Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 30 June 2023
https://doi.org/10.14295/CS.v14.4048

Production of Beauregard Sweet Potato in vertical farming under different fertilization technologies

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Abstract

Ipomoea batatas, popularly known as sweet potato, is a species of the Convolvulaceae family, with probable origin between Mexico and northern South America. Among the genotypes with economic potential, the biofortified cultivar Beauregard (*Ipomoea batatas*) stands out due to its rusticity and easy handling. Controlled-release fertilizers were mostly used in studies developed in other countries, and their study being necessary in Brazilian soil and climatic conditions. This study aimed to evaluate the development of Beauregard biofortified cultivar, submitted to different fertilization technologies in vertical farming system. The plantlets received different doses of controlled-release fertilizer: 0.0 (control); 30; 60; 90; 120g and a dose of 40g per pit of NPK 13-13-28 of ready solubility. At 180 days, biometric and production parameter data were collected and submitted to regression analysis and variance analysis followed by the Scott-Knott test for mean separation. The application of controlled-release fertilizer showed a positive effect on the production of the studied cultivar, favoring the performance of the plants and promoting the increase especially in height, length of branches and number of leaves. The base application of controlled-release fertilizer at a dose of 30g per plant and traditional NPK fertilizer at a dose of 40g per plant promote higher yields of dry mass of shoots and root when compared to unfertilized plants in the cultivation of sweet potatoes in vertical farming.

Keywords: Fertilizing, Controlled-Release Fertilizer, *Ipomoea batatas*, Plant Nutrition

Introduction

The sweet potato (*Ipomoea batatas*) is a tuberous root belonging to the Convolvulaceae family. There is no exact identification of the place of origin of this crop, but it is believed that it is a plant with origin in the Americas and Mexico (Silva et al., 2015).

The study by (Silva et al., 2015) showed that sweet potato planting is found in several regions of Brazil, being cultivated by family farmers because it is considered a relatively easy management plant and of wide climatic adaptation, with economic importance.

The sweet potato presents a social and economic importance resulting from its rusticity, as it adapts well in different places and presents a considerable production in a short time of cultivation (Cajango et al., 2021).

Brazil has significant production of sweet potatoes in areas where family farming predominates. The states of Rio Grande do Sul, São Paulo and Ceará are the main producers, although the cultivation still presents low productivity considering the real productive potential of the species (Balduino, 2021).

There are few studies on the indication of sweet potato cultivars and production and harvesting techniques for certain regions (Viana et al., 2011). In this sense, the study of cultivation systems and better production techniques become necessary to increase the productivity and profitability of the crop.

One of the cultivars with high productive and market potential is the biofortified Beauregard sweet potato (*Ipomoea batatas*), a cultivar of North American origin, developed by the Louisiana Agricultural Experiment Station in 1987 (Embrapa, 2010). This cultivar has orange colored pulp, rich in carotenoids (up to 115µg per kilo of root) and antioxidants (Nolêto et al., 2015). In addition, it presents good productive results and a potential for eradication of nutritional deficiency in children and

Received: 27 July 2022
Accepted: 20 March 2023

women (Berni, 2014).

One of the technologies under development that can be studied for its potential for technical efficiency is the Slow-Release (SRF) or Controlled-Release (CRF) Fertilizers, valued by the fertilizer industries (Naz & Sulaiman, 2016). (Zheng et al., 2016) point out that the use of this type of fertilizer promotes labor reduction and increased productivity. Several studies have been carried out to improve the use of slow or controlled-release fertilizers, in order to obtain the best formulation that meets the nutritional need of plants (Chawakitchareon et al., 2016; Chen et al., 2018). (Rossa et al., 2013) point out, through studies on Paricá seedlings, that there are few studies on the benefits of using SRF compared to the use of traditional mineral fertilizers and that studies on economic viability are necessary.

