leaching, mainly on low cation exchange capacity soils.

The mean masses obtained from this study demonstrated the effect of the potassium sulfate source, regardless of the splitting, on sweet potatoes. This may be attributed to the potassium activity of the starch synthase enzyme, associated with sulfate ion functions, in the formation of amino acids (cysteine, methionine, and cystine). These are essential protein components in the metabolic processes of vegetables (Chrysargyris et al., 2017; Nakai & Maruyama-akashita, 2020).

Splitting of potassium chloride at planting, 30 and 60 DAP, did not differ from the splitting at 50% after planting and at 30 or 60 DAP and potassium sulfate provided after planting and 60 DAP provided the highest production of marketable roots per plant at 210.34 and 243.3 g, respectively (Table 3). The higher increment provided by the potassium sulfate could be attributed to the part of the supply at planting that favored root growth. In addition, the sulfate reacted in non-acidic soils, as these contain substantial amounts of calcium favoring the formation of gypsum ($CaSO_4$), which promotes an improvement in soil fertility in depth, thereby increasing the size of the plant root system and consequently the yield (Pauletti et al., 2014; Taiz et al., 2017).

The performance of potassium sulfate was superior to that of potassium chloride for sweet potato yield. This nutrient is recommended for increasing the production of marketable roots per plant, splitting it into equal parts at planting and then at 60 DAP. This nutrient source can favor the formation and redistribution of carbohydrates because of its composition. Leaching of fertilizers can hamper production and impact the environment. However, when fertilizers are applied at the time of the greatest crop demand, leaching losses are avoided.

The total yield was the highest when 100% potassium was provided at 30 DAP (27.45 Mg ha^{-1}) and 60 DAP (30.96 Mg ha^{-1}), with potassium chloride and potassium sulfate, respectively (Table 4). The higher increments of potassium sulfate are likely due to its composition and the leaf area of the plants, resulting in better use of the nutrients. This was likely because the leaves provide the necessary tension in the xylem to extract soil water and nutrients via transpiration (Cochard, 2014; Taiz et al., 2017). However, there were no significant differences between the sources in terms of total yield (Table 4).

Table 4. Total (TY) and marketable (MY) yield of sweet potato roots in response to potassium sources and fertilization splitting

Source	Splitting (%)			TY	MY
	Planting	30 DAP	60 DAP	(Mg ha^{-1})	
KCl	100	0	0	17.67 cA	15.86 bA
	0	100	0	27.45 aA	22.28 aA
	0	0	100	18.85 cB	15.21 bB
	50	50	0	23.35 bA	17.36 bB
	50	0	50	18.10 cA	16.10 bA
	0	50	50	19.64 cB	14.23 bB
	33	33	33	24.27 bA	20.75 aA
K_2SO_4	100	0	0	17.01 cA	15.13 cA
	0	100	0	25.50 bA	20.83 bA
	0	0	100	30.96 aA	25.16 aA
	50	50	0	24.87 bA	20.72 bA
	50	0	50	17.19 cA	15.35 cA
	0	50	50	26.52 bA	23.70 aA
	33	33	33	18.02 cB	17.80 cA

Lowercase letters compare the means of the splitting treatments within each source. Capital letters compare the means between sources within each splitting. Means followed by the same letter do not differ from each other according to the Scott-Knott cluster test ($p \leq 0.05$). DAP: days after planting

