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# RELATIONSHIP OF POTASSIUM DOSES WITH BIOETHANOL YIELD IN SWEET POTATO IN CERRADO SOIL

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**Abstract**

Sweet potato-bioethanol yield was evaluated in response to potassium fertilizer application. Experiments were performed using a 5 × 2 factorial design in which factors included the amount of $K_2O$ applied to the soil, with five levels (0, 30, 60, 120, and 240 kg $ha^{-1}$) and genotype, with two levels (industrial genotype BDGPI #25 and table genotype BDGPM #04). Root yield, root starch and soluble solid contents, bioethanol yield, and economic viability of potassium application for bioethanol production were evaluated. Potassium affected root yield of both genotypes, with the highest yield observed at 140 kg $K_2O$ $ha^{-1}$. Root starch concentration at harvest depended on genotype potential rather than potassium dose. Soluble solid content in fresh roots was lower than that in cooked roots, in which case, maximum conversion efficiency was observed at 109,69 and at 123.75 kg $K_2O$ $ha^{-1}$ for BDGPM#04 and BDGPI#25, respectively. Bioethanol yield reached 10,484 and 9,839 L $ha^{-1}$ at 151.87 and 136 kg $K_2O$ $ha^{-1}$ for BDGPI#25 and BDGPM#04, respectively. Genotype BDGPI#25 was more efficient than sugarcane in converting potassium to bioethanol at 151.87 kg $K_2O$ $ha^{-1}$, producing 10,484.29 L of bioethanol. In turn, BGDPM#04 showed maximum conversion efficiency relative to sugarcane at 122 kg $K_2O$ $ha^{-1}$.

**Keywords:** Ethanol. *Ipomea Batatas*. Starch. Tropical.

## 1. Introduction

Renewable energy resources, among which bioethanol is highly representative, as it comprises approximately 80% of the liquid biofuels used, account for approximately 46% of all energy consumed in Brazil (EPE 2019; Selin and Lehman 2020; EPE 2020), where bioethanol is primarily extracted from sugarcane through the fermentation of the plant biomass. On the other hand, sweet potato *(Ipomoea batatas* (L.) Lam.) shows important advantages over sugarcane; namely, it readily adapts to a wide range of climatic conditions, its cultivation can be easily fully mechanized, it is highly tolerant to environmental variation, production costs are relatively low, and the crop cycle is short enough that up to two commercial crops can be grown per year under tropical conditions (Vizzoto et al. 2018; Lima et al. 2019; Nasser et al. 2020). Currently, China is the world largest producer of sweet potatoes, with an estimated total production of over 100 million tons (FAO 2021); in turn, Brazil is the 26th largest producer globally.

Sweet potato cultivars for both table (*in natura* consumption) and industrial use are available. Although the crop is mainly used for human consumption, the high efficiency of the plant in transforming solar into chemical energy and storing it as starch in the roots makes it an attractive alternative for bioenergy production, as approximately 82.3% of the root dry mass is composed of carbohydrates, which enable a bioethanol yield of nearly 724 L $ton^{-1}$ (Santana et al. 2013; Oliveira et al. 2019). Furthermore, the potential for bioethanol production increases with appropriate crop management coupled to the use of high-yielding genotypes, i.e., those that are able to partition large amounts of dry matter to the roots (Oliveira et al. 2017).

When soil texture is adequate, fertilization management enables an increase in the number of roots and the accumulation of dry mass in sweet potatoes (Diaconu et al. 2019). Among plant nutrients, potassium (K) is the mineral element that sweet potato plants extract in larger quantities, thus contributing to plant and root development, and accelerating carbohydrate biosynthesis in the leaves and their translocation to the roots, a process during which the starch concentration and yield of tuberous roots continuously increases (Pushpalatha et al. 2017).

Therefore, determining the optimum dose of K fertilizer is a prerequisite to realize the great potential of sweet potatoes for bioethanol production, both in regions where sugarcane is already present, and in those where the climate is not favorable for high sugarcane productivity. In addition, table and industry sweet-potato cultivars have been developed, which requires consolidation of information for the different cultivars that provide greater bioethanol production via a greater K use efficiency.