The use of balanced doses of fertilizers reduces leaching losses and increases the growth potential of the plant, considering environmental, productive and economic issues (Bernardi et al., 2008). However, (Rossa et al., 2013) cite that in seedlings of forest species, the use of SRF presents a disadvantage due to its high market value, making it necessary to study the adequacy of doses in different systems to optimize production.

Although this fertilizer has been studied in seedlings of forest and fruit species (Gomes et al., 2020), data on controlled-release fertilization in field sweet potato cultivation are scarce.

Together with the creation of technologies that seek to meet the increase in vegetable production in an alternative way, (Celestrino et al., 2017) state that family farming stands out in the sustainable production of vegetables and that due to commercial requirements, a change in the mode of production is necessary. A more sustainable management system, in addition to being able to provide an increase in family income, enables the production of quality food, easy management, space saving, as well as providing opportunities for the use of recyclable materials (Ventura, 2015). Thus, vertical farming has the potential to be another alternative of productive diversification in rural properties and to assist in sustainable rural development. Conventional farming causes soil degradation, erosion, silting of rivers and stimulates the germination of spontaneous plants, causing a greater infestation in the area making it difficult to control (Rós et al., 2014). This shows the importance of access to new cultivars, production technologies and different cultivation systems, which can represent new sources of income for family farmers. In addition to taking advantage of small spaces of the idle areas of rural properties.

Due to the lack of technical information on the use of controlled-release fertilizer in sweet potato roots, the objective of this study was to evaluate the production of Beauregard sweet potato in vertical farming system under different fertilization technologies.

Material And Methods

The experiment was conducted in field conditions, in a rural property, in the municipality of Massaranduba, Santa Catarina, Brazil, located under the geographical coordinates 26°34`30,64" S latitude and 48° 55` 01,42" W longitude and 362 m A.S.L. altitude.

The climate of the region is humid subtropical with hot summers being classified as Cfa in the classification system of Köppen (Köppen, 1931). In the course of the experiment, the maximum temperature recorded was 39.3°C and the minimum 9.98°C. The weather data under which the experiment was conducted are presented in (**Figure 1**).

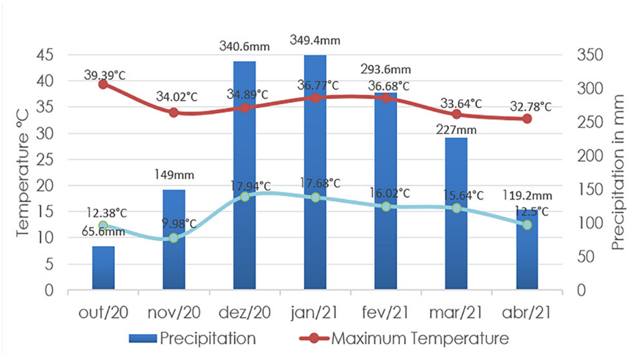

Figure 1. Climate data of precipitation and temperature in the period of development of Beauregard sweet potato plants. Massaranduba/SC, 2020/2021
Source: Weather Station EPAGRI/CIRAM, 2021.

To make the planting pots in order to establish the vertical cultivation system, white laminated raffia sacks with a diameter of 0.35m, height of 0.80m and volume of 0.07m.$^{-3}$ were used. Each raffia sack was lined with a black, low density polyethylene plastic bag with three holes at the bottom for drainage. The bags were filled with agricultural soil taken from an area with a history of cultivation of the rural property. Soil composite samples were collected from 0 to 20 cm deep and sent to the analysis laboratory, the results of which are presented in (**Table 1**).

