Journal of Sustainable Development; Vol. 18, No. 2; 2025
ISSN 1913-9063 E-ISSN 1913-9071
Published by Canadian Center of Science and Education

Alternative Sources of Potassium for Soybean Crops

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Received: January 1, 2025 Accepted: February 1, 2025 Online Published: February 6, 2025

doi:10.5539/jsd.v18n2p1 URL: https://doi.org/10.5539/jsd.v18n2p1

Abstract

Over the last three decades, soybean production in the Brazilian agricultural sector has experienced significant yield growth. The soil must have adequate fertility to provide nutrients for good agricultural yield. This study aimed to evaluate the effect of different sources and doses of potassium on the soybean grain yield and its components. The experiment was conducted in the 2022/2023 crop season at the experimental field of the Goiás State University in Ipameri, GO. The experimental design used was randomized blocks arranged in a 3 x 5 factorial scheme, with three potassium sources potassium chloride (KCl: 58% K_2O), Phonolite (Ph1:8% K_2O and 25% Si), and Hydrothermalized Phonolite (HPh2:12% K_2O and 25% Si) and five doses (0, 50, 100, 150, and 200 kg ha^{-1}), with four replications. The management used the no-till system on sorghum straw planting the NEO 750 IPRO soybean cultivar. According to the results, there was an influence of the interaction between the factors only on the number of pods per plant. The potassium doses influenced the first pod insertion height, hectoliter mass, and grain yield. Based on the results, potassium fertilization using the alternative sources, Ph1 and HPh2, reached satisfactory grain yield levels compared to KCl, with the maximum grain yield value, regardless of the source, occurring at a dose of 138.18 kg ha^{-1} of potassium.

Keywords: bioinputs, *Glycine max* L, phonolite, yield

1. Introduction

Over the last 30 years, the soybean crop has shown remarkable growth in yield in the Brazilian agricultural sector (Ramos et al., 2020). The state of Goiás has played a significant role in soybean production, standing out as one of the main producers of this commodity in the country, contributing to increased yield in the 2022/2023 crop season, helping Brazil to become the world's largest producer and exporter of the product (Diniz et al., 2023; Paulino et al., 2020).

In the state of Goiás, the nutritional requirements for the soybean crop are expressly associated with the low availability of nutrients such as calcium (Ca), magnesium (Mg), phosphorus (P), and potassium (K), which are relatively low in Cerrado soils (Gonçalves Júnior et al., 2010). These nutritional conditions are even more impactful for potassium (K), as this is the second most demanded nutrient by the soybean crop, second only to nitrogen (N) (Zancanaro et al., 2019).

Cerrado soil nutritional deficiency impacts the region's grain yield, affecting important crops such as soybeans, corn, sorghum, millet, cotton, and sugarcane. The low natural availability of potassium in these soils requires specific management strategies, including applying potassium fertilizers to increase the amounts of this nutrient in the soil (Cavalli & Anderson, 2018).

Tackling these nutritional deficiencies highlights the need for targeted agricultural practices to ensure sustainability and efficiency in production and minimize the impacts of this nutritional limitation (Maciel et al., 2021). Cerrado soil is still economically viable for Brazilian agriculture despite needing nutritional correction. This viability has enabled the expansion of agricultural production areas, strengthening the country's agricultural sector (Taglieber et al., 2022). For the 2023/2024 crop season, production is estimated at 317.5 million tons of grain on 78 million hectares under cultivation, with an average yield of 4.07 t ha^{-1} (Conab, 2023). To achieve gains in grain yield, it is necessary to understand the crop nutritional requirements. Thus, for every 1000 kg of soybeans produced from different cultivars, the following can be extracted from the soil: 63 to 93 kg ha^{-1} of N, 4.7 to 8.5 kg ha^{-1} of P, 29 to

62 kg ha^{-1} of K, 15 to 30 kg ha^{-1} of Ca, 9 to 11 kg ha^{-1} of Mg, and 3.6 to 4.7 kg ha^{-1} of S (Gonçalves Júnior et al., 2010).

For a nutrient to be considered essential to plants, it needs to be part of three basic principles, be necessary for the entire life cycle of the plant performing a vital function in its development, another element cannot replace it to perform its specific metabolic functions, and the deficiency of this element results in specific symptoms where its addition to the soil or substrate leads to the recovery or improvement of these symptoms (Batista et al., 2018). These principles are verified for K, so the deficiency of this nutrient directly affects crop yield, especially for soybeans, where K is the second most demanded nutrient by the crop. In this context, this study aimed to evaluate the effect of different sources and doses of potassium on the soybean grain yield and its components.