Bioethanol yield is presumably influenced by K fertilization because of its interaction with biomass yield and root starch content in different genotypes. Therefore, the objective of this study was to verify the increase in sweet potato-bioethanol yield in response to potassium fertilization in a Cerrado type of soil.

## 2. Material and Methods

Two experiments were conducted over two consecutive years in Gurupi, Tocantins State, Brazil (11°44'42" S, 49°03'05" W, at 287 m a.s.l.). The climate in the region (Figure 1) is of the B1wA'a type, i.e., humid tropical with a moderate water deficit (Köppen1948).

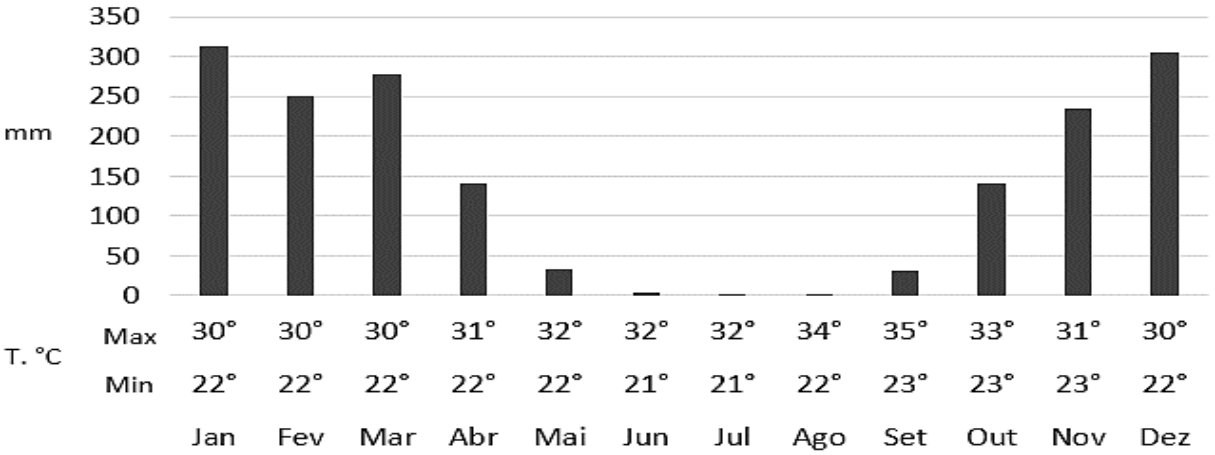


**Figure 1.** Mean precipitation, and minimum and maximum temperatures at the study site over the last 30 years (Source: Clima tempo 2021).

The soils at the study site are red-yellow Latosols with a sandy clay loam texture (EMBRAPA 2018). The chemical and physical characteristics in the 0–20 cm topsoil layer are listed in Table 1.

**Table 1.** Chemical and physical characteristics of the 0 to 20 cm topsoil layer at the study site.

| pH | CO | MO | P meh | K | Ca | Mg | Al | H+Al | SB | T | V | Argila | Silte | Areia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CaCl_2$ | dag.$kg^{-1}$ | | mg.$dm^{-3}$ | .....$cmol_c.dm^3$..... | | | | | | | | .....% | | |
| 5,4 | 1,2 | 2,1 | 5 | 0,19 | 2,8 | 1,4 | 0 | 2,2 | 4,39 | 6,59 | 67 | 25 | 5 | 70 |

*pH: hydrogen potential; CO: organic carbon; MO: organic matter; P meh: phosphorus meshlich; K: Potassium; Ca: Calcium; Mg: Magnesium; Al: aluminum; H + Al: hydrogen + aluminum; SB: sum of bases; T: total cation exchange capacity (CEC); V: base saturation.

A two factorial (5 x 2) experiment with three replications was laid in a randomized complete block design. The treatments consisted of five $K_2O$ doses combined with two genotypes evaluated over two consecutive years. The following potassium ($K_2O$) treatments were established on the basis of soil analysis: 0, 30, 60, 120, and 240 kg $ha^{-1}$. Sweet potato genotypes included BDGPI#25 (experimental sweet potato genotype selected for the industry, with oval-shaped roots, white skin, and pulp) and BDGPM#04 (experimental sweet potato genotype selected for table consumption, with an elliptical root shape, pink skin color, and white pulp).