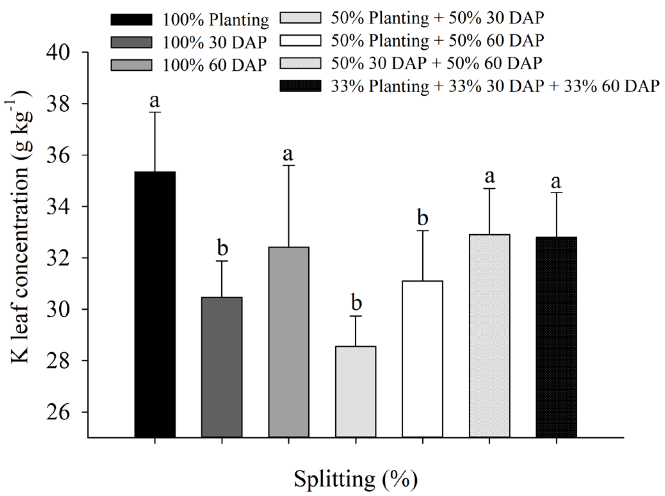
The splitting use of potassium chloride applied 100% at 30 DAP and 33% at planting, 33% at 30 and 33% at 60 DAP, resulted in a yield of marketable roots of 22.28 and 20.75 Mg ha^{-1}. Higher yield (25.16 and 23.70 Mg ha^{-1}) was obtained when potassium sulfate was provided 100% at 60 DAP and 50% at 30 DAP and 60 DAP, respectively (Table 4). These results are above average productivity for the state of Paraíba (7.78 Mg ha^{-1}) and national productivity (14.07 Mg ha^{-1}), according to Landau et al. (2020).

The highest marketable yield was obtained using potassium sulfate. Similarly, Cardoso (2018) evaluated the fertilization of sweet potatoes with different potassium sources under the same edaphoclimatic conditions and obtained higher yield when potassium was supplied in the form of potassium sulfate. Taye et al. (2015) evaluated the response of potato (*Solanum tuberosum* L.) to two sources of potassium and observed a, higher tuber yield using potassium sulfate rather than potassium chloride. This demonstrates that potassium sulfate supplied as a split dose or in a single dose when plants have higher leaf area increases yield and meets the nutritional requirements for sweet potatoes.

When the influence of potassium sources on marketable yield was compared, the application of potassium sulfate had a more pronounced effect. This is likely due to its composition, which comprised 50% K_2O and 18% sulfur. The absorption of sulfate (SO_4^{-2}) has a beneficial effect on the metabolic process of vegetables because it is an essential component of proteins through amino acids and an active constituent of numerous coenzymes (Kopriva et al., 2015; Dong et al., 2017). Therefore, proper management of nutrients such as potassium and sulfur is crucial. Both are macronutrients that play essential roles in plant growth and development, favoring enzymatic processes, assimilating translocation, and amino acid synthesis, thereby resulting in higher productivity (Kopriva et al., 2015; Taiz et al., 2017).

The highest leaf K concentration was obtained with the application of 100% potassium after planting. However, this did not differ statistically from the results obtained on 100% supply at 60 DAP and on splitting fertilizer application by two (50% at 30 and 60 DAP) and three times (33% after planting, 33% at 30 DAP, and 33% at 60 DAP) (Figure 2). Regardless of the sources used, potassium splitting led to leaf K concentrations within the correct range for this crop (4 - 43 g kg^{-1}), according to Batista et al. (2018).

The findings of our study are similar to those reported by Cecílio Filho et al. (2016) on the effect of potassium on sweet potato, with leaf K concentrations ranging from 21.5 - 44.6 g kg^{-1}. Therefore, regardless of the K source used, the K concentration in the leaves is a consequence of the availability of this nutrient in the soil and the conditions of absorption by the roots (Taiz et al., 2017; Batista et al., 2018).



Fertilization splitting means followed by the same letters do not differ statistically by the Scott-Knott test at $p \geq 0.05$. DAP: days after planting

Figure 2. Leaf K concentration in response to fertilization splitting in sweet potato

CONCLUSIONS

1. Potassium sulfate application results in higher sweet potato yields.

2. When supplied in a single application, chloride and sulfate potassium increase the total and commercial yield only when the plants are at 60 days after planting (DAP).

3. The splitting of potassium chloride and potassium sulfate into three applications (planting, 30 and 60 DAP) and two applications (30 and 60 DAP), respectively, is recommended for sweet potato cultivation.

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