2. Materials and Methods

2.1 Experimental Area

The experiment was conducted under field conditions in the 2022/2023 crop season, according to agricultural zoning in the experimental area of the Goiás State University, South Campus, University Unit of Ipameri, located in Ipameri, GO at 17°71'85“ S, 48°12'81” W, and an altitude of 794 m.

According to the Köppen Geiger classification (Cardoso et al., 2014), the climate of the region is tropical (Aw-type), with a dry season in winter. The soil in the experimental area was classified as Latossolo Vermelho-Amarelo distrófico, with a sandy clay texture (Scariot, 2005). The soil's chemical and physical attributes were determined by soil analysis before the experiment was set up. According to the methodology proposed by Ribeiro et al. (1999), the chemical attributes in the 0-20 cm layer were as follows: 3.7 mg dm^{-3} of P (Melich), 14.0 mg dm^{-3} of O.M., pH in $CaCl_2$ of 5.4, 0.13 mg dm^{-3} of K, 1.10 cmol$_c$ dm^{-3} of Ca, 0.54 cmol$_c$ dm^{-3} of Mg, H+Al of 4.12 cmol$_c$ dm^{-3}, CEC of 6.40 cmol$_c$ dm^{-3}, and base saturation of 31.1%. The values of the physical attributes were: sand: 490 g kg^{-1}, silt: 66 g kg^{-1}, and clay: 444 g kg^{-1}.

2.2 Experimental Design

The experimental design used was randomized blocks, with four replications, arranged in a 3 x 5 factorial scheme. Three potassium sources (potassium chloride, Ph1, and HPh2) and five doses (0, 50, 100, 150, and 200 kg ha^{-1}), applied via soil, were evaluated. The potassium concentrations of the respective sources are: Potassium chloride (KCL: 58% K_2O), Phonolite (Ph1: 8% K_2O and 25% Si), and Hydrothermalized Phonolite (HPh2: 12% K_2O and 25% Si). Each plot consisted of six five-meter-long rows spaced 0.50 m apart, with 12 plants per meter, giving a total area of 20 m². The useful area consisted of the three central rows, with 1.0 m left out at both ends of each plot.

2.3 Experiment Management

The no-till system was used on sorghum straw. The fertilization in the sowing furrow was conducted according to the soil analysis and the recommendations of Ribeiro et al. (1999) using 250 kg ha^{-1} of MAP (11% N and 52% P_2O_5). The soybean cultivar used was NEO 750 IPRO, with an indeterminate cycle. Sowing was conducted using a 7-row precision seeder equipped with horizontal honeycomb disc seed distribution mechanisms and furrower fertilizer application mechanisms.

The seeds were treated with a systemic insecticide with the active ingredient Cyantraniliprole (600 g L^{-1}), using 60 mL of the product for every 100 kg of seeds. The systemic fungicide Thiophanate Methyl (350 g L^{-1}) plus Fluazinam (52.5 g L^{-1}) was also used at 200 mL of the product for every 100 kg of seeds. Inoculation was liquid using 240 mL per 100 kg of seeds with *Bradyrhizobium japonicum* and *Bradyrhizobium elkani* bacteria, with a guarantee of $7x10^9$ CFU mL^{-1}.

The potassium sources were applied manually, with their respective treatments in each plot 30 days before sowing. Other crop treatments, such as weed control, used herbicides. Fungicides and insecticides were also applied as recommended by Sediyama et al. (2015), conducted mechanically using tractor sprayers.

2.4 Variables Analyzed

Relative chlorophyll index: the chlorophyll content of the soybean leaves was read indirectly using a portable chlorophyll meter (chlorofiLOG model CFL 1030) when the plants were at the R1 stage, using the methodology proposed by Silva et al. (2020), where the leaves in the middle third of the plant were evaluated. The reading was taken on five soybean plants randomly in each plot, obtaining the average per plot and the results were expressed as the Falker chlorophyll index (FCI).

Potassium, sodium, and *silicon leaf content*: 30 leaves were collected from random plants within each plot, with the third leaf from the apex on the main stem being chosen, as recommended by Ribeiro et al. (1999), and the samples were determined according to the methodology described by Malavolta et al. (1997) for potassium and sodium, and by Korndorfer et al. (2004) for silicon;

Potassium content in the grain: 50 g of seeds were collected from each plot, as recommended by Ribeiro et al. (1999), and the samples were analyzed according to the methodology described by Malavolta et al. (1997) for potassium.

