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Effect of NPK fertilizer rates and growth regulator concentrations on sweet potato crop yield

Níveis de fertilização NPK e efeito de concentrações de regulador de crescimento na produtividade da batata-doce

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ABSTRACT - The low mean yield of sweet potato crops in Brazil is related to several inadequate crop management practices. Considering the increasing production of this vegetable, the objective of this work was to evaluate the yield response of sweet potato crops subjected to different NPK fertilizer rates (NPK) combined with different growth regulator concentrations. The experiment was carried out in a randomized block design, with a 5×5 factorial arrangement consisted of 5 NPK fertilizer rates (0, 696, 1044, 1392, and 1740 kg ha^{-1}) combined with 5 growth regulator concentrations (0, 20, 25, 30, and 35 mL L^{-1}). Numbers of total and commercial roots per plant were affected by the factors tested, presenting a linear increase as the rates and concentrations were increased. The highest estimated sweet potato yield was 43 Mg ha $^{-1}$, which was obtained using a NPK rate of 1522.64 kg ha^{-1} and a growth regulator concentration of 34.69 mL L^{-1}. The higher NPK rates improved water use efficiency up to a maximum value of 8.1 kg m^{-3} with application of the NPK rate of 1740 kg ha^{-1}. After determining a fixed yield level, the production factors tested act as imperfect substitutes in some intervals of variation of the inputs.

Keywords: *Ipomoea batatas* (L.) Lam. Irrigation water yield. Production function. Isoquants.

RESUMO - A baixa produtividade média da batata-doce no Brasil está ligada a uma série de práticas inadequadas no manejo dessa cultura. Tendo em vista a crescente produção dessa hortaliça, este trabalho objetivou avaliar a resposta do rendimento de batata-doce submetida a diferentes níveis de adubação (NPK) associada a diferentes concentrações de regulador de crescimento (RC). Foi realizado um experimento em blocos casualizados em esquema fatorial 5 x 5, sendo 5 níveis de adubação NPK (0 ; 696; 1044; 1392 e 1740 kg ha^{-1}) combinado com 5 concentrações de RC (0; 20; 25; 30 e 35 mL L^{-1}). O número de raízes totais e comerciais é influenciado pelos insumos testados e aumentam linearmente com aumento das doses e concentrações testadas. A produtividade máxima estimada da batata-doce é de 43 t ha^{-1}, a ser obtida com aplicação de 1522.64 kg ha^{-1} de NPK e 34.69 mL L^{-1} de regulador de crescimento. Doses maiores de NPK favoreceram o aumento da eficiência do uso da água, até alcançar o valor máximo de 8.1 kg m^{-3} com a aplicação da dose de 1740 kg ha^{-1}. Determinado um nível de rendimento fixo, os fatores de produção testados comportam-se como substitutos imperfeitos em alguns intervalos de variação dos insumos.

Palavras-chave: *Ipomoea batatas(L.) Lam*. Produtividade da água de irrigação. Função de produção. Isoquantas.

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INTRODUCTION

China is the world's largest sweet potato producing country, with a production of more than 49.2 million Mg in 2020, which presented a mean yield of 21.8 Mg ha $^{-1}$ (FAO, 2022). Brazil had a production of 847,900 Mg in 2020, with a national mean yield of 14.2 Mg ha $^{-1}$ (IBGE, 2022).

The low sweet potato yield in Brazil is due to multifactorial causes, standing out the use of low-quality propagation materials (AMARO et al., 2017; MASSAROTO et al., 2014) and a high degeneration degree due to continued and successive use of the same propagation material (MELO et al., 2020). Therefore, although sweet potato crops have insufficient phytosanitary support (OLIVEIRA et al., 2019), they can result in healthy plants by using clonal cleaning methods; however, this solution is not accessible to all growers, as this vegetable is predominantly grown by people with no technical training and without production technologies (NAKAO et al., 2020; PEDROSO et al., 2021).