Each experimental plot comprised 16 plants that were used to plot the 12 central plants.

Soil preparation included plowing and harrowing. The seeding beds were manufactured by a ridge-bed manufacturer. As per soil analysis (Table 1), fertilization included 60 and 100 kg $ha^{-1}$ of N and P, respectively. The entire dose of $P_2O_5$ was applied at planting. Meanwhile, N and $K_2O$ were fractioned for application as follows: 50% at planting, 25% at 30, and 25% at 60 d after planting. In addition, borax was applied at planting at a rate of 10 kg $ha^{-1}$. Sprinkler irrigation was used to ensure an unlimited water supply for plant growth. Manual weed control was performed as needed. Harvest was conducted 150 d after transplanting and the following parameteres were measured: root yield (t $ha^{-1}$), starch content after Cereda (2001) as adapted by Machado and Abreu (2007), soluble solid content (°Brix) of raw and cooked pulp was determined by using a portable refractometer, bioethanol yield (L $ha^{-1}$), and economic viability of bioethanol production from sweet potato compared to sugarcane.

Statistical analysis of the data was performed using the Sisvar statistical package version 5.7 (Ferreira 2018). The regression models that better explained the variation in the measured parameters with applied $K_2O$ were adjusted using the means. Plots were constructed using SigmaPlot (version 10.0).

## 3. Results

Estimated root yield ranged from 25.45 to 44.79 t $ha^{-1}$ for genotype BDGPI#25 with a quadratic response pattern (Figure 2A). In the absence of K fertilization, the yield was 24.18 t $ha^{-1}$, which increased to 42.77 t $ha^{-1}$ at 120 kg $ha^{-1}$ $K_2O$. Maximum sweet potato root yield estimated by the equation was 44.79 t $ha^{-1}$ at 146.25 kg $K_2O$ $ha^{-1}$. As for the BGDPM#04 genotype, the estimated root yield ranged from 16.41 to 35.96 t $ha^{-1}$, also showing a quadratic response (Figure 2A). Similarly, in this case, the yield was 14.33 t $ha^{-1}$ without K fertilization, increasing up to 33.20 t $ha^{-1}$ at 120 kg $K_2O$ $ha^{-1}$. The highest estimated yield of sweet potato roots for this genotype was 44.79 t $ha^{-1}$ at 146.25 kg $K_2O$ $ha^{-1}$.