For the yield components, the samples were made up of ten plants from the useful area of each plot, which were separated at the time of harvest and taken to the laboratory to determine the following variables:

Plant height: from the ground to the apex of the plants, individually at random in the plot, and then the result of the averages was presented in centimeters (cm);

Stem diameter: measured at the base of the stem using a digital caliper to two decimal places in millimeters (mm);

First pod insertion height: this was determined by measuring the distance between the soil surface and the point of insertion of the first pod in centimeters (cm);

Number of pods per plant: the pods on each of the ten plants in each plot were collected and counted;

Pod length: this was done using a graduated ruler, measuring from one end of the pod to the other in centimeters (cm);

Number of grains per pod: the number of grains present in the pods was counted, and the total number of grains was then divided by the total number of pods on each plant, resulting in the average;

100-grain mass: 100 grains per plot were counted and weighed using a precision scale in grams (g);

Hectoliter mass: determined by the density of the grains from the 30 plants collected per plot on a special 0.25 L hectoliter mass scale, with the water content of the grains corrected to 13% (wet basis).

Grain yield in kg ha^{-1}: determined by harvesting and threshing the useful plot, taking 30 plants per plot. To calculate the yield after threshing, the water content of the grains was adjusted to 13.0%, and impurities were also deducted, with the result expressed in kg ha^{-1}.

2.5 Experimental Analysis

The data was subjected to analysis of variance (F-test) and the means were compared using the Tukey test at 5% probability. Regression analyses were conducted for the sources and doses. The statistical analyses were processed using the R software, version 4.2.2 (R CORE TEAM, 2023).

3. Results and Discussion

Figure 1 shows the maximum and minimum temperatures and rainfall during the months of the experiment. It can be seen that the rainfall was regular, with the month that provided the least rainfall during the experiment being October 2022, with an accumulation of 86.8 mm. January 2023 had the highest volume of rainfall, with an accumulation of 359.9 mm.

During the experiment, the average daily temperature was close to 25.26°C (Figure 1), which is considered ideal for developing the soybean crop since, according to Embrapa (2010), the ideal temperature range for soybeans is between 20 and 35°C.

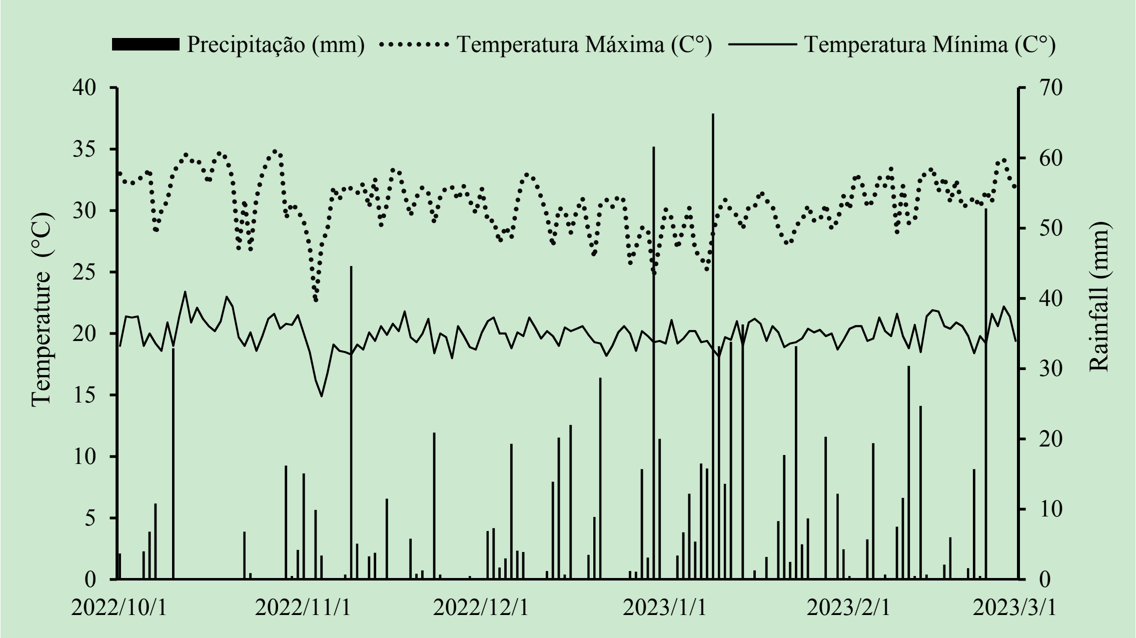

Figure 1. Maximum and minimum temperatures and rainfall at the Goiás State University, Ipameri University Unit, between October 2022 and February 2023. Ipameri GO, 2023. Source: INMET, 2024

Concerning the sources evaluated in this study, the results were similar for the following variables: leaf potassium content, leaf sodium content, leaf silicon content, relative chlorophyll index, plant height, and stem diameter. The doses influenced only the first pod insertion height.