The use of agricultural inputs in Brazil has considerably grown in the last years. According to data of the 2006 and 2017 Agricultural Census, the number of rural properties that use synthetic or organic compounds in the region in which the present work was carried out (Serra de Ibiapaba, CE, Brazil) increased from 7,505 to 8,703. Regarding the application of soil fertilizers to sweet potato crops using organic or mineral sources, researches have confirmed that the availability of nutrients is indispensable for high yield indexes (AGUIRRE et al., 2020; RÓS; NARITA; HIRATA, 2014).

Sweet potato, as other vegetables, has a relatively high demand for primary macronutrients. According to Echer, Dominato and Creste (2009), the nutrient absorption pace is a predominant factor for recommendations of soil fertilizers for sweet potato crops; they reported that nitrogen, calcium, and potassium are absorbed in greater amounts. Regarding the form of application of fertilizers of mineral origin, studies have indicated that fertilizer application through soil is more efficient than fertilizer application through leaves, because sweet potatoes are roots (OLIVEIRA et al., 2006). In addition, splitting fertilizer applications during the crop cycle has shown to be efficient and a strategy to ensure a better use of the nutrients available in the soil (ALVES et al., 2009).

The dynamics of evolution of adventitious roots into storage roots is not fully understood (SINGH et al., 2021); however, Villordon et al. (2012) reported that an adequate soil moisture content may promote the initiation of storage roots, which are the plant parts of economic interest to growers (ECHER; DOMINATO; CRESTE, 2009).

According to Rós, Narita and Araújo (2015), the application of growth regulator is an alternative to increase sweet potato crop yield by promoting a more intense rooting of stems. In this context, absorbing roots could increase the absorption of nutrients and water and the storage roots could increase in volume. Severino et al. (2003) reported that some problems of low root development, emergence, and initial unevenness are factors that negatively affect the crop production performance; in these cases, the application of growth regulators is also recommended at the initial stages of the crop (OLIVEIRA et al., 2017; NEUMANN et al., 2017). However, researches evaluating production attributes of sweet potato as a function of plant hormone rates are scarce.

Inputs stand out among the production factors due to their representativeness in production costs and, mainly, due to the need for their efficient use to allow the edaphic sustainability (SOUZA; GOMES; ALVES, 2020; RIBEIRO et al., 2021). In addition, significant variations in sweet potato crop yields in response to variations in levels of these resources can occur, denoting the yield high sensitivity to the levels of these production factors (SILVA et al., 2022; ICHIKAWA; FERNANDES; MOTA, 2019).

The crop production functions are a valuable information that can be used in decision making models, allowing the optimization of the use of factors involved in the production (SALGADO et al., 2010, FRIZZONE, 1993).

The hypothesis raised in the present study is that the use of plant hormones combined with soil fertilizer application (NPK) results in larger number of adventitious and storage roots and, therefore, in higher yield.

In this context, the objective of the present study was to evaluate the yield response of sweet potato crops subjected to different NPK fertilizer rates (NPK) combined with different growth regulator concentrations applied to the stems.

MATERIALS AND METHOD

The experiment was conducted from September to December 2020 in Guaraciaba do Norte, state of Ceará, Brazil (04°10'01"S, 40°44'51"W, and altitude of approximately 950 m). This region presents a dry sub-humid climate, with a mean annual rainfall depth of 1179.1 mm, and a mean estimated annual reference evapotranspiration of 1852.06 mm (FUNCEME, 2020).

The experimental area had been managed under a crop rotation with sweet potato, maize, and common bean.

The chemical attributes of the 0.0-0.2 m soil layer were: pH of 6.2; 32.79 g kg^{-1} of organic matter; electrical conductivity of 0.85 dS m^{-1}; 0.24 cmol$_c$ kg^{-1} of K^{+}; 4.7 cmol$_c$ kg^{-1} of Ca^{++}; 0.7 cmol$_c$ kg^{-1} of Mg^{++}; base saturation of 58%; 0.19 cmol$_c$ kg^{-1} of Na^{+}; and 44 g kg^{-1} of assimilable P. The soil subsurface (0.2-0.4 m layer) presented pH of 6.4; 32.27 g kg^{-1} of organic matter; electrical conductivity of 0.52 dS m^{-1}, 0.21 cmol$_c$ kg^{-1} of K^{+}; 4.2 cmol$_c$ kg^{-1} of Ca^{++}; 1.0 cmol$_c$ kg^{-1} of Mg^{++}; base saturation of 60%; 0.2 cmol$_c$ kg^{-1} of Na^{+}; and 30 g kg^{-1} of assimilable P. The textural classes of the soil layers are shown in Table 1. The soil samples were collected at approximately 3 months before the implementation of the experiment.