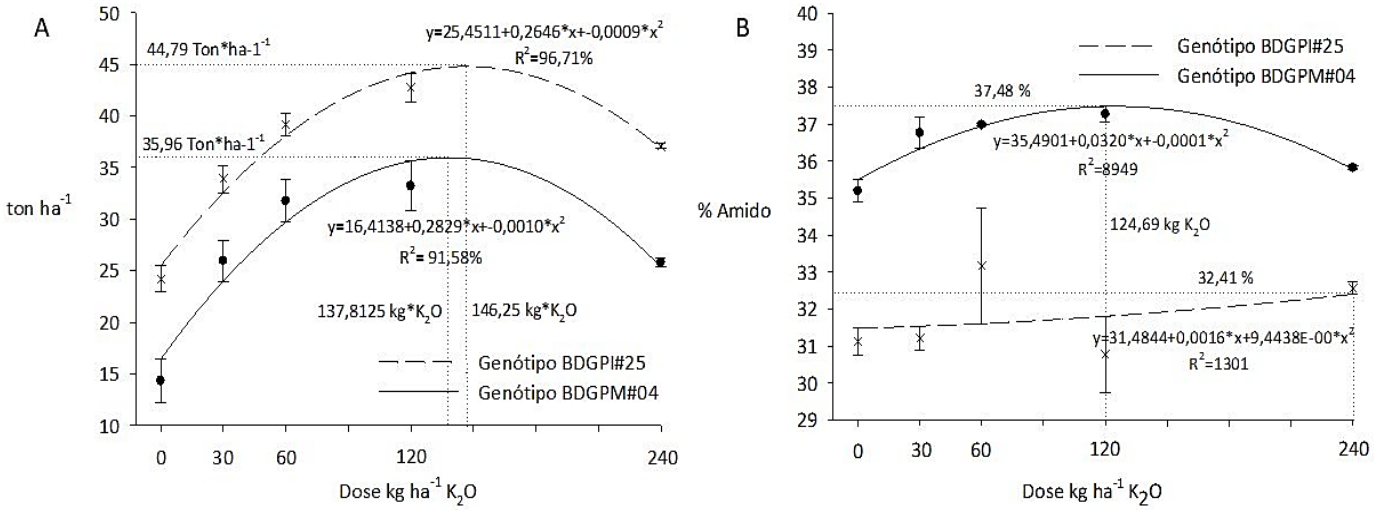


**Figure 2.** A - Response curve of sweet potato-root yield and B - starch concentration (%) as a function of potassium fertilization in a sandy-textured Cerrado soil. Data for two independent experiments conducted in two consecutive years.

Starch concentration in BDGPI#25 varied linearly from 31.48% to 32.48% in a K-dependent manner (Figure 2B). Thus, without K fertilization, the starch concentration was 31.11%, increasing as $K_2O$ applied increased up to 120 kg $ha^{-1}$. The highest starch concentration estimated by the equation was 32.41% for

the 240 kg $K_2O$ $ha^{-1}$ treatment. In turn, the estimated concentration of starch in BGDPM#04 roots ranged from 35.49% to 37.48%, also showing a quadratic response pattern (Figure 2B), such that, without K fertilization, the starch concentration was 35.2% and it increased as $K_2O$ applied increased up to 120 kg $ha^{-1}$. The highest estimated starch concentration in sweet potato roots was 37.48% for 124.69 kg $ha^{-1}$ as K treatment.

Root soluble-solids content before cooking ranged from 3.84 to 4.32 °Brix in genotype BDGPI#25, following a quadratic response pattern (Figure 3A). Thus, without K application, soluble solid content was 3.88 °Brix, which increased up to 4.33 °Brix at 120 kg $K_2O$ $ha^{-1}$. The highest soluble solid content estimated by the equation was 4.32 °Brix at 116.25 kg $K_2O$ $ha^{-1}$. As for BGDPM#04, root soluble-solid content ranged from 4.17 to 4.64 °Brix, with a quadratic response (Figure 3A). Without K fertilization, the soluble solid content was 4.38 °Brix, which decreased as K application increased up to 120 kg $K_2O$ $ha^{-1}$. The highest estimated root soluble-solid content before cooking in sweet potato roots was 4.64 °Brix at 240 kg $K_2O$ $ha^{-1}$.