Table 1. Foliar potassium content (FPC), foliar sodium content (FSCT), foliar silicon content (FSCT), relative chlorophyll index (RCI), plant height (PLAH), stem diameter (STED), and first pod insertion height (FPI) in soybean plants according to the potassium sources and doses. Ipameri GO, 2023

K sources	FPC	FSCT	FSCT	RCI	PLAH	STED	FPI
	---- g kg^{-1} DM ----			FCI	Cm	Mm	Cm
KCl	14.21	2.49	1.46	42.01	90.45	7.81	13.23
HPh2	13.43	2.52	1.49	42.58	90.36	7.74	13.61
Ph1	13.78	2.56	1.49	42.65	90.82	7.68	13.28
F-value (Sources)	0.78^{ns}	1.21^{ns}	0.44^{ns}	1.05^{ns}	0.06^{ns}	0.21^{ns}	0.73^{ns}
K doses (kg ha^{-1})							
0	13.85	2.43	1.47	42.51	87.85	8.23	---
50	13.14	2.51	1.49	42.36	91.36	7.66	---
100	14.86	2.58	1.48	42.37	89.98	7.58	---
150	13.44	2.88	1.43	42.22	90.15	7.45	---
200	13.75	2.57	1.54	42.63	93.36	7.80	---
F-value (Doses)	1.31^{ns}	2.47^{ns}	1.60^{ns}	0.13^{ns}	2.33^{ns}	2.48^{ns}	3.69^{*}
F-value (Interaction)	0.49^{ns}	0.99^{ns}	0.94^{ns}	0.86^{ns}	0.82^{ns}	0.58^{ns}	0.70^{ns}
CV (%)	14.28	5.47	7.13	3.60	5.07	8.51	8.08

Means compared by the Tukey test at 5% probability. ^{ns} = Not Significant; * = Significant at 5% probability.

Table 1 shows the F values, coefficients of variation, and the means of the treatments. In the study by Petter et al. (2012), no differences were observed between the control and the treatments with potassium doses up to 150 kg ha^{-1}. However, this increase in K concentrations in the leaves did not influence the relative chlorophyll content (Table 1), showing no direct correlation between K levels in the leaves and chlorophyll synthesis. An increase in the K content of soybean plants was found by Serafim et al. (2012) with the application of increasing doses of potassium chloride. As for chlorophyll content, these data corroborate those obtained by Sousa et al. (2010), who found no effect of K application on chlorophyll content in corn and bean plants, respectively.

Crusciol et al. (2022) observed an increase in leaf content of potassium in corn, soybean, bean, and rice crops in a Latossolo Vermelho distroférrico with clayey texture in the region of Botucatu SP and found that foliar potassium concentrations were significantly affected by fertilizer doses but not by phonolite and silicate sources, their data kept within the range of 17 to 25 g of potassium per kg^{-1} of leaf dry matter, values considered adequate for soybean crops. In this study, leaf content of potassium ranged between 13.14 and 14.86 g kg^{-1}. These values were slightly lower than those of Crusciol et al. (2022). This difference is related to using different varieties with specific adaptation characteristics for each region and climate.

The results in Table 1 indicate no significant difference in the leaf content of sodium, with the control treatment showing 2.43 g kg^{-1}. No studies were found evaluating the contents of this element in soybean leaves, but only in seeds. Azambuja et al. (2015) stated in their studies that the amounts of sodium in soybean seeds can vary from 1.77 to 3.37 g kg^{-1} of dry mass.

The average leaf silicon content was not significant, as shown in Table 1. The Ph1 and HPh2 sources have 25% silicon in their mineral composition. The control treatment had 1.47 g kg^{-1} of leaf content of silicon, while the highest value was found for the dose of 200 kg ha^{-1}, with 1.54 g kg^{-1}. In a study by Crusciol et al. (2022), soybean plants received 2.5 to 3.6 g kg^{-1} of foliar silicon. Their results showed that silicon provided more pods per plant and, consequently, higher grain yields for soybean, bean, and peanut crops.

The results in Table 1 indicate no significant difference in the relative chlorophyll index concerning the different potassium sources and doses. This pattern is consistent with previous studies by Boldrin et al. (2019) on corn and bean crops, which found no significant differences in the relationship between potassium sources and doses and the relative chlorophyll index.

The results did not show a significant influence of potassium sources and doses on the plant height and stem diameter. The plant height ranged between 87.85 cm and 93.36 cm for the control and 200 kg ha^{-1} of potassium, respectively, and the stem diameter between 7.45 mm and 8.23 mm for the 150 kg ha^{-1} and control treatments. These results were divergent from the values found by Petter et al. (2014), where soybean plants showed a quadratic regression for the treatments evaluated with a dose of 90 kg ha^{-1} of potassium, obtaining greater plant height and stem diameter. Potassium is an essential element that acts in photosynthesis since it participates in synthesizing the enzyme ribulose 1.5 bisphosphate carboxylase oxygenase, which is fundamental in the carbon fixation for the formation of glucose. For this reason, different potassium concentrations can interfere with plant development in height and diameter (Silva et al., 2022).