The results obtained in the physical analysis of the soil indicated: 23.1% clay, 28.1% silt, and 48.8% sand, characterizing it according to the Normative Instruction N°2 of October 9th, 2008 of the Ministry of Agriculture, Livestock and Food Supply (MAPA), as Type 2 soil, defined by medium-textured soils, with a minimum content of 15%

Table 1. Chemical and granulometric characteristics of the agricultural soil in the area of the Beauregard sweet potato production experiments in a vertical cultivation system. Massaranduba/SC, 2020

Granulometry										
Clay				Sand		Silt			Type soil	
----------------------g kg^{-1} ------------------										
23.1				48.8		28.1			Soil type 2	
Chemical characteristics										
pH $CaCl_2$	SMP	P Mg^3/dm^3	M.O %	Al^{+3} $cmol_c/dm^3$	K^+ mg^3/dm^3	Ca^{+2} $cmol_c/dm^3$	Mg^{+2}	H^++Al^{+3}	SB	V %
6.6	6.7	111.3	2	0.0	156.4	8.2	4.1	1.9	12.6	86.9

Source: EPAGRI (2020).

clay and less than 35%, in which the difference between the percentage of sand and the percentage of clay is less than 50. Therefore, according to the classification proposed by (Santos et al., 2015) the cultivation soil was identified as a sandy clay loam textural class. From the soil acidity results analyzed, there was no need for liming that presented pH SMP and $CaCl_2$ 6.7 and 6.6 respectively.

The implementation of the experiment was carried out on October 20th, 2020, with propagules presenting 4 to 5 leaves and an approximate height of 20 cm. The clones were produced by the company CLONAGEN Biotecnologia Vegetal™, through the technique of tissue culture by micropropagation.

A total of 18 growing pots were used in the experiment, with a distance of 1.5 m between them. In each growing pot, 3 pits were made with a depth of 10 cm each hole. Each pit received the respective treatment dose and then 1 propagule per pit was planted, at a spacing of 8 cm between plants. The 3 pits in each pot were subjected to the same fertilization technology, totaling 54 plants in the experiment.

During the experiment, the weeds inside the pots were controlled weekly with manual pulling, and those around the pots with manual weeding every two weeks. No phytosanitary procedures were required to control pests and diseases. Irrigation control of the propagule in the first 30 days was performed weekly by manual sprinkling, applying the volume of 0.001 $m.^{-3}$ by pot. After this period, considering rainfall regime with sufficient rainfall volume, no irrigation was required.

The experimental design was in completely randomized blocks, with 6 treatments. The experimental unit consisted of a pot with 3 plants each with 3 replications. The following treatments were applied: control (without fertilization), controlled-release fertilizer at doses of 30, 60, 90 and 120g per planting pit and 40g per pit of a different NPK of ready solubility, according to the interpretation of soil analysis and recommendation of the manual of fertilization and liming for the states of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC, 2004). Controlled-release fertilizer manufactured by Compo GmbH & Co was used. KG (Germany), of trade mark Basacote® 12M Plus, with formulation 15-08-12 (N_2-P_2O_5-K_2O) and Fertipar brand NPK fertilizer with formulation 13-13-28 (N_2-P_2O_5- K_2O), whose specifications of chemical formulations are presented in (**Table 2**).

The Basacote® Plus 12M is a controlled-release NPK complex fertilizer fully coated with an elastic polymer that ensures a uniform release of nutrients for 12 months (Compo Expert, 2021).

At 180 days after planting, the biometric variables were evaluated: height (H), collar diameter (SD), number of leaves (NL), number of branches (NB), length of branches (LB) and chlorophyll (CL), as well as data on production variables: fresh shoot biomass (FSB), dry shoot biomass (DSB), fresh root biomass (FRB), dry root biomass (DRB).

The length of the branches (cm) and height (cm) were measured with a graduated ruler and measuring tape, measuring them from the collar to the apex of the plant (Neumann et al., 2017). The number of branches and the number of leaves were counted individually.

The diameter of the collar diameter was measured with a digital caliper (mm) at 0.5 cm from the ground (Rossa et al., 2011) (**Figure 2**).

The aerial part of the plants was harvested at 5cm above from the ground, with the help of pruning shears and then they were weighed to determine the FSB. The roots were harvested with a garden shovel and washed with a brush. After this procedure they were weighed.