Table 1. Granulometry and textural class of the 0-0.2 and 0-0.4 m soil layers.

Layer (m)	Granulometry (g kg^{-1})					Textural Class
	Coarse sand	Fine sand	Silt	Clay	Natural clay	
0- 0.20	517	282	92	110	30	Loamy sandy
20-0.40	463	321	118	99	25	Loamy sandy

The experiment was conducted in a randomized block design, with four blocks, in a 5×5 factorial arrangement consisted of five rates of a NPK formulation and five growth regulator concentrations. The experimental plot consisted of ten plants, in an area of 2.7 m^2 (3.0 m × 0.9 m). Eight plants of the center of each plot were considered for the evaluations.

The soil preparation was mechanized using plowing and harrowing, followed by manual raising of ridges using hoes.

The propagation material used was sweet potato stems of purple skins and white pulp from plants of a local variety obtained from farmers in Guaraciaba do Norte. This variety is characterized by elongated, fusiform roots and aerial part with rounded, three-pointed leaves. The stem cuttings were prepared with an average of eight internodes each, with an apical part, as described by Santos Neto et al. (2017) and

Oliveira et al. (2006). The planting was carried out manually; the stems were arranged horizontally, burying all internodes, leaving only the apical part exposed.

The NPK formulation was based on recommendations of the Brazilian Agricultural Research Corporation (EMBRAPA, 1995), considering the nutritional requirements of sweet potato, which consisted of 60 kg ha^{-1} of N, 150 kg ha^{-1} of P, and 150 kg ha^{-1} of K. The sources used were ammonium sulfate for nitrogen, simple superphosphate for phosphorus, and potassium chloride for potassium. The fertilizers were applied in a single application before the planting of stems, using the following rates of the NPK formulation: 0.0 kg ha^{-1}; 696 kg ha^{-1}; 1044 kg ha^{-1}; 1392 kg ha^{-1} and 1740 kg ha^{-1}.

The growth regulator was applied to the stems before planting. The propagation material was immersed in containers with different concentrations of the commercial product Stimulate® (0.005% of indole-3-butyric acid - auxin; 0.009% of kinetin; and 0.005% of gibberellic acid) for 30 minutes and then shade dried before planting. The concentrations used were: 0.0 mL L^{-1}; 20 mL L^{-1}; 25 mL L^{-1}; 30 mL L^{-1}; and 35 mL L^{-1}. The concentrations were chosen based on the manufacturer's recommendations and on the concentrations tested by Rós, Narita and Araújo (2015).

A manual weeding was carried out for the crop at the fifth week, and no pesticide were applied during the crop cycle.

The water used for crop irrigation was from a well. The water quality attributes were: pH of 6.3; electrical conductivity of 0.14 dS m^{-1}; and 140 mg L^{-1} of dissolved solids. The water presented a classification C1S1, i.e., no restrictions for irrigation, with low risk of soil salinization and sodification (BERNARDO; MANTOVANI; SOARES, 2019).

A localized irrigation method was used through a drip irrigation system, with one emitter per plant, spaced according to the crop distribution in the experimental area (spacing between plants of 0.30 m and spacing between rows of 0.90 m).

The reference evapotranspiration (ETo) was determined using the software EVAPO (MALDONADO; VALERIANO; ROLIM, 2019), through the Penman-Monteith method (FAO 56), with daily replacement of the irrigation water depth.

The crop evapotranspiration (ETc) was obtained by multiplying the ETo value by the crop coefficient (Kc) for each phenological stage of the crop. According to Allen et al. (2006), Kc values for sweet potatoes are: $Kc_{initial} = 0.5$; $Kc_{mean} = 1.15$ and $Kc_{final} = 0.65$. The correction of ETc for localized system was carried out based on the following Equation 1:

$$ETc_{LOC} = \text{ETc} \times 0.1 \times \sqrt{Pw} \qquad (1)$$

where:
ETc = potential evapotranspiration of the crop (mm day^{-1});
Pw = percentage of wet or shaded area, using the highest value (%);

Variables analyzed

The variables analyzed were total yield, commercial yield, number of roots per plant, and number of roots with commercial standard. There is no established classification for sweet potato in Brazil, thus, commercial roots were considered as those that presented weight equal to or above 80 g and length greater than 10 cm, and presented no cavities or tortuosity; this classification was adapted by the Brazilian Agricultural Research Corporation (EMBRAPA, 1995).

The irrigation water yield was obtained by the ratio between total yield (kg ha^{-1}) and amount of water applied (m^3 ha^{-1}) in each treatment until the end of the crop cycle (COELHO; COELHO FILHO; OLIVEIRA, 2005).

Statistical analysis

The normality and homoscedasticity of the data were verified by the Shapiro-Wilk test and Levene test, respectively, at 5% significance level. The results were subjected to analysis of variance by the F test for comparison of mean squares, at 0.05 probability. Polynomial regression analyses were also used to evaluate the effect of NPK rates and growth regulator concentrations on the variables evaluated, testing linear and quadratic models to explain the results, selecting the one that presented significance and the highest coefficient of determination (R^2) and the one that better represented the performance of the results obtained (considering the signs of the parameters of the statistical models and comparing with the response curves of agricultural crop), using the software SISVAR and STATISTICA (FERREIRA, 2008; STATSOFT, 2004).

Production function

The production function, used for estimating the yield as a function of the NPK rates (X) and concentration of regulated of growth (E), was defined by testing ten statistical models, as described by Aguiar (2005). The choice of the model that better represented the function y = y(X,E) was carried out considering analyses of coefficient of determination and adjusted coefficient of determination, F test for analysis of variance, t test for coefficients of the variables, and coherence of the signs of the variables in the model.

The production function of sweet potato as a function of NPK rates and growth regulator concentrations was used for obtaining the marginal physical products of the tested factors and determining the production isoquants.

The marginal physical product of a factor represents the increase in yield when adding one unit of the factor (SOARES et al., 2002). The marginal physical products of the factors growth regulator and fertilizer were obtained through the first derivative of the production function in relation to the considered factor, represented by the Equation 2:

$$PMg(f) = \frac{\partial Y}{\partial f} \qquad (2)$$

where:
PMg(f) = marginal physical product of the factor;
$\frac{\partial Y}{\partial f}$ = derivative of the function in relation to the factor.

The marginal rate of substitution of the factor growth regulator concentration by the factor fertilizer rate corresponds to the amount of the growth regulator that must be disregard to add one unit of the fertilizer, while maintaining the same yield level (MONTEIRO et al., 2007); it is obtained by following Equation 3:

$$\mathrm{MRS}_{\frac{X}{E}} = -\frac{\mathrm{PMg\ X}}{\mathrm{PMg\ E}} \qquad (3)$$

where:
$\mathrm{MRS}_{X/E}$ = marginal rate of substitution of the factor growth regulator factor (E) by the factor fertilizer (X);
$\mathrm{PMg}_{(E)}$: marginal product of the factor growth regulator;
$\mathrm{PMg}_{(X)}$: product marginal of the factor fertilizer.

The production function was used to determine the isoquants or iso-product curves, which correspond to curves that connect points of different combinations of growth regulator concentrations and fertilizer rates presenting the same yield (PINDYCK ; RUBINFELD, 2013).

RESULTS AND DISCUSSION

Mean numbers of roots per plant and commercial roots per plant

The factors NPK and growth regulator (GR) had significant effect (p<0.001), by the F test, on number of roots per plant (NRP) and number of commercial roots per plant (NCRP). However, the interaction between the factors was not significant (Table 2).

The NPK rates fitted to a quadratic model for NRP, with a maximum estimated NRP of 6.3, which was found with a NPK rate of 1333.3 kg ha^{-1} (Figure 1).

Table 2. Analysis of variance of number of roots per plant (NRP) and number of commercial roots per plant (NCRP) as a function of NPK rates and growth regulator concentrations.