The first pod insertion height (FPI) results show a significant difference concerning the treatments only for the doses. Firmiano et al. (2022) observed no differences between the control treatment and the treatments with potassium doses up to 90 kg ha^{-1}, the authors point out that FPI is a very important variable since insertions too close to the ground represent losses at harvest since the combine header can cut the plants above the first pod. As shown in Figure 2, the highest FPI value occurs for applications of 137.56 kg ha^{-1} regardless of the source evaluated, with a height of 13.86 cm. In their study, Zambiazzi et al. (2017) highlighted the good operational performance of the harvester for soybean plants with an FPI of 12 cm or more. However, for most production areas, the satisfactory height is around 12 to 15 cm above ground level (Rocha et al. 2012).

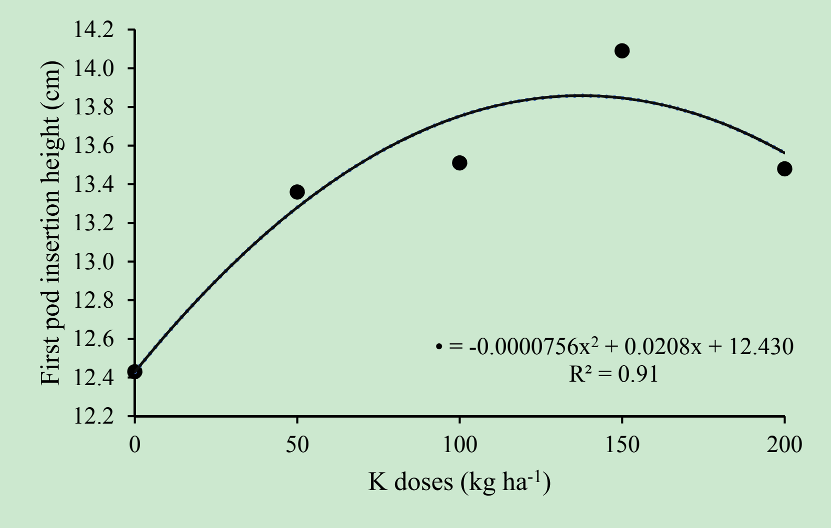

Figure 2. First pod insertion height of soybean according to the potassium doses. Ipameri GO, 2023.

The first pod insertion height, often referred to as the height of insertion of the first flower, is most often influenced by genetic and environmental factors, such as the soybean genotype, weather conditions, water availability, temperature, photoperiod, and agricultural management practices (Liu et al., 2022). However, it is important to maintain a proper balance of nutrients in the soil to promote optimal plant growth, including ensuring adequate levels of potassium and other essential nutrients. Balanced fertilization practices and careful soil management can help promote healthy plant development (Gierth, 2007).

There was no influence of the potassium sources and doses on pod length, number of grains per pod, potassium content in the grains, and 100-grain mass (Table 2). The number of pods per plant was influenced by the interaction between the factors (potassium sources and doses). Hectoliter mass, potassium exported by the grains, and grain yield were influenced (Table 2) only by the potassium doses.

Table 2. Pod length (PL), number of pods per plant (NP), number of grains per pod (NGP), potassium content in the grain (PCG), hectoliter mass (HM), 100-grain mass (M100), potassium exported by the grains (PEX), and grain yield (YLD) of soybean according to the potassium sources and doses. Ipameri GO, 2023

K sources	PL	NGP	M100	NP	PCG	HM	PEX	YLD
	cm	---	g	---	g kg^{-1}	kg 100L^{-1}	kg ha^{-1}	kg ha^{-1}
KCl	3.82	2.74	15.91	---	11.45	73.16	49.17	4295.15
HPh2	3.80	2.78	15.81	---	11.31	73.11	46.33	4096.85
Ph1	3.84	2.78	15.57	---	11.76	72.98	50.87	4318.60
F-value (Sources)	0,25^{ns}	0.21^{ns}	1.35^{ns}	5.04*	0.76^{ns}	0.43^{ns}	1.11^{ns}	1.88^{ns}
K doses (kg ha^{-1})								
0	3.89	2.85	15.58	---	11.52	---	---	---
50	3.81	2.71	15.66	---	11.20	---	---	---
100	3.76	2.70	15.63	---	11.40	---	---	---
150	3.79	2.73	15.90	---	11.26	---	---	---
200	3.84	2.83	16.04	---	12.15	---	---	---
F-value (Doses)	0.71^{ns}	1.15^{ns}	1.04^{ns}	17.13*	1.22^{ns}	3.11*	2.94*	5.57*
F-value (Interaction)	0.66^{ns}	0.29^{ns}	0.67^{ns}	3.75*	1.11^{ns}	1.48^{ns}	1.75^{ns}	2.13^{ns}
CV (%)	5.16	8.12	4.24	4.75	10.33	0.81	14.43	6.79

Means compared by the Tukey test at 5% probability. ^{ns} = Not Significant; * = Significant at 5% probability.