For the drying of the biomass of leaves and roots, a forced air circulation dryer was used at 70° C until it reached a constant weight.

For comparison of high solubility fertilizer and controlled-release fertilizer, data were submitted to analysis of variance (ANOVA), followed by the Scott-Knott Test at 5% for the comparison of the means, using the statistical program ASSISTAT (Silva & Azevedo, 2016). The data regarding different doses of controlled-release fertilizer were submitted to a regression analysis and the maximum technical efficiency doses were calculated.

Table 2. Chemical characteristics of controlled and conventional release fertilizer applied in vertical cultivation of Beauregard sweet potato

	N (%)	P_2O_5 (%)	K_2O (%)	Mg (%)	S (%)	Fe (%)	B (%)	Cu (%)	Mn (%)	Mo (%)	Zn (%)
Controlled – release Fertilizer	15.00	8.00	12.00	1.2	5.00	0.4	0.02	0.05	0.06	0.015	0.02
Conventional Fertilizer	13.00	13.00	28.00	-	2.00	-	-	-	-	-	-

Source: Compo Expert (2021) and Fertipar (2022).

Figure 2. Soil preparation in vertical growing pots (A), experimental arrangement with growing pots (B), pot with planted propagules (C), measurement of plant collar diameter with caliper (D), measurement of plant height (E), Beauregard sweet potato (F). Source: The Author (2020).

Results and Discussion

The results of the mean production variables for fresh shoot biomass (FSB), dry shoot biomass (DSB), fresh root biomass (FRB), dry root biomass (DRB) of the Beauregard Sweet Potato evaluated at 180 days after planting are presented in (**Table 3**).

It was observed that there was no significant response to the production parameters FSB, FRB with the application of controlled-release fertilizer (Table 3). However, the application of 40 g of conventional NPK fertilizer promoted higher values of fresh mass of the shoot and fresh biomass of the root when compared to treatment without fertilization and treatments with controlled-release fertilizer.

The parameters dry shoot biomass (DSB) and dry root biomass (DRB), obtained better results with the application of 30g per pit of controlled-release fertilizer compared to the control. For DSB, the treatment of 30g of controlled-release fertilizer did not differ significantly from the use of 40g per pit of traditional NPK, both superior to the treatment without fertilization and other doses of controlled-release fertilizer. The DSB parameter presented a response of 89.2g, with the dose of 30 g of controlled-release fertilizer, a rate of 36.5% higher compared to the treatment without fertilization that produced 56.6g.

For dry root biomass, the treatment with 30g per pit of controlled-release fertilizer produced a result of 236.6g, a value 47.8% higher compared to the control treatment that responded with 123.4g. Treatment with 40g per pit of fertilizer NPK 13-13-28 stood out in the result of DRB, a rate of 62.3% higher compared to treatment without fertilization, being also superior to treatment with 30g of controlled-release fertilizer. Similar results were found by (Rossa et al., 2013), when they studied the development of Paricá plantlets, they observed the increase of DSB and DRB with the use of SRF.

Studies carried out by (Gomes et al., 2020) confirmed positive responses of the use of controlled-release fertilizer on the accumulation of root and shoot dry biomass in loquat seedlings. This result of the increase in biomass in plants due to the application of SRF or controlled-release was also verified in several studies with fruit and forest species (Gomes et al., 2020).

The accumulation of biomass is important, since it is related to the amount of carbon present in the plant (Modrzyński et al., 2015) and may reflect higher production of root biomass, especially for species that accumulate energy in the form of starch in tubers, may represent higher production of sweet potatoes.

In general, the use of controlled-release fertilizer promoted significant increases in indicators of vegetative growth of sweet potato cv. Beauregard grown in vertical farming system. The dose of 30g of controlled-release fertilizer per planting pit resulted in higher dry biomass of shoot and root when compared to the treatment without fertilization, being, however, surpassed by the use of conventional NPK fertilizer at a dose of 40g per pit.