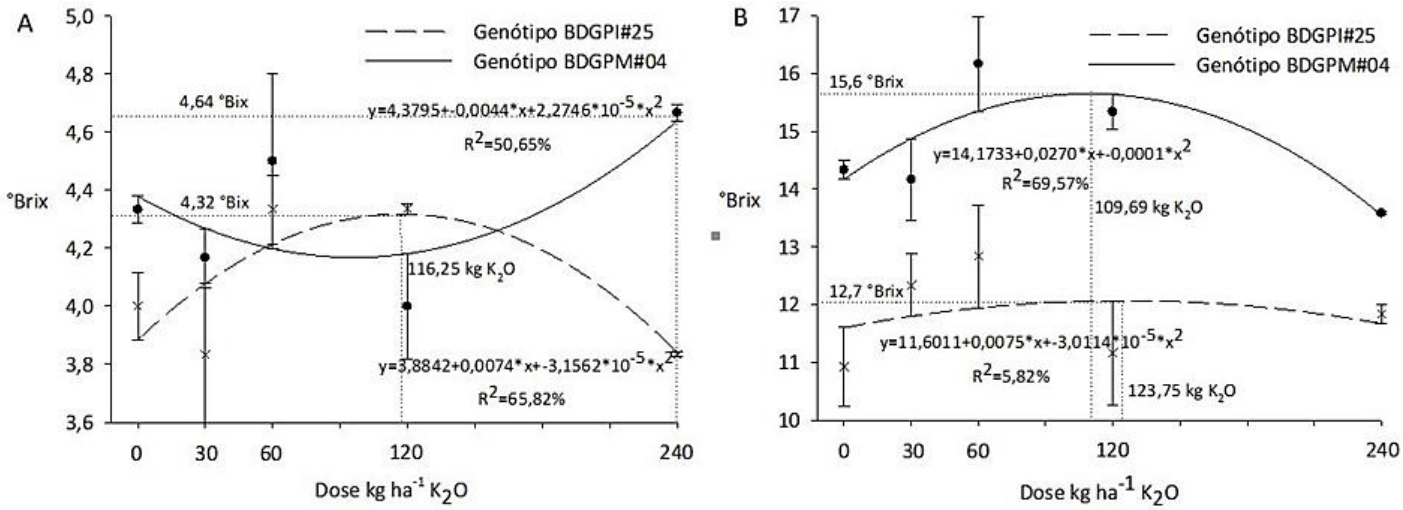


**Figure 3.** Response curve of soluble solids content (°Brix) in sweet potato roots A - before cooking, and B - after cooking, as a function of K fertilization in a sandy-textured Cerrado soil. Data are for two independent experiments conducted in two consecutive years.

Root soluble-solid contents in BDGPI#25 after cooking ranged from 11.6 to 12.7 °Brix, with a quadratic response (Figure 3B). Without K application, the soluble solid content was 10.91 °Brix, increasing up to 12.84 °Brix at 60 kg K2O ha-1. The highest root soluble-solid content estimated by the equation was 12.7 °Brix at 123.75 kg ha-1 of K2O. As for the BGDPM#04 genotype, the root soluble-solid content ranged from 14.17 to 16.6 °Brix, also with a quadratic response pattern (Figure 3B). Thus, when no K was applied, the soluble solid content was 14.33 °Brix, increasing as K increased up to 60 kg K2O ha-1. The highest root soluble-solid content estimated after cooking was 15.6 °Brix at 109.69 kg K2O ha-1.

The estimated bioethanol yield of BDGPI#25 ranged from 5,931 to 10,484 L ha-1 with a quadratic response (Figure 4A). In the absence of K fertilization, bioethanol yield was 5,602 L ha-1, which increased as K increased to 120 kg K2O ha-1. The maximum bioethanol yield estimated by this equation was 10,484 L ha-1 at 151.87 kg K2O ha-1. Meanwhile, BGDPM#04 showed an estimated bioethanol yield ranging from 4,331 to 9,840 L ha-1 with a quadratic response pattern (Figure 4A). Without K fertilization, the yield was 3,776 L ha-1, increasing as K increased up to 120 kg K2O ha-1. The highest estimated bioethanol yield from sweet potato roots was 9,839 L ha-1 which was obtained when a rate of 136 kg K2O ha-1 was applied.

The estimate of the fertilization cost of sweet potato cultivated for bioethanol production was obtained using final yield (L ha-1) data, the amount of potassium used (kg ha-1), the market price (R$) of a kg of K2O, and the market price (R$) of a liter of bioethanol. This approach allowed the identification of the contribution of each fertilizer nutrient to the final price of bioethanol.