Pod length and number of grains per pod were not influenced by the potassium sources and doses, with the pod length varying between 3.76 and 3.89 cm for the 100 kg ha^{-1} and control treatments, respectively. The number of grains per pod ranged from 2.70 to 2.85 grains per pod for the 100 kg ha^{-1} and control treatments, respectively. These two variables are directly linked since the larger the pods, the greater the number of grains present, considered when all the grains are well formed.

For the 100-grain mass, the results found in Table 2 were not significant for potassium sources and doses; the mass ranged from 15.58 g (control) to 16.04 g (200 kg ha^{-1}). Bazzo et al. (2021) found that the plants receiving a dose of 200 kg ha^{-1} of potassium chloride produced grains with the highest mass without significantly differing from the treatments with 50, 100, and 150 kg ha^{-1}. The lowest value for this variable was found in the treatment with no potassium fertilization.

When evaluating the number of pods per plant, there was a quadratic adjustment of the data for the sources and doses evaluated, as shown in Figure 3. The maximum points estimated were 102.66, 132.14, and 178.72 kg ha^{-1} of HPh2, Ph1, and KCl, respectively, and the values for the number of pods were 57, 60, and 67 for the HPh2, Ph1 and KCl sources, respectively.

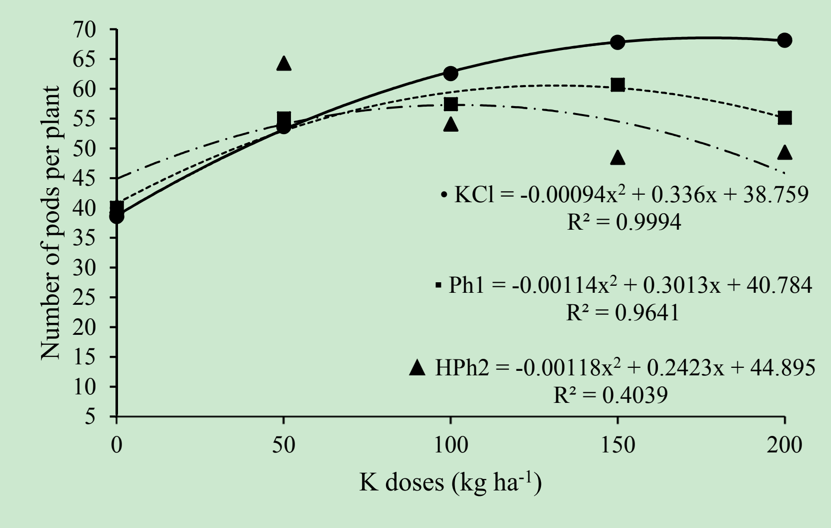

Figure 3. Number of pods per plant of soybean according to the potassium sources and doses. Ipameri GO, 2023.

The availability of potassium below the levels required by the soybean crop can negatively affect crop development, including reducing the number of pods per plant. This highlights the importance of potassium fertilization for suitable soybean crop development (Tonini et al., 2023). The Ph1 and HPh2 sources have low solubility, which leads us to believe that during the flowering process, the soybean plants did not have significant amounts of potassium in the soil solution to ensure a greater number of pods per plant (Teixeira et al., 2015).

Potassium is an essential element that helps prevent the flowers from aborting, and these flowers are fundamental for the formation of pods and later grains. As the Ph1 and HPh2 sources did not have time to make part of their potassium available until the pod formation stage, it leads us to believe that the soil did not yet have significant amounts of this element, thus causing the plants to abort or produce a smaller amount of flowers, which consequently led to a variation in the number of pods lower than the highly soluble source (KCl) (Nóbrega et al., 2017; Batista et al., 2018).

The potassium content in the grains was not influenced by the potassium sources and doses (Table 2). The content ranged between 11.22 g kg^{-1} and 12.15 g kg^{-1} of seed for the 50 kg ha^{-1} and 150 kg ha^{-1} potassium treatments, respectively. These results were divergent from those found in the study by Serafim et al. (2012), where the increase in K content in the grain had a quadratic relationship with the K doses, with the maximum accumulation of K in the grain being 18.5 g kg^{-1} for 200 kg ha^{-1} of potassium chloride. The transport of photoassimilates through the phloem requires the presence of K and is restricted when this nutrient is deficient (GURGEL et al., 2010), so the increase in K in the grain is expected, as it is the main drain of the soybean plant.