According to the regression analysis, there was a significant effect of the controlled-release fertilizer for all the evaluated biometric parameters, except for the collar diameter. Under these conditions, the controlled-release fertilizer demonstrated potential use for sweet potato production. The regression models and respective equations and coefficients of determination (R^2) for the biometric data are presented in Figures 3, 4, 5 and 6.

Plant height increased with controlled-release fertilizer doses. Treatment with 120g of fertilizer per pit resulted in plants 38% higher than the control (**Figure 3**). Similar results were identified by (Gomes et al., 2020) with okra plantlet. The authors mention that the effect of SRF on the height increase may occur due to the availability of N, P and K throughout the growth period of the plant (Gomes et al., 2020). Similar results were described by (Rossa et al., 2011) & (Rossa et al., 2013) with forest species.

The linear increase in height may be related to nitrogen fertilization, as this effect is similar to the studies of (José et al., 2009) & (Rossa et al., 2013), when the height of seedlings of *Schinus terebinthifolius*, increased as fertilizer levels increased, containing a significant proportion of nitrogen in its composition. The controlled-release fertilizer used in this experiment has 15% nitrogen and considering that the soil before planting had a low rate of organic matter (2%), it is possible to infer that the supply of this nutrient is directly related to plant growth. According to information by (Naz & Sulaiman, 2016), it can be stated that only 20-30% of nitrogen-containing fertilizer is absorbed by plants, the rest is lost due to the effects of volatilization, leaching and nitrification. These losses can cause low production, higher labor costs and environmental degradation. The positive effect of the controlled-release fertilizer on height is possibly related to the continuous availability of potassium and nitrogen to the plants. In controlled-release fertilizers, potassium leaches little over time when compared to other fertilizers considered traditional (Bley et al., 2017). Currently the use of slow-release fertilizer is considered to be the appropriate product to reduce nutrient losses and environmental contamination (Yuni et al., 2019). The release of nutrients with the use of controlled-release fertilizer happens by a diffusion process making them available according to the nutritional requirements of the crops, reducing leaching and salinity that can influence the reduction of plant development (Compo Expert, 2021).

Controlled-release fertilizer also promoted significant increments in the number of Beauregard sweet potato leaves. There was an increase of 41.2% in plants treated with 120g of controlled-release fertilizer when compared with plants that did not receive fertilizer (**Figure 4**).

In a study evaluating the biometric parameters of sugarcane-- as a function of different levels of fertilization, (Freitas et al., 2013) state that the higher the nitrogen dose, the greater the number of leaves. N stimulates vegetative growth, resulting in a greater number of leaves per plant and an increase in shoot diameter (Nunes et al., 2016). The number of leaves is an interesting factor because it is an important indicator of the photosynthetic capacity of the plant and its carbon assimilation capacity (Gomes et al., 2017). The growth of the number of leaves and height is greater when the soil has high fertility, especially in soils with high phosphorus and potassium content, and the supply of these minerals by the controlled-release fertilizer may be related to the increase of these variables in sweet potato plants cv. Beauregard.

Table 3. Averages of the variables of fresh shoot biomass, dry shoot biomass, fresh biomass of the root and dry biomass of the Beauregard sweet potato root produced in vertical farming system, under different fertilization technologies

Production parameters				
Time (180 days)				
Doses of SRF	FSB(g)	DSB(g)	FRB(g)	DRB(g)
0 g	338.05 Ba*	56.61Bb	768.89Ba	123.43Cb
30g	257.78Ba	89.24Aa	962.22Ba	236.65Ba
60g	248.33Ba	40.30Bb	728.33Ba	121.53Cb
90g	305.00Ba	45.82Bb	934.30Ba	198.25Ca
120g	258.33Ba	45.91Bb	731.66Ba	156.25Cb
40g NPK	536.66A	80.92A	2050.00A	327.70A
CV (%)	15.46	21.19	17.19	19.72

*Means followed by the same letter in the column do not differ from each other by the Scott-Knott Test at the level of 5% probability.

