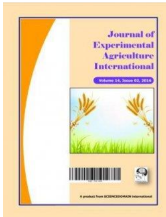

Journal of Experimental Agriculture International

32(4): 1-10, 2019; Article no.JEAI.47797
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Agronomic Performance of New Potato Genotypes Submitted to Increasing Doses of NPK

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Authors' contributions

This work was carried out in collaboration among all authors. Authors KCS, JK and GCG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AG managed the analyses of the study. Authors SP and RHC managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2019/v32i430109
Editor(s):
(1) Dr. Renata Guimarães Moreira-Whitton, Professor, Departamento de Fisiologia - Instituto de Biociências-USP, Cidade Universitária, Brazil.
Reviewers:
(1) Martín María Silva Rossi, Argentina.
(2) Şahane Funda Arslanoglu, Ondokuz Mayis University, Turkey.
(3) Lawal M. Anka, Nigeria.
Complete Peer review History: http://www.sdiarticle3.com/review-history/47797

Original Research Article

Received 01 January 2019
Accepted 06 March 2019
Published 15 March 2019

ABSTRACT

Aims: Estimate the morphological characteristics of potato genotypes grown with different doses of NPK fertilizer 4-14-8.
Study Design: The experiment was conducted in randomized blocks with subdivided plots and three replicates.
Place and Duration of Study: The experiment was carried out in the municipality of Guarapuava – PR, Brazil, during the growing seasons of 2013/2014 and 2014/2015.
Methodology: In the main plots the doses of 0, 2, 4 and 6 t ha^{-1} of NPK fertilizer 4-14-8 were arranged and in the subplots the genotypes (Ágata, BRS Camilla and clone C0205). Were evaluated: The leaf area index (LAI), percentage of light absorption, number of tubers, fresh mass of tubers. In the first agricultural year the evaluations were performed at 25 and 45 days after the emergency (DAE) and in the second seasson at 28 and 48 DAE. Interaction between potato genotypes and fertilizer rates for LAI was observed at 45 DAE in 2013/14 and absorbance at 25

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DAE in 2013/14. For the seasson 2013/14, the genotypes showed a significant difference for LAI, absorbance, number of tubers and fresh mass of tubers at 25, LAI and fresh mass of tubers at 45 DAE, clone C0205 presented the largest differences for these characteristics. Fertilizer doses did not influence LAI, absorbance at 25 DAE and 45 DAE in 2013/14 and, at 2014/15 at 28 DAE, there was no response for tuber number and LAI, and at 48 DAE for tuber number, absorbance. There was no significant interaction between fertilizer doses and potato plant genotypes for the data on number of primary stems and number of secondary stems in both seassons The genotypes responded to NPK fertilizer doses 4-14-8 for LAI, and clone C0205 presented the best results. The genotypes responded to the light absorption percentage, with C0205 presenting the best results, so that plants with greater leaf area presented greater light absorption. The genotype C0205 presents greater productive capacity when compared to the Agata and Camila genotypes, being evident the greater number and fresh mass of tubers produced.

Keywords: Solanum tuberosum; fertility; variety; absorbance.

1. INTRODUCTION

The potato production chain (*Solanum tuberosum*) is one of the largest and most complex in the Brazilian scenario, as it encompasses a series of activities for food production ranging from seed potatoes to direct production for consumption as food [1].

Brazil, in the 2017 harvest stood out with a production of 3.6 million tons in a planted area of 118 thousand hectares, leaving the country in seventh position in the world ranking [2]. However the country faces problems related to potato cultivation, such as: cultivars susceptible to diseases, climatic factors and high need fertilization to obtain high yields [3]. Between the main cultivars used in Brazil, the cultivar Agata is highlighted. This cultivar was developed for temperate regions, which are characterized by long days and mild summer temperatures. When used in a tropical climate, it can have its productivity compromised, due to the high temperatures and short photoperiod. When subjected to these conditions the photosynthetic capacity of the plants is affected by the increase and losses with the respiration [4].

When evaluating the productive potential of a plant, it is necessary to verify the different contributions of plant growth [5]. Decision making regarding the timing of the use and management of certain cultivars will be influenced by the morphological characteristics of the plants [6]. The greater number of stems of a plant can lead to greater productivity. According Feltran e Lemos [7], the greater number of stems of a plant can lead to greater productivity. Potato breeders face the challenge of providing genotypes that meet the needs of producers and consumers The need of the producers is for cultivars of early cycle, allied to the high yield, whereas for the consumer the need is of tubers with quality [8].

Among the factors that may influence the productivity of potato plants, the leaf area index (LAI) is one of the main factors, as it is directly related to the photosynthesis of the plants. According to Cardoso [9], to achieve high productivity it is necessary to keep the plants with the photosynthetically active leaf area longer. The more available nutrients are in the soil, the greater the LAI, because the larger plants create demands for nutrients that must be satisfied by the complementary fertilization of the soil. However, fertilization of NPK and micronutrients together provided higher LAI than fertilization of micronutrients and NPK when used alone [10].

Understanding the behavior of the morphological characteristics of the potato plants is fundamental for success in productivity and maximizing the productive potential of the genotypes. Potato plants that are not developed for Brazilian climate conditions may be affected by the tropical climatic conditions of the country. When submitted to low light intensity, stem elongation is higher, increasing plant height, reducing leaf size, delaying the initiation of tuberization and foliar senescence, reducing the production of tubers per plant. On the other hand, high light intensity results in increased photosynthesis, stimulates flowering, increases the dry mass of tubers and accelerates the process of initiation and filling of tubers [9].