Factor of variation	DF	Mean square	
		NRP	NCRP
NPK	4	4.23225***	2.91385***
Linear regression	1	8.995135**	7.907515***
Quadratic regression	1	4.153414*	0.451113^{ns}
GR	4	10.48075***	3.00035***
Linear regression	1	33.60960***	11.30126***
Quadratic regression	1	0.835007^{ns}	0.027604^{ns}
NPK × GR	16	0.633938^{ns}	0.189913^{ns}
CV (%)		15.31	13.8

ns = not significant, *** = significant at 0.1%, ** = significant at 1%, and * = significant at 5% probability by the F test. DF = degrees of freedom.

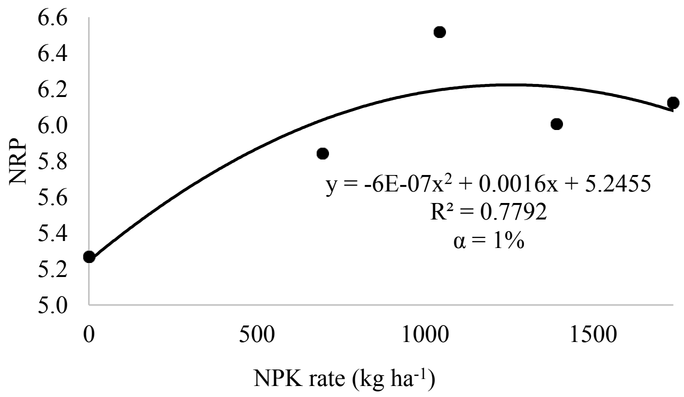

Figure 1. Number of roots per plant (NRP) as a function of NPK rates.

NRP of sweet potato varies according to the cultivar and quality of the propagation material used. Amaro et al. (2019) evaluated the performance of different sweet potato cultivars in the state of Sergipe, Brazil, using stems subjected to clonal cleaning, and found a mean NRP of 11.28 for the cultivar Brazlândia Branca, 12.55 for the cultivar Brazlândia Roxa, 9.58 for the cultivar BRS-Rubissol, and 7.33 for the cultivar Princesa.

The plant response for the variable NCRP was positive and directly proportional to the NPK rates, presenting a linear fit. The mean maximum estimated NCRP was 4.2, found with a NPK rate of 1740 kg ha^{-1}, and the lowest mean was 3.4, found in the treatment with no fertilizer application (Figure 2).

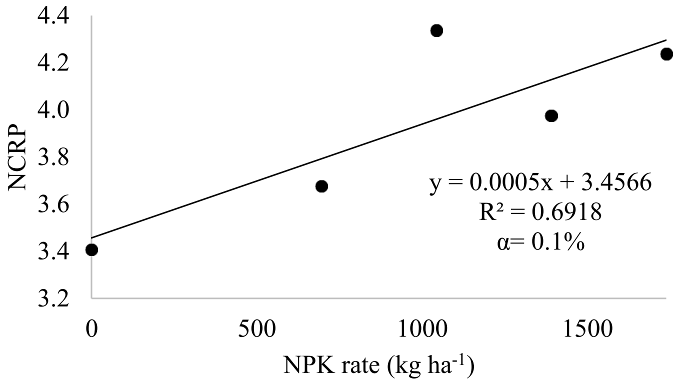

Figure 2. Number of commercial roots per plant (NCRP) of sweet potato as a function of NPK rates.

NCRP is relative and varies according to criteria established for classification of roots for marketing, with an evident variation in mean NCRP among different cultivars (AMARO et al., 2019).

NRP was affected by GR concentrations (Figure 3), and the maximum NRP (6.5) was found with application of 35 mL L^{-1}; plots not treated with GR resulted in a mean NRP of 4.99.

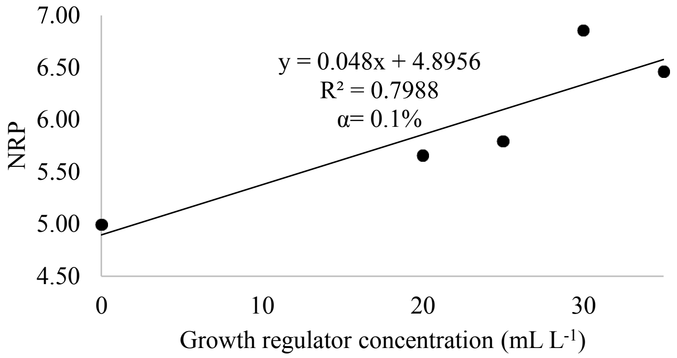

Figure 3. Number of roots per plant (NRP) of sweet potato as a function of growth regulator concentrations.

Neumann et al. (2017) reported that applications of plant hormones to sweet potato seedlings have positive results to the crop; they found improvements in initiation of roots, which assisted in the seedling vigor due to an early root system development. Under these conditions, it is expected that the plants can be transplanted with less stress.

Similarly, NCRP was affected by application of growth regulator, with increase in NCRP as the GR concentration was increased. The concentration of 35 mL L^{-1} resulted in a maximum mean NCRP of 4.2, whereas the treatment with no GR application resulted in a NCRP of 3.3 (Figure 4).

According to Sharma et al. (2012), the main drivers of plant development and growth are connected to chemical factors; in this sense, plant hormones are chemical indicators, storing information and changing the physiological status of tissues and cells. Moreover, Neumann et al. (2017) reported that the application of a product can result in different responses of plants at different growth stages; thus, the variation in storage root yield is dependent on the biostimulator application timing.

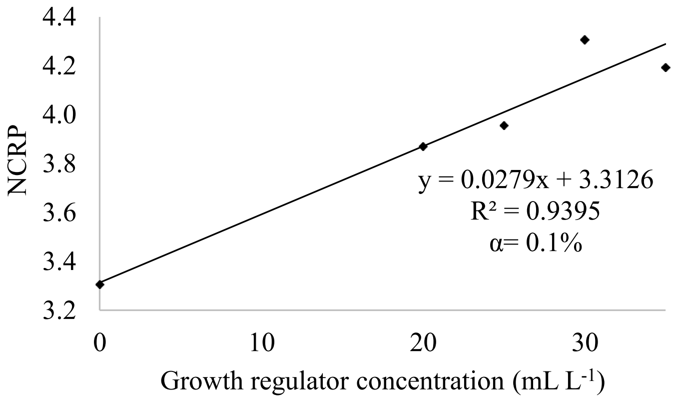

Figure 4. Number of commercial roots per plant (NCRP) as a function of growth regulator concentrations.

Sweet potato production function

The model that best fitted the experimental data obtained was the quadratic polynomial, with no intercept or no significant interaction between NPK rate and GR concentration. Based on the statistical significance, the model obtained can be used to estimate sweet potato yields under the experimental conditions of the present study, as the F test of the equation was significant at 0.1% and presented a R^2 of 91.95%. The signs of the variables in the representation of a biological phenomenon were coherent, with positive linear and negative quadratic terms. The equation obtained to fit the data was: $Y = 34.29X + 992.88E - 0.01126X^2 - 14.31E^2$.

The parameters b_1, b_2, b_3 were significant at the level of 0.1%; however, the term b_4 presented significance at the level of 7.68% (Table 3). According to Teodoro et al. (2013), quadratic parameters in second degree polynomial equations determine the end of yield response curves of agricultural crops for production factors; however, yield values present significant decreases from the maximum point of the curve, which is a dynamic not observed in practice.

Table 3. Coefficient values of the statistical model of sweet potato yield response to NPK rates and GR concentrations, with the respective errors, t test, and probability (Prob>F).

Parameters	Factors	Coefficients	Standard error	T	Prob>F
b_1	X	34.29	4.75	7.21	0.0000
b_2	E	992.88	258.74	3.84	0.0002
b_3	X^2	-0.011	0.00	-3.92	0.0002
b_4	E^2	-14.31	8.00	-1.79	0.0768

According to the model chosen, the highest estimated sweet potato yield was 43,328.19 kg ha^{-1}, which could be obtained using 1522.64 kg ha^{-1} of NPK and 34.69 mL L^{-1} of GR.