Uppercase letters for comparison of means of controlled-release fertilizer and NPK treatments. Lowercase letters for comparison of averages of treatments with controlled-release fertilizer.

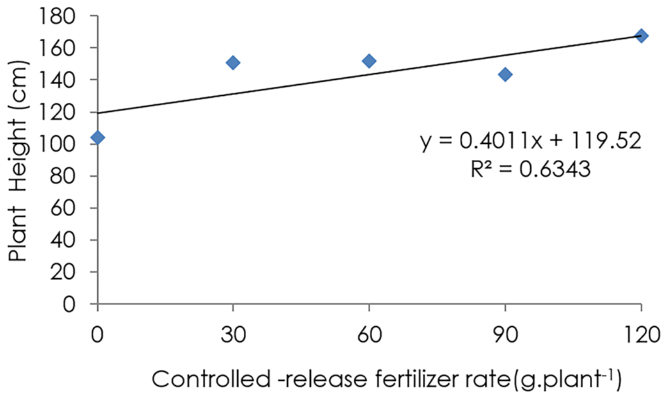

Figure 3. Regression analysis for height (H) of Beauregard sweet potatoes, submitted to different doses of controlled-release fertilizer in vertical farming system. Massaranduba – SC, 2021.
**Significant at 1% probability.

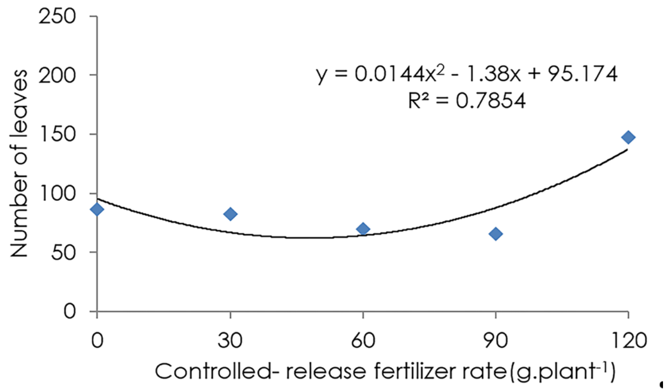

Figure 4. Regression analysis for number of leaves (NL) of Beauregard sweet potato, submitted to different doses of controlled-release fertilizer in vertical cultivation system. Massaranduba – SC, 2021.
**Significant at 1% probability.

According to (Prado et al. 2016), there is an increase in sweet potato productivity in soils of high fertility, mainly with high availability of potassium, nitrogen, phosphorus, calcium and magnesium. It is possible to infer that the process of applying the controlled-release fertilizer in sweet potatoes ensured the availability of mineral nutrients necessary to the nutritional requirements of the crop, especially N that was low in the soil.

Regarding the diameter of the collar, there was no significant effect of the fertilizer compared to the control treatment. This result may be related to the fact that the soil used for planting has sufficient nutrients for the development of the collar and the synthesis of chlorophyll, regardless of the use of fertilizer in the vertical cultivation of Beauregard sweet potato.

The number of branches responded significantly to the controlled-release fertilizer used in sweet potato cv. Beauregard (**Figure 5**).

The study pointed to treatment without any fertilizer supply (control) as the best result. The use of controlled-release fertilizer discreetly reduced the number of branches, possibly the increase in the number of leaves per branch compensated for this effect, since moderate doses of fertilizer promoted an increase in dry biomass of the shoot and root. The results may indicate that controlled-release fertilizers may inhibit vegetative growth in species of agricultural interest when applied to soils that already have high levels of mineral nutrients. The results would possibly be more pronounced if considered equivalent doses of high solubility fertilizers.

Evaluating the length of branches, it is possible to observe that it presented a quadratic growth behavior in relation to the doses of controlled-release fertilizer, demonstrating that the length of branches reached the maximum growth as a function of fertilizer doses (**Figure 6**).