The potassium sources did not influence hectoliter mass; however, the potassium doses influenced this variable; the highest hectoliter mass (73.28 kg 100L^{-1}) was estimated at 176.66 kg ha^{-1} (Figure 4). Cavalcante et al. (2016) found a significant influence of nitrogen and potassium doses on the hectoliter mass of wheat. Paredes et al. (2023)

found decreasing hectoliter mass values as nitrogen and potassium doses increased from 0 to 200 kg ha^{-1}. Hectoliter mass refers to the gross weight of the seed in a volume of 100 liters. This variable is considered a quality factor for the wheat crop, where denser hectoliter masses produce a greater quantity of better-quality flour (Santos et al., 2015). There are still no defined standards for hectoliter mass for soybean crops, and the results presented in this study are pioneering. However, it is worth noting that the average value for hectoliter mass for wheat crops concerning six varieties was 69.73 kg 100L^{-1}, which is slightly lower than the hectoliter mass for soybean crops found in this study.

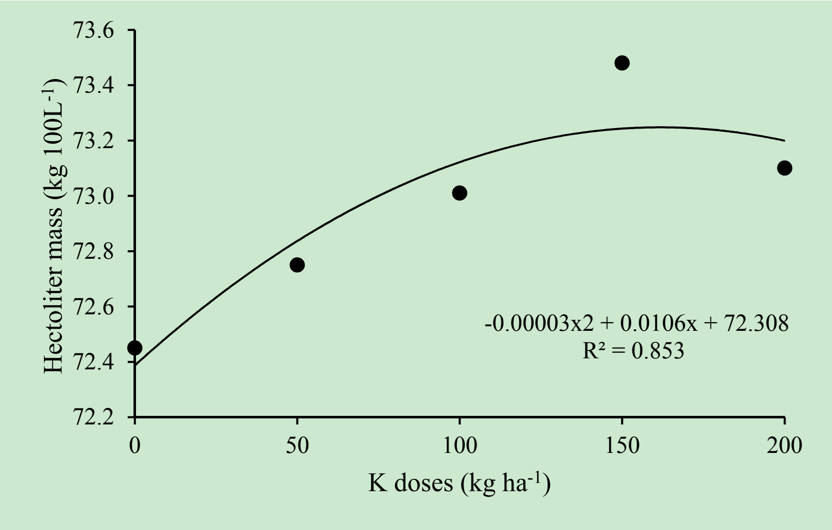

Figure 4. Hectoliter mass of soybean according to the potassium doses. Ipameri GO, 2023.

According to Frigo et al. (2018), soybean cultivars with indeterminate growth habit have a higher potassium extraction demand. Soybeans can export up to 53% of the potassium present in the plant (Mendes et al., 2018). As shown in Figure 5, the extraction of potassium by the soybeans did not show significant values for the sources, but the higher the dose of potassium applied, the grains absorbed more of the element.

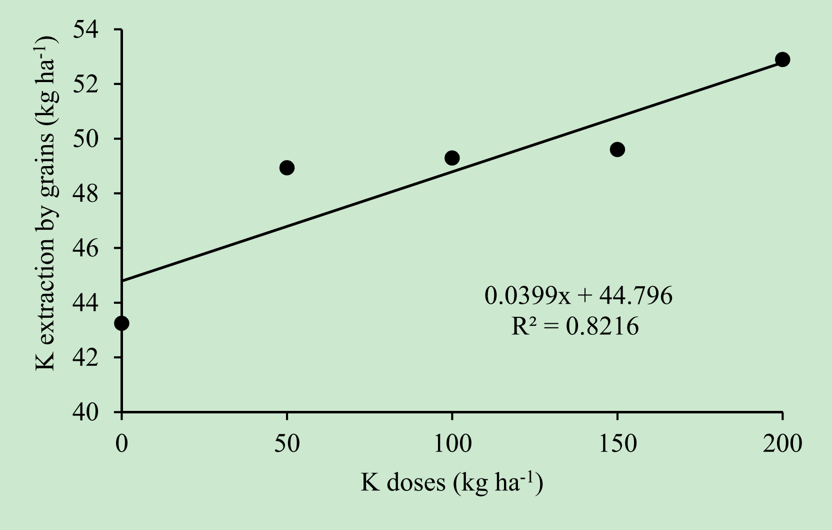

Figure 5. Amount of potassium (K) extracted from the soil by soybeans (in kg ha^{-1}) according to the potassium doses. Ipameri GO, 2023.

Azambuja et al. (2015) cite in their study that there is a sequence of nutrient accumulation in seeds, regardless of their size, variety, and shape, in the following order of magnitude N>K>P>Ca>Mg>S. This leads us to understand how important potassium fertilization is for high grain yield.