The marginal physical products of NPK and GR for the different NPK rates and GR concentrations are shown in Table 4. The values were obtained from the first derivative of the production function:

Table 4. Marginal physical product of NPK for the different NPK rates (upper value) and marginal physical product of GR (lower value) for the different GR concentrations.

	E (mL L^{-1})				
X (kg ha^{-1})	0	20	25	30	35
0	34.29 992.88	34.29 420.48	34.29 277.38	34.29 134.28	34.29 -8.82
696	18.63 992.88	18.63 420.48	18.63 277.38	18.63 134.28	18.63 -8.82
1044	10.8 992.88	10.8 420.48	10.8 277.38	10.8 134.28	10.8 -8.82
1392	2.97 992.88	2.97 420.48	2.97 277.38	2.97 134.28	2.97 -8.82
1740	-4.86 992.88	-4.86 420.48	-4.86 277.38	-4.86 134.28	-4.86 -8.82

The marginal physical products of a factor did not vary in relation to other factor, which is explained by the absence of a significant interaction between NPK rate and GR concentration.

The marginal physical products of NPK and GR decreased as the NPK rate and GR concentration were increased, respectively, until reaching the value zero, where the maximum yields were found. The marginal product of NPK was zero when the NPK rate applied was 1522.64 kg ha^{-1}. Similarly, the marginal product of GR reached zero when the GR concentration was 34.69 mL L^{-1}.

The negative results found for marginal physical products of NPK and GR, respectively, for the rate of 1740 kg ha^{-1} and concentration of 35 mL L^{-1} (Table 4), denote a decrease in sweet potato yield as the NPK rate and GR concentration were increased. Thus, the applied quantities of both production factors become uneconomical from these values onwards.

As the quantities of production factors was increased, the productivity increased at decreasing rates until reaching the maximum yield, which is consistent with the law of diminishing return (MANKIW, 2021). This dynamic is reported for other agricultural crops, such as melon (MONTEIRO et al., 2007) and watermelon (SOARES et al., 2002).

Isoquants

Isoquants represent the different combinations of NPK rate and GR concentration that result in the same yield (Figure 5). The possible combinations of production factors decreased as the yield was increase up to the point that only one combination of NPK and GR was possible, which was the combination that resulted in the maximum sweet potato yield (43.32 Mg ha^{-1}).

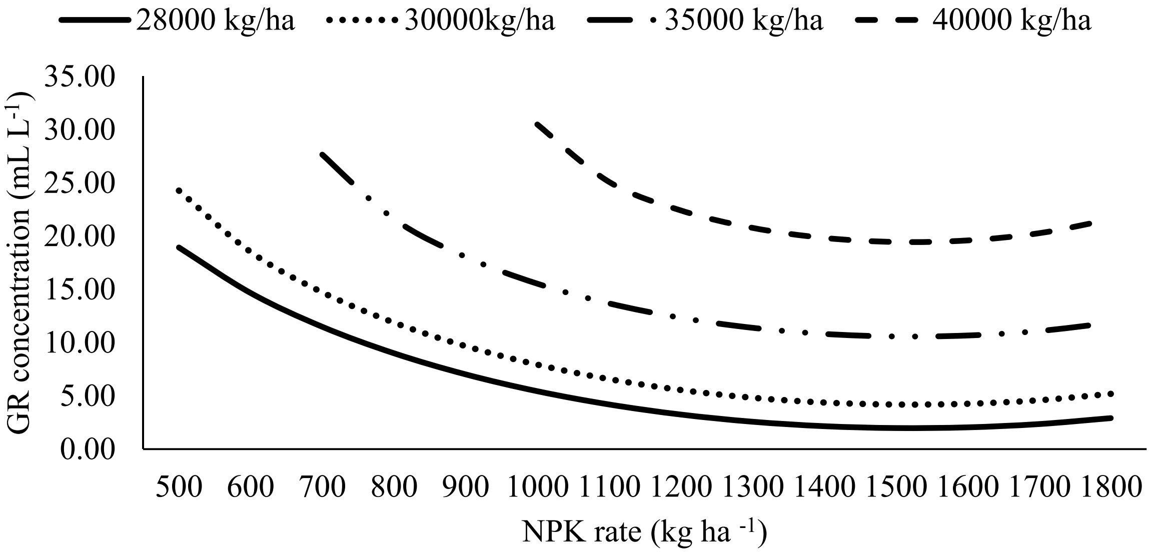

Figure 5. Isoquants for sweet potato yield as a function of NPK rates and growth regulator (GR) concentrations.