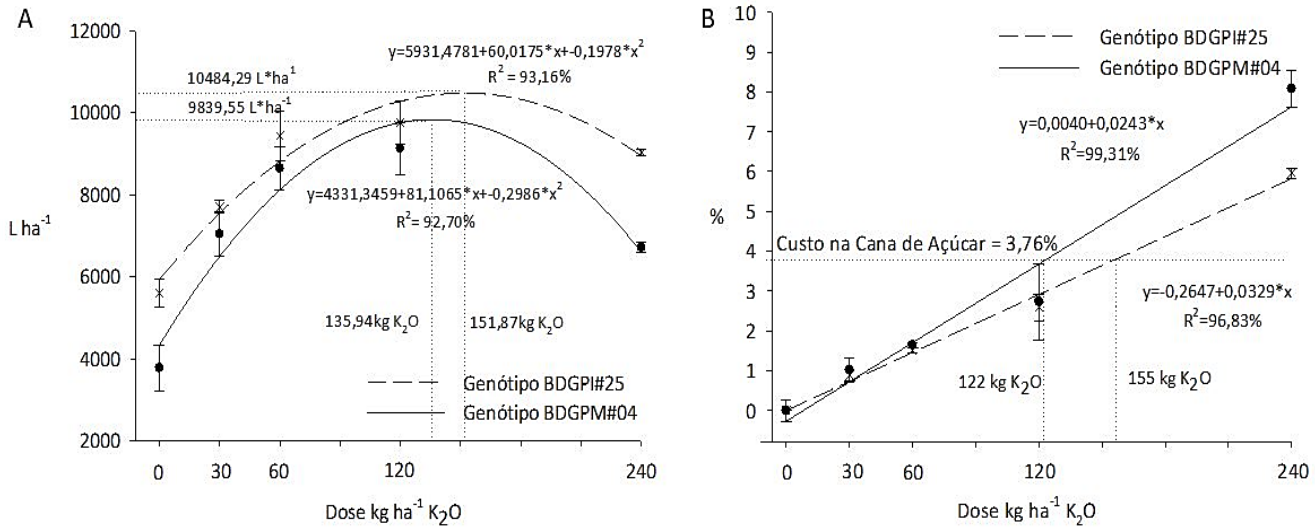


**Figure 4.** A - Bioethanol yield-response curve of sweet potato genotypes and B - economic viability of potassium fertilization of sweet potato for bioethanol production, relative to that of sugarcane.

## 4. Discussion

Ferreira (2019) reported that sweet potato yield depends on the cropping conditions and productive potential of the genotype under cultivation. According to the data reported herein (Figure 2A), BDGPI#25, which was directly selected for the industry, showed a superior yield, with a greater volume of roots of different sizes and shapes. Meanwhile, BGDPM#04, which in turn was selected as a table variety, has the characteristics most desirable for commercialization, such as a standard size, shape, and a mass of approximately 300 g per root. The yield (Figure 2A) of both genotypes decreased when 240 kg $K_2O$ $ha^{-1}$ were applied to the soil. Because of the high mobility of K in sandy soils, application at very high doses reportedly increases plant K content, which in turn reduces the concentration of solids and dry mass in addition to enhancing K leaching through the soil profile (Mota et al. 2016).

Starch is the predominant form of chemical energy stored in sweet potato roots, and its content directly determines the potential of any given genotype for bioethanol production (Lázari et al. 2014). Herein, we found that BGDPM#04 had the highest starch concentration (Figure 2B). This genotype was selected for table consumption based on consumer preference with regard to its elliptical root shape, pink skin color, white flesh, and sweet flavor. Potassium enhances the concentration of starch in sweet potatoes, as it is a part of the starch formation metabolic process and of its transport to reserve organs (Neumann 2014). The two genotypes tested herein showed different responses to K fertilization. Thus, a minimal influence of $K_2O$ dosage on root soluble-solid content before cooking was observed (Figure 3A), with BDGPM#04 showing a higher concentration than BDGPI#25. Oliveira (2017) evaluated K doses but did not identify their influence on °Brix values before cooking. In contrast, soluble solid content increased significantly after cooking (Figure 3B), particularly in BDGPM#04. In this respect, Risso (2014) argued that at high temperatures, hydrogen bonds break, thereby changing the molecular arrangement of starch granules, which in turn leads to the conversion of starch into soluble sugars, ultimately resulting in an increased soluble solid content after cooking. This response after cooking is very important, as starch itself cannot be converted into bioethanol to any large extent, having to go through the liquefaction process (i.e., cooking sweet potato between 80 - 150 °C) to change starch structure such as to enable chemical or enzymatic hydrolysis (breakdown of starch) to glucose. Thereafter, the process is very similar to that used for bioethanol production from sugarcane, with ensuing fermentation and distillation to obtain bioethanol (Risso 2014; Stroparo et al. 2019).

High-yielding and high starch-accumulating sweet potato genotypes reportedly result in higher bioethanol yield. Thus, for example, Lourenço (2018) selected genotypes with higher starch concentration that correlated with higher bioethanol yield. In our experiments, although BDGPI#25 showed higher sweet potato yield (Figure 2A), it was surpassed by GPM#04 with respect to starch concentration (Figure 2B),

which allowed both genotypes to ultimately produce similar bioethanol yields close to 10,000 L $ha^{-1}$ (Figure 4A). Specifically, BDGPI#25 produced on average approximately 645 L $ha^{-1}$ more than BDGPM#04.