There was no influence on the potassium sources of soybean grain yield (Figure 6). Figure 6 shows the fit of the yield data concerning the potassium doses. The highest grain yield was estimated at 138.18 kg ha^{-1} of potassium. The average grain yield was 4,445.3 kg ha^{-1}. The grain yield in this study was higher than the national average for the 2023/2024 crop season of 3,508 kg ha^{-1} and the average of 3,900 kg ha^{-1} in Goiás (Embrapa, 2023).

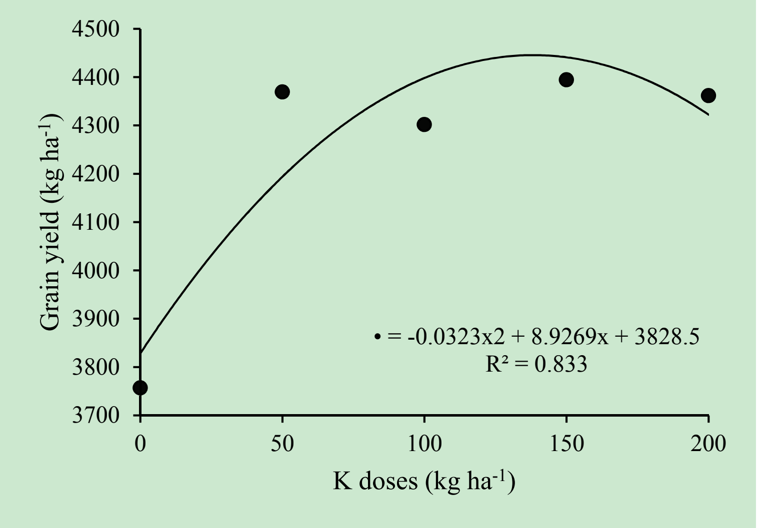

Figure 6. Soybean grain yield according to the potassium doses. Ipameri GO, 2023.

Many studies have been conducted to establish the critical values of potassium in the soil for soybean crops so that the crop response to this element can be assessed (Zambiazzi, 2017). Based on this assumption, the potassium sources applied via soil showed significant responses for the suitable development of the soybean crop since the soil in this experiment had 50.83 mg dm^{-3} of potassium before the experiment was set up. The agronomic bulletins point out that for high grain yield, the soybean crop needs approximately 91 mg dm^{-3} of potassium in the soil, according to the Soil Chemistry and Fertility Commission of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC, 2016), which makes us certain that the application of the potassium sources was able to make up for the deficit of the element in the soil.

4. Conclusion

The Phonolite and Hydrothermalized Phonolite potassium sources achieved satisfactory soybean grain yield levels compared to the potassium chloride source.

The potassium sources evaluated did not show significant results regarding grain yield for the soybean crop, with the maximum yield estimated at 138.18 kg ha^{-1} of potassium applied, regardless of the source.

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Acknowledgments

This study was conducted with the support of the Goiás State University (UEG), with funds from the Institutional Platform for Research and Innovation in Bioinputs/Goiás State University. Financial resources from the Call for Proposals: UEG PrP 32/2022 and UEG PrP 21/2023 - Pró-Projetos BioInsumos, Funding Term No. 36396217 and 52514554, SEI process No. 202200020023143. To the Study and Research Group in Phytotechnics (GEPFi) for conducting the project. To the "National Council for Scientific and Technological Development – CNPq and "Goiás State Research Support Foundation" – FAPEG, SEI process No. 202310267000445, project call FAPEG/CNPQ No. 09/2022 – Program to support the staying of Young Doctors in Brazil.

Authors contributions

Prof. Dr. Cleiton Gredson Sabin Benett, Prof. Dr. Katiane Santiago Silva Benett, Yago César Rodrigues Morais and Natália Arruda were responsible for study design and revising. Yago César Rodrigues Morais, Alex Oliveira Campos, Lyvia Nunes Arantes de Oliveira, Tainá Aparecida Alves Souza, Erick Junqueira, Rafael Maragoni Montes and Natália Arruda were responsible for data collection. Prof. Dr. Cleiton Gredson Sabin Benett, Prof. Dr. Katiane Santiago Silva Benett and Yago César Rodrigues Morais drafted the manuscript and Prof. Dr. Cleiton Gredson Sabin Benett, Prof. Dr. Katiane Santiago Silva Benett and Natália Arruda revised it. All authors read and approved the final manuscript.

Funding

This study was conducted with the support of the Goiás State University (UEG), with funds from the Institutional Platform for Research and Innovation in Bioinputs/Goiás State University. Financial resources from the Call for Proposals: UEG PrP 32/2022 and UEG PrP 21/2023 - Pró-Projetos BioInsumos, Funding Term No. 36396217 and 52514554, SEI process No. 202200020023143.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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