Considering the branch length variable, the maximum calculated technical efficiency value was 69.39g per planting pit. It is found that the plant reached greater lengths of branches with moderate doses of 30g

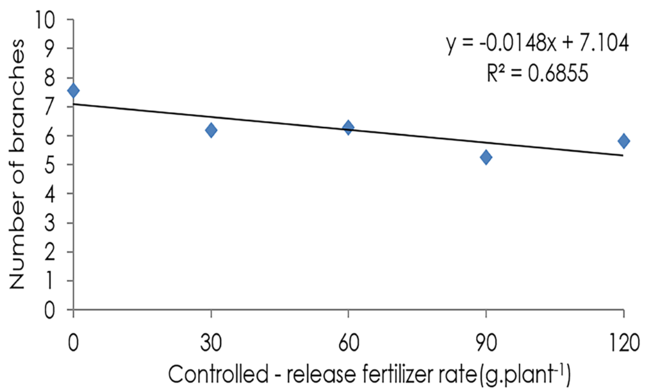

Figure 5. Regression analysis for number of branches (NB) of Beauregard sweet potato, submitted to different doses of controlled-release fertilizer in vertical farming system. Massaranduba – SC, 2021.
*Significant at 5% probability.

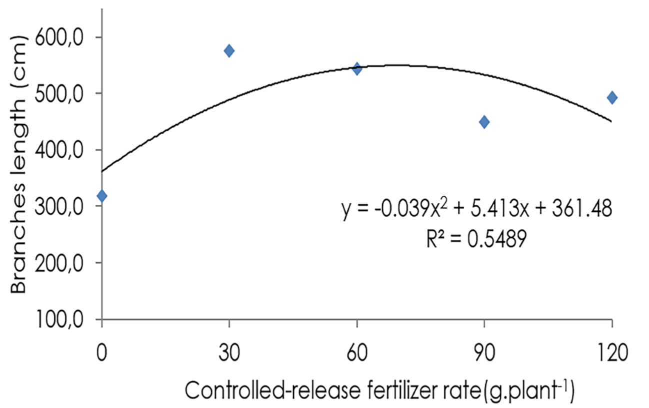

Figure 6. Regression analysis for the length of branches (LB) of Beauregard sweet potato, submitted to different doses of controlled-release fertilizer in vertical farming system. Massaranduba – SC, 2021.
**Significant at 1% probability.

and 60g per pit. However, with higher fertilizer dosages there was inhibition in the growth of branch length. (Rossa et al., 2013) obtained a similar result when assessing the seedling height of the forest species *Sebastiania commersoniana* that decreased with increased utilization of controlled fertilization. This response may be associated with excess fertilizer, especially potassium, the second nutrient in greater abundance in the fertilizer used. With the use of SRF, potassium is available in the soil for a longer time causing less loss of nutrients by leaching compared to other types of fertilizers (Bley et al., 2017). For (Cunha et al., 2021), the advantage of reducing leaching makes the plant absorb more nutrients and an increase in its growth in the production phase of the propagule and field plantings, resulting in a decrease in the applied doses of fertilizers and consequently environmental gain. Even with these advantages, higher doses appear to inhibit branch growth compared to lower doses. This fact illustrates the need to study balanced doses considering the nutritional requirements of each cultivar and the initial soil conditions.

The results presented in this study demonstrate the potential for increasing production of the Beauregard cultivar, in alternative production systems such as vertical farming, associated with the practice of soil fertilization with conventional and controlled-release fertilizers. Future studies are needed for the development of fertilization technologies specific to other soil types and other genotypes of the crop.

Conclusion

The application of controlled-release fertilizer promotes the increment in height, branch length and number of leaves in Beauregard sweet potato plants. The base application of controlled-release fertilizer at a dose of 30g per plant and traditional NPK fertilizer at a dose of 40g per plant promote higher yields of dry mass of shoots and root when compared to unfertilized plants in the cultivation of sweet potatoes in vertical farming.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.