The genotypes evaluated herein proved promising for bioethanol production, with yields well above the average yield (5,900 L $ha^{-1}$) obtained from sugarcane (Oliveira et al. 2019; CONAB 2019). In addition, because of the short duration of their crop cycle, sweet potatoes can be cultivated twice a year, which would allow obtaining as much as up to three times the volume of bioethanol obtained from sugarcane (Viana et al. 2017).

The cultivation of high-yielding plant materials is the first step in the production of bioethanol for sale at gas stations. Further, throughout the entire chain, costs of production, transport and marketing contribute to determine the final price of the fuel.

A bioethanol production of 5900 L $ha^{-1}$ from sugarcane required the application of 100 kg $K_2O$ $ha^{-1}$, at R$ 10.00 per kg $K_2O$ and the price of bioethanol was R$ 4.50. Thus, the cost of the potassium used to fertilize sugarcane to produce this amount of fuel was estimated at approximately 3.76% of the final product price. In turn, the cost of K fertilization for bioethanol production from BDGPI#25 increased linearly from 0 to 5.83%, as the K dose increased (Figure 4B). The maximum K dose estimated by the equation with the same cost of $K_2O$ for bioethanol as that of sugarcane was 155 kg $ha^{-1}$. Similarly, the cost of K fertilization for bioethanol production from BGDPM#04 increased linearly from 0 to 7.62%, as the K dose increased (Figure 4B), with the maximum K dose estimated by the equation at 122 kg $K_2O$ $ha^{-1}$ for the same cost as that of sugarcane-based bioethanol production.

Potassium fertilization plays an important role in increasing biomass yield and starch biosynthesis. Considering the estimated cost of production (Figure 4B), the recommended K dose for BDGPI#25 represented 3.68% of the cost of bioethanol production, indicating that in addition to being more productive, the lower cost of production entailed makes bioethanol production from this genotype more economically viable than those from either BGDPM#04 or sugarcane. On the other hand, although the K dose recommended for BGDPM#04 represented 4.2% of the cost of bioethanol production, when the K dose was adjusted to the same K cost as that paid when BDGPI#25 was used, the resulting estimated bioethanol production from BDGPM#04 reached 9,782 L $ha^{-1}$, a level of productivity that is certainly more economically viable than that of sugarcane.

## 5. Conclusions

Potassium fertilization affected the root yield of the two sweet potato genotypes tested, with a higher yield at 140 kg $K_2O$ $ha^{-1}$ under the conditions of the sandy-textured Cerrado soils prevalent in the region.

Up to the genetic potential limit expressed by each genotype, herein, the increase in final starch concentration in sweet potato roots was determined to a larger extent by genotypic potential than by K dose.

Soluble solid contents in raw roots were lower than those in cooked roots, and varied with K fertilization. For cooked roots and both genotypes, maximum K use efficiency (i.e., liters of bioethanol produced per kg of K fertilizer) was achieved with 109.69 kg $K_2O$ $ha^{-1}$ for genotype BDGPM#04 and 123.75 kg $K_2O$ $ha^{-1}$ for genotype BDGPI#25.

Bioethanol yield showed a quadratic behavior as a function of $K_2O$ dose for both genotypes tested. Specifically, 10,484 L $ha^{-1}$ of bioethanol were produced using BDGPI#25 fertilized with 151.87 kg $K_2O$ $ha^{-1}$ while 9,839 L $ha^{-1}$ were produced using BGDPM#04 fertilized with 136 kg $K_2O$ $ha^{-1}$.

Sweet potato genotype BDGPI#25 was more efficient than sugarcane in converting K into bioethanol, requiring 151.87 kg $ha^{-1}$ to produce 10,484.29 L of bioethanol. Meanwhile, compared with sugarcane, the K dose required for maximum productivity of genotype BGDPM#04 was 122 kg $K_2O$ $ha^{-1}$.

**Authors' Contributions:** COELHO, R.S.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; NASCIMENTO, I.R.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; NETO, J.F.M.: acquisition of data, drafting the article, and critical review of important intellectual content; SILVEIRA, M.A.: critical review of important intellectual content; MOMENTÉ, V.G.: critical review of important intellectual content; SOUSA, A.P.: acquisition of data and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

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**Ethics Approval:** Not applicable.

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