The factor GR can be substituted by NPK up to a limit that allows the obtaining of a same yield. The point on each isoquant where the marginal rate of substitution is null or infinite delimits the rational production region.

The existence of an imperfect substitutability between the production factors is assumed due to the convex shape of isoquants. The production factors would only be perfect substitutes if their marginal rates of substitution were a constant, and they would be perfect complements if their isoquants formed right angles (PINDYCK; RUBINFELD, 2013).

These results are coherent from the agronomic perspective, since the functions of the nutrients in the NKP formulation would not be fully developed only with plant hormones from the growth regulator.

The isoquants show combinations of inputs that can optimize agricultural management, as this information allows field technicians to make coherent decisions when facing changes in markets of agricultural inputs. According to Crisostomo et al. (2008), isoquants are useful for optimizing decision making regarding possible combinations of N and K_2O rates for maximum production of banana crops in Paraipaba, state of Ceará, Brazil, reaching the best price.

Irrigation water yield

Increases in the NPK rate resulted in increases in water use efficiency up to the maximum value of 8.13 kg m^{-3}, with application of the NPK rate of 1740 kg ha^{-1}; the absence of fertilizer application resulted in an irrigation water yield of 5.70 kg m^{-3} (Figure 6). The accumulated water depth over the sweet potato production cycle was 449.6 mm, presenting a total volume of applied water of 134.8 L per plant.

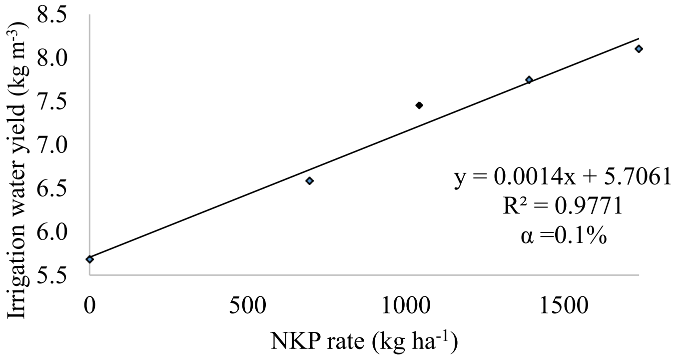

Figure 6. Irrigation water yield of sweet potato as a function of NPK rates.

Mantovani et al. (2013) evaluated the sweet potato cultivars Duda and Amanda in Viçosa, MG, Brazil, and found irrigation water yields of 16.1 and 20.0 kg m^{-3}, respectively, which were higher than that found for the local variety evaluated in the present work. However, it is known that the evapotranspiration demand of crops varies over the year and is different for each location (NOGUEIRA et al., 2015). In general, it is assumed that the crop cycle requires between 450 and 650 mm of water; when this water depth is from rainfall, a good distribution is required, mainly in the first month of the crop cycle, as it is essential maintain the soil moisture for successful seedling development and initial growth. Therefore, water use efficiency can be high when using increasing soil fertilizer rates; however, a good management of these factors should be carried, within the limits found, to achieve economic return.

CONCLUSIONS

NPK fertilizer and growth regulator (GR) are production factors that increase the numbers of total root per plant and commercial roots per plant for sweet potato crops. The maximum numbers of total roots per plant are obtained with a NPK rate of 1333.3 kg ha^{-1} and a GR concentration of 35 mL L^{-1}.

The highest estimated commercial yield of sweet potato was 43.32 Mg ha^{-1}, which was obtained with application of a NPK rate of 1522.64 kg ha^{-1} and a GR concentration of 34.69 mL L^{-1}.

The interaction between the production factors NPK and GR was not significant. Thus, they are not perfect substitutes nor perfect complements from the perspective of microeconomics.

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