Another important factor for the production of potatoes is the amount of nutrients needed for the production of tubers, because the potato has a high extraction of nutrients from the soil [11]. In addition, nutrition is one of the factors that most affect the productivity and quality of tubers, between other factors such as growing environment, genetic potential and age of plants [12].

In order to meet the nutritional needs of the crop and to achieve high yields, it is necessary to apply high amounts of inputs, especially in tropical soils with a low fertility characteristic [13], which leads to an increase in production costs, promoting a impact on the environment [14]. In view of this, potato farmers opt for high fertilization investments to avoid possible nutrient deficiencies during the crop cycle [15], since plants are not necessarily able to use these nutrients effectively by the root system. Thus, more and more, there is a need to search for genotypes that are more adapted to the Brazilian climate conditions, in order to optimize the available inputs. In addition, it is necessary to understand the role of fertilization in the different physiological processes of the crop, thus allowing precise supply of nutrients, avoiding expenses and consequently maintain productive potential.

Thus, the objective of this work was to evaluate the productive potential and to estimate the growth of potato genotypes grown with different doses of NPK fertilizer 4-14-8.

2. MATERIALS AND METHODS

The experiments were carried out in the seassons of 2013/14 and 2014/15 in the city of Guarapuava-PR. In the sesson 2013/14, the experiment was conducted at Fazenda Lageado Grande, district of Palmerinha, with central coordinates of 25 ° 18'23 "S and 51 ° 36'40" W, from December 2013 to April 2014, and in the second seasson (2014/15) conducted in the experimental field of the State University of the Center-West, with central coordinates in 25º23'04 " S and 51º29'36"O, from October 2014 to February 2015.

According to Reccanello [16], in the region of Guarapuava, Paraná, the estimated area planted is 4000 ha, with an average production of 120,000 tons per year and average yield of 30 t ha^{-1}, being the cultivar Agate produced in about 90% of the areas planted in the region of Guarapuava-PR.

Soil preparation was started one month prior to the implantation of the crop with subsoiling and two gradations followed by the area grooving, as described by Schlegel et al. [17], phytosanitary management and cultural treatments was performed according to recommendations for potato crop [18]. The soil in both sites is classified as Latossolo Bruno [19], and the initial chemical characterization, in the layer of 0.00 - 0.20 m, the chemical analysis of the soils in the areas presented the following chemical characterization: pH (ClCa 2) = 4.8 and 4.8; P (Mehlich) = 2.4 and 5.8 mg dm 3; K = 0.4 and 0.4; Ca = 1.8 and 3.3; Mg = 1.8 and 1.8; Al = 0.0 and 0.0; H + Al = 5.2 and 5.2; SB = 4.0 and 5.5; CTC: 9.20 and 10.7 cmol dm 3 V% = 44 and 52.

Tubers of the Agata genotype were purchased from the producer in the two agricultural years, while the tubers from genotypes C0205 and 'BRS Camila' were supplied by Embrapa Produtos de Mercado (Canoinhas / SC).

In the agricultural year 2013/14 the planting of the tubers was carried out on 07 Dec 2013, with a heap made 15 days after the emergency (DAE). In the agricultural year 2014/15, the planting was carried out on 04 October 2014, with heap held 18 DAE.

The experimental design, in both seassons, was in randomized blocks, in a subdivided plot scheme, with three replications. The fertilizer doses (0, 2, 4 and 6 t ha^{-1} of the commercial formulation NPK 4-14-8) were allocated to the main plots and the potato genotypes (Agate cultivar, BRS Camila cultivar and clone C0205) were allocated to subplots. The subplot measured 3 x 4.8 m, composed of 6 lines, with 10 plants per line, spacing 0.80 m between rows and 0.30 m between plants in in both seassons. NPK fertilizer was distributed in total dose just prior to manual planting of the tubers. Genotype C0205 was used only in the first seasson.

Samples were collected for morphological characteristics at 25 and 45 DAE in the seasson 2013/14 and at 28 and 48 DAE in the seasson of 2014/15. Four whole plants were collected from each subplot, always leaving the two external lines as a border and a border plant between the collections.

Morphological parameters analyzed in the two agricultural years were: number of primary and secondary stems, leaf area index (LAI), percentage of light absorption, number of tubers (number pl^{-1}) and fresh mass of tubers (g pl^{-1}).

Light data were obtained using the Prochec RFA quantizer (Decagon Devices), and data collection was performed the following day after each sample collection (at 10:00 am). The radiation was measured in three points below the plants: in the planting line, in the line between and between the planting line and the line, in each of these three points the radiation was quantified 4 times. In addition to these measurements below the canopy, two measurements of radiation above the canopy were made. The data were annotated and the mean of the data below and above the canopy was then averaged, and then the percentage of light absorption was calculated.

For determination of dry mass (DM), the samples were dried in a forced circulation air oven at 70ºC until reaching a constant mass and then weighed. For the evaluation of the LAI, leaf samples of the plots were used, which had their area quantified with the aid of an integrator of leaf area of table (LI-3100 C, Liquor) and, based on the quantification of the leaf area, MS total of the leaves and the planting density, the IAF was calculated.

The analysis of variance, Tukey test and regression for NPK doