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Yacon development and production under different potassium fertilisation doses

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Abstract

Increased interest in yacon root consumption has led to the need of developing research on such a culture. Mineral nutrition is one of the important points to be investigated since information about this subject remains scarce for this species. Thus, understanding the role played by potassium in expanding yacon culture is of paramount importance, since this mineral plays key role in plants' growth and development processes, mainly in plants accumulating reserves in underground organs due to their most varied functions in metabolite transport processes. Thus, the aim of the current study is to assess the development and yield of yacon roots subjected to different potassium fertilisation doses. The experiment has followed a completely randomized block design, with 4 repetitions and 5 treatments: 178.7 $kg.ha^{-1}$, 357.4 $kg.ha^{-1}$, 536.1 $kg.ha^{-1}$ and 714.8 $kg.ha^{-1}$ of potassium chloride (KCl), which corresponded to 50%, 100%, 150% and 200% of reference value; and one control (non-fertilized soil). Morphological, physiological, and productive features were assessed based on the applied doses. Results have shown that the application of 357.4 $kg.ha^{-1}$ of KCl (100% dose) was the one presenting the best agronomic efficiency for yacon root culture. It was also the dose providing the greatest economic efficiency because it produced larger number of roots in the most valued classes available in the market.

Keywords: Potassium; prebiotics; tuberous roots; *Smallanthus sonchifolius*; yield.

Introduction

For many years now, there has been an agenda about adversities associated with human health, in parallel to discussions about food types and nutrients with potential to provide benefits to our health (Freitas and Jackix, 2005).
Smallanthus sonchifolius, popularly known as yacon root, is a plant species native to the Andes region, in South America (Caetano et al., 2016). Most tuberous roots store energy in the form of starch. However, it is not the case of yacon roots, since they store carbohydrates in the form of fructans, mainly as fructooligosaccharides (FOS), which have functional and prebiotic features (Campos et al., 2012).
Several positive outcomes are associated with yacon root intake, such as immune system strengthening (Santana and Cardoso, 2008) and control of different diseases like diabetes (Valentová et al., 2005; Genta et al., 2010), arteriosclerosis (Valentová et al., 2003), high blood pressure and cholesterol levels (Vignale and Gurni, 2005), and colon cancer (Moura et al., 2012). In addition to the benefits attributed to yacon root intake, its flowers and leaves also have enormous potential to help improving human health, since they are sources of phenolic compounds and flavonoids that have considerable antioxidant properties (Andrade et al., 2014).
Yacon roots were introduced in Brazil by the 1990s, by Japanese immigrants who lived in São Paulo State. However, their consumption has only increased in the 2000s, when they became popularly known as diet potato or yacon potato, as they are known to the present day (Ojansivu et al., 2011). Santa Maria de Jetibá County, which is located in the mountainous region of Espírito Santo State, stands out for recording the largest yacon production scale.
It is essential increasing yacon production fields due to the growing interest in consuming this root given the medicinal effects attributed to it. Thus, it is necessary conducting studies about yacon culture management since information about it remains scarce in the literature. Mineral nutrition is one of the most important points about all crops; therefore, it is essential investigating macro and micronutrients in adjusted doses, since they play key role in root formation processes – they can change both root production and quality.
Potassium is a mineral nutrient that plays essential role in plants' growth and development processes. In addition, it is the first nutrient extracted from the soil by tuberous roots, due to its most varied functions in plants' metabolic processes (Filgueira, 2003). This nutrient is highly required by most cultivated plants; thus, potassium replenishment in the soil is of paramount importance to help maintaining productivity in Brazilian agricultural systems, in an economically viable way (Benites et al., 2010).
The proper management of potassium fertilisers - such as source, time, application mode and doses to be used - is in the mainstream of some studies; factors such as the amount of fertiliser demanded by different crops and their potential losses must be taken into account (Yamada and Roberts, 2005). Therefore, it is essential investigating the ideal fertiliser doses to be used in order to establish the specific demand of each crop to enable their ideal development and

establishment in the field. Thus, the aim of the current study was to assess the effect of different potassium fertiliser doses on yacon roots' development and yield.

Results and Discussion

Morphophysiological assessments

The influence of potassium fertilisation was better perceived on morphological variables such as number of leaves, leaf area and plant height, which always recorded higher values after potassium fertilisation than the control (non-fertilized plants) (Figure 1ABC).

The number of stems presented difference at the beginning of the cycle. It also recorded higher values after potassium fertilisation. However, this behaviour was no longer noticed 60 days after the application of the second fertilisation part (Figure 1D). Stem diameter did not show difference between treatments (Figure 1E).

Physiological variables such as chlorophyll, anthocyanin and flavonoid contents virtually did not present any difference between treatments, although the trend line recorded for non-fertilized plants was slightly above the one recorded for potassium-fertilized plants (Figure 1FGH). Linear model coefficients ($\hat{y} = a+bx$) adjusted to data are shown in Table 1.

Overall, the 100% dose (357.4 $kg.ha^{-1}$ of KCl) stood out among all the applied doses, whereas the 200% dose (714.8 $kg.ha^{-1}$ of KCl) has shown trend towards the worst results, which may be associated with potassium excess in soil triggered by this dose.

According to Folegatti and Blanco (2000), excess of salts in the soil changes the metabolic activity of cells, mainly with respect to cell elongation, which reduces due to limitations in cell wall elasticity and leads to decreased plant growth and development. Based on this information, one can understand why the behaviour of features such as plant height, number of leaves and leaf area (Figure 1ABC) was more promising in plants subjected to 357.4 $kg.ha^{-1}$ of KCl (100%).

The trend line observed for chlorophyll contents in leaves (Figure 1F) of non-fertilized plants was subtly above that of potassium-fertilized plants. It may have happened because N contents in leaves decreased as potassium concentrations increased, as shown in Figure 2A.

It is known that chlorophyll is directly linked to nitrogen contents found in leaves and that decreased N contents lead to reduced chlorophyll levels (Clarkson and Hanson, 1980; Hák and Nátr, 1987). There are indications that increased potassium content can lead to decreased N values and, consequently, to decreased leaf chlorophyll values. Passos et al. (2020) have investigated beetroot response to potassium doses and found that K doses have influenced leaf nitrogen contents, whereas increased K doses led to decreased N contents. Similarly, Gazola (2017) has also observed that nitrogen contents in cassava culture have linearly decreased as potassium fertilisation doses increased.

Increased potassium fertilisation doses led to increased potassium contents in plants' leaves, stems, rhizophores, and roots (Figure 2ABCD) at the end of the cycle (210 days after planting). This result was expected since high potassium availability in the soil and favourable abiotic conditions enable plants to absorb larger amounts of this element by adopting a behaviour known as "luxury consumption" (Fullin et al., 2007). Similar behaviour had been previously observed for other vegetables, such as sweet potatoes (Silva, 2013) and beetroots (Passos et al., 2020).

However, high potassium content may have had deleterious effect on reserve accumulation in yacon plants since there was dry mass decrease in organs such as rhizophores and tuberous roots at the end of the cycle in plants subjected to dose higher than 100% (Figure 3CD). On the other hand, this effect was not noticed on plants' shoot (leaves and stems), whose dry mass accumulation was not affected by the applied potassium doses (Figure 3AB).

This result has indicated that 357.4 $kg.ha^{-1}$ of KCl would be the ideal dose to be used in yacon crops and that the application of higher doses, which would lead to high potassium accumulation rates, can be harmful since it leads to decreased dry mass accumulation - mainly in reserve organs such as rhizophores and tuberous roots - and, consequently, to decreased production rates.

Decrease in dry mass accumulation would result from nutritional imbalance (Silva and Trevizam, 2015) since, according to Marschnner (2011), increased potassium contents may lead to lower absorption of other ions and even affect plant growth. The effects of increased potassium doses on the reduced absorption of other nutrients, mainly of calcium and magnesium, have already been reported by Mascarenhas et al. (2000), Prado et al. (2004) and Fernandes et al. (2017).

Yacon production and yield

Yacon production behaviour has reflected what was observed for dry mass accumulation. It showed that the largest number of roots per plant and yield were recorded at KCl dose of 357.4 $kg.ha^{-1}$ (100% of the reference value) and that doses higher than that had negative effects on yacon production (Figure 4AC). Mean root weight was not affected by the applied potassium doses; this outcome has shown that variance in these data is likely not explained based on the applied doses, a fact that features them as independent factors (Figure 4B).

The indifferent behaviour of mean root weight towards potassium doses has shown that yield gains, noticed after potassium application, were associated with the increased number of reserve roots produced by yacon, rather than with the increased weight of each root. It was different from what was observed in cassava crops by Gazola (2017), who found that higher potassium doses resulted in mean root weight decrease, in comparison to other lower doses.

Cardoso (2018) has observed similar behaviour for sweet potatoes, which presented decreased number of roots as potassium doses got above the recommended; this outcome has shown that excessive potassium doses hindered root formation. Accordingly, Borges (2019) observed that increased potassium dose led to decreased yield in sweet potato, cultivar Amanda. Silva et al. (2017) observed that carrot yield has decreased after the application of potassium doses above the recommended.

Notably, high potassium accumulation generated by doses above the reference value may have caused nutritional imbalance in plants, a fact that led to production losses. Potassium competes with other cations at root system-input sites; it leads to antagonism of other nutrients, such as calcium and magnesium, which results in the shortage of these nutrients and impairs plant development and yield (Wakeel, 2013).

Assumingly, such an imbalance may have promoted lower calcium absorption, which is associated with cell wall

Table 1. Linear model coefficients (ŷ = a+bx) adjusted to the number of leaves, leaf area, height, number of stems, diameter, chlorophyll, anthocyanin and flavonoids in yacon plants subjected to different potassium fertilisation doses. Alegre County-ES, 2020. Significance level at 5% (*); 1% (**); 0.1% (***), based on Student's t test.

Variable	Dose (%)	a	b	R^2
	0	4.18	0.186**	0.9344
	50	8.12	0.218***	0.9638
Number of leaves	100	8.18	0.242***	0.9702
	150	8.65	0.220***	0.9558
	200	8.94	0.182**	0.9464
	0	142.58	0.947***	0.9845
	50	200.83	0.932***	0.9513
Leaf area	100	209.64	1.112**	0.9343
	150	203.91	0.880**	0.9465
	200	189.34	0.747**	0.9468
	0	20.56	0.349**	0.8849
	50	29.14	0.510***	0.9969
Height	100	31.44	0.523***	0.9972
	150	30.11	0.504***	0.9973
	200	26.49	0.438***	0.9705
	0	1.10	0.013**	0.8899
	50	1.46	0.009**	0.8703
Number of stems	100	1.37	0.011**	0.8468
	150	1.38	0.011*	0.8197
	200	1.34	0.011**	0.8636
	0	1.21	0.007**	0.9251
	50	1.29	0.007**	0.8497
Diameter	100	1.29	0.006**	0.9177
	150	1.27	0.006***	0.9591
	200	1.34	0.006**	0.9466
	0	33.38	0.052***	0.9868
	50	31.65	0.053*	0.8144
Chlorophyll	100	31.57	0.049**	0.9169
	150	31.65	0.052***	0.9627
	200	31.64	0.047**	0.8894
	0	0.16	0.0004**	0.8870
	50	0.16	0.0004**	0.9359
Anthocyanin	100	0.16	0.0004**	0.8608
	150	0.17	0.0004**	0.8620
	200	0.18	0.0003*	0.7947
	0	0.95	0.003**	0.9141
	50	0.96	0.003**	0.8689
Flavonoids	100	0.97	0.003*	0.7902
	150	0.97	0.003**	0.8461
	200	1.00	0.003**	0.9059

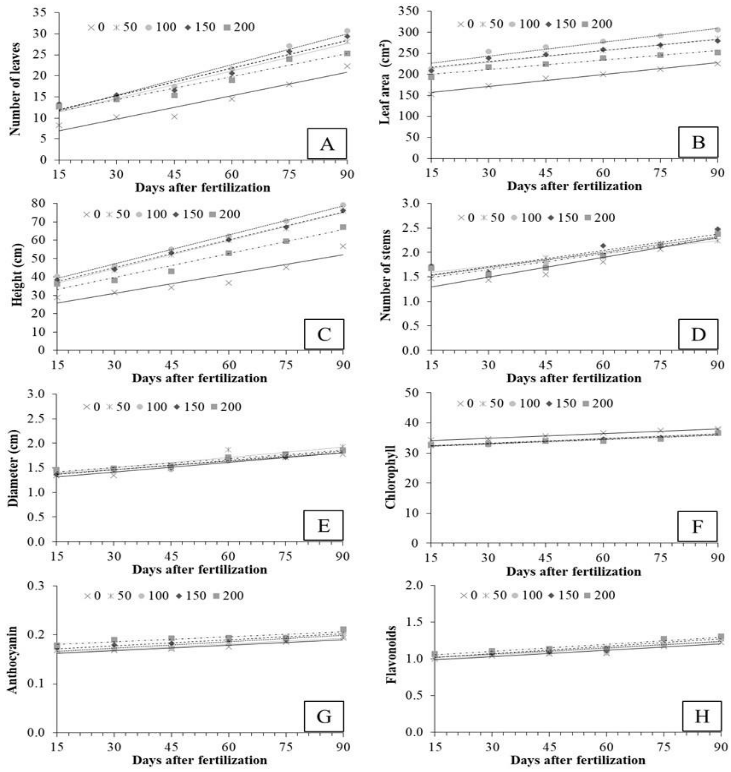

Figure 1. Number of leaves (A), leaf area (B), height (C), number of stems (D), diameter (E), chlorophyll (F), anthocyanin (G) and flavonoids (H) in yacon plants subjected to different potassium fertilisation doses. Alegre County-ES, 2020.

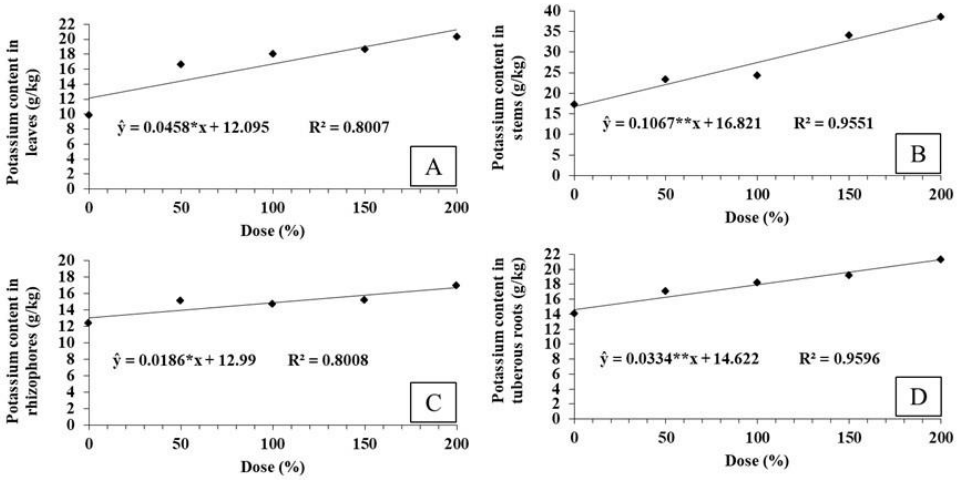

Figure 2. Potassium content in leaves (A), stems (B), rhizophores (C) and tuberous roots (D) of yacon plants subjected to different potassium fertilisation doses. Alegre County-ES, 2020. Significance level at 5% (*) and 1% (**), based on Student's t test.

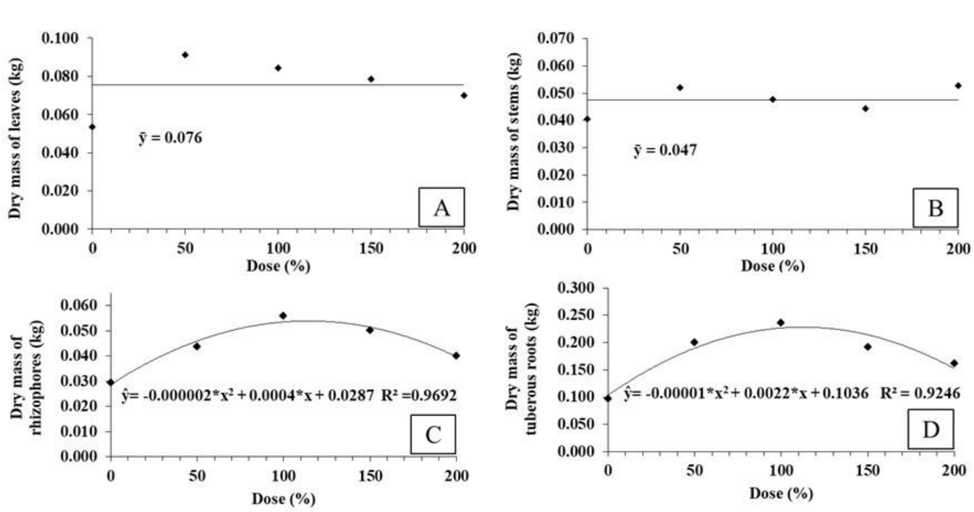

Figure 3. Dry mass of leaves (A), stems (B), rhizophores (C) and tuberous roots (D) of yacon plants subjected to different potassium fertilisation doses. Alegre County-ES, 2020. Significance level at 5% (*), based on Student's t test.

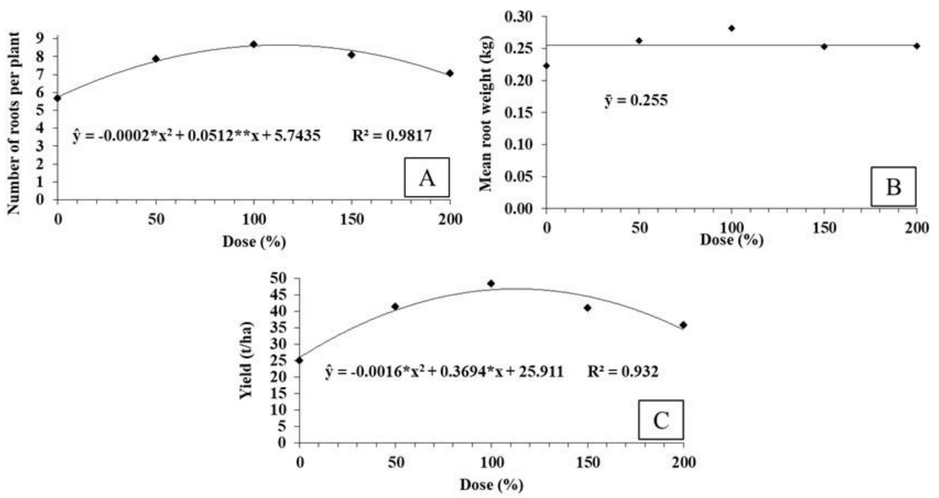

Figure 4. Number of roots per plant (A), mean root weight (B) and yield (C) of yacon plants subjected to different potassium fertilisation doses. Alegre County-ES, 2020. Significance level at 5% (*) and 1% (**), based on Student's t test.

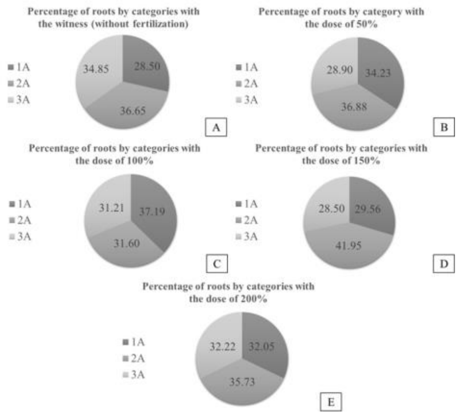

Figure 5. Yacon root production rates in categories 1A, 2A and 3A of plants subjected to doses corresponding to 0% (A), 50% (B), 100% (C), 15 05 (D) and 200% (E) of potassium fertilisation. Alegre County-ES, 2020.

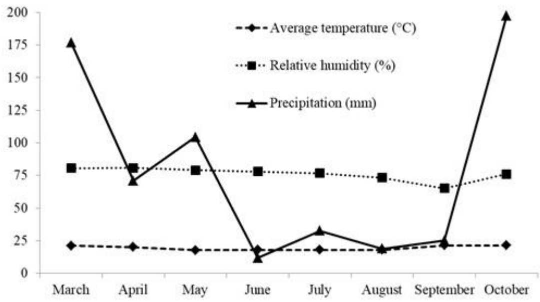

Figure 6. Mean monthly temperature, relative humidity and rainfall rates during the experimental period. Alegre County-ES, 2020. Source: Incaper (2020).

formation. Thus, plants lacking calcium may have had a hard time forming reserve organs such as rhizophore and tuberous roots, since they prioritize calcium allocation to form shoot organs, such as leaves and stems, which are the most vital organs for plants' survival (Oliveira et al., 2010). It would likely be the cause of the non-observance of difference in dry mass accumulation in these organs (leaves and stems). Plants would have prioritized investment in organs directly involved in sunlight absorption and photosynthesis, to the detriment of reserve organs (Oliveira et al., 2010).

Thus, the higher agronomic efficiency after the application of fertiliser dose corresponding to 100% of the reference value (357.4 kg.ha-1 of KCl) becomes clear in comparison to the control treatment (non-fertilized soil), since the aforementioned dose has increased by 35 % the number of roots per plant and by 48%, its yield (Figure 4AC). This outcome has evidenced the key role played by proper potassium fertilisation management in yacon development and production.

Potassium fertilisation doses have also influenced the classes of roots produced by yacon plants. The application of potassium dose corresponding to 100% of the reference value has led to the highest rate (37.19%) of roots in class 1A (large root > 300 g), as shown in Figure 5C. This outcome has shown the high potential of economic profitability enabled by the application of the aforementioned dose, since root class 1A was the one recording the highest commercial values (Carvalho et al., 2020).

The application of higher fertiliser doses has led to the highest rates of roots in class 2A (41.95% and 35.73%, for doses corresponding to 150% and 200% of the reference value, respectively), which present median values in the market (Figure 5DE). The same outcome was observed for plants subjected to the application of fertiliser dose lower than the reference value (50%) and for the control (non-fertilized soil) (Figure 5AB).

Materials and Methods

Characteristics of the experimental area

The experiment was carried out in a rural property in Celina district, Alegre County, Espírito Santo State (latitude 20°47'1" S; longitude 41°36'56" W; altitude 680 m). According to Köppen's international classification, the climate in the region is humid tropical (Pezzopane et al., 2012).

Mean temperature, relative humidity and rainfall data were provided by Incaper automatic meteorological stations in Iúna County/ES (latitude 20°21' S, longitude 41°33" W; altitude 758 m), since they are the closest stations to the culture field. Accumulated rainfall rate during the experimental period (March to October 2020) was 638 mm, mean maximum temperature was 21.43 °C and mean minimum temperature was 17.79 °C (Figure 6).

Soil and plant material preparation

The soil in the experimental plot was classified as oxisol. Samples were subjected to laboratory analysis and presented the following chemical features: pH 4.80 in water, 3.95 mg dm^{-3} of P, 42.00 mg dm^{-3} of K, 0.68 cmol$_c$ dm^{-3} of Ca, 0.22 cmol$_c$ dm^{-3} Mg, 1.00 cmol$_c$ dm^{-3} Al, 1.01 cmol$_c$ dm^{-3} sum of exchangeable bases, 2.01 cmol$_c$ dm^{-3} of effective cation exchange capacity and 8.89% of base saturation index.

Soil preparation was based on plowing (down to the 40-cm layer) and on subsequent harrowing. Liming was carried out with dolomitic limestone with 96% PRNT to increase base saturation to 70%. Yacon planting was carried out 60 days after liming. The plant material used for yacon propagation was an ecotype found in the mountainous region of Espírito Santo State, to which all cultivated materials have genetic similarity (Lorenzoni et al., 2017). Rhizophores of approximately 30 grams, with 3 to 4 buds, were used for propagation purposes, as recommended by Pedrosa et al. (2020). They were planted (in separate) in seedbeds, at 1.0 m x 0.5 m spacing, as recommended by Carvalho et al. (2020).

Experimental design and treatments

The experiment has followed a randomized block design (RBD), with four repetitions; treatments consisted in four different potassium fertilisation doses, which corresponded to 50%, 100%, 150% and 200% of the reference value; and a control (non-fertilized soil). The experimental plot comprised 5 rows with 5 plants; the useful area was the one occupied by the 3 central plants of the 3 central rows, and it provided 9 useful plants to be evaluated.

The reference value adopted in the current study was that recorded by Mendes (2019), who found accumulation of 106.8 $kg.ha^{-1}$ of K in yacon plants, 210 days after planting. This value was converted to K_2O in order to calculate the doses to be used in treatment applications, since potassium chloride (KCl) was the herein selected fertiliser - results have shown KCl dose of 128.65 $kg.ha^{-1}$. Potassium was the nutrient investigated in the current study; thus, recovery efficiency of 60% was also taken into consideration (Santos, 2016).

Thus, the herein applied doses were: 178.7 $kg.ha^{-1}$ of KCl; 357.4 $kg.ha^{-1}$ of KCl; 536.1 $kg.ha^{-1}$ of KCl; 714.8 $kg.ha^{-1}$ of KCl, which corresponded to 50%, 100%, 150% and 200% of the reference value, respectively.

Experimental conduction

Cover fertilisation was the herein selected application type. It was split into two times: the 1^{st} application was carried out when 80% of plants had emerged - the emergence point corresponded to the opening of the first two leaves - (80 days after planting) and the 2^{nd} application took place 30 days later (110 days after planting).

Nitrogen and phosphate fertilisations have followed the same procedure, as recommended by Mendes (2019), who found accumulation of 172 $kg.ha^{-1}$ of N and 33.2 $kg.ha^{-1}$ of P, which were converted into P_2O_5 and resulted in 76.07 $kg.ha^{-1}$. Phosphate fertilisation was carried out at planting time and nitrogen fertilisation was carried out at top dressing, along with potassium fertilisation, based on simple superphosphate and urea fertilisers, respectively. Irrigation was carried out through sprinklers and weeds were controlled through manual weeding, whenever necessary.

Morphophysiological analysis, production and yield

Vegetative development was assessed every two weeks (15, 30, 45, 60, 75 and 90 days after the application of the second potassium fertilisation portion, which corresponded to 125, 140, 155, 170, 185 and 200 days after planting) throughout the experimental period (March to October 2020). The following features were measured: number of leaves, leaf area, plant height, number of stems, stem base diameter, as well as chlorophyll, anthocyanin and flavonoid contents.

The following variables were evaluated at the end of the experimental cycle (210 days after planting), when plants were 7 months old: dry mass and potassium content in leaves, stems, rhizophores and tuberous roots; the number of roots per plant, and mean root weight. In addition, roots were classified based on their commercial standard and yield.

Individual counting for the number of leaves and stems was carried out. Stem base diameter and plant height were measured with calliper and measuring tape, respectively. Leaf area was measured with a ruler: leaf width was measured perpendicularly to its vein and in parallel to its length, without taking into consideration the petiole. Values were calculated through the following equation, developed by Erlacher et al. (2016): $\hat{A}f\mathrm{LW} = -27.7418 + \left(\frac{3.9812\mathrm{LW}}{ln\mathrm{LW}}\right)$, wherein W is leaf width and L is leaf length. Chlorophyll, anthocyanin and flavonoid contents were measured in Dualex device.

The number of roots per plant was calculated based on the total number of roots divided by the number of plants per treatment. Mean root weight was calculated by dividing the total root mass per plant by the number of roots per plant. All leaves, stems and rhizophores were weighed to find the fresh mass of each of these parts. Next, samples of approximately 300 grams were collected, placed in paper bags and taken to forced air circulation oven at 70 ± 5°, for 72 hours, to find the dry mass. Total dry mass was calculated based on moisture rate. Subsequently, samples were ground in knife mill and subjected to nutrient analysis – the potassium content of each plant part was investigated through nitric-perchloric digestion.

Roots were weighed in separate to enable classifying their commercial standard as follows: 1A (root heavier than 300 grams), 2A (root weight ranging from 120 to 300 grams) and 3A (root lighter than 120 grams) (Oliveira, 2016). Root yield was determined by multiplying root mass production per plant by the number of plants grown in one hectare (20,000 plants), at 1.0 m x 0.5 m spacing.

Statistical analysis

Linear regression models were tested to evaluate equation adjustments by associating the investigated variables with potassium doses. Models were selected based on evaluations about the behaviour observed in the graph of variables, in the sum of squares of complete models, in the coefficient of determination (R^2) and in the significance of regression coefficients through Student's t test. All statistical procedures were performed in R Environment (R Core Team, 2020).

Conclusion

It is possible concluding that the dose corresponding to 100% of the reference value (357.4 $kg.ha^{-1}$ of KCl) was the one presenting the highest agronomic efficiency (the largest number of roots per plant and yield) for yacon culture. In addition, it can lead to greater economic efficiency, since it enabled the production of a larger number of roots in the most valued classes available in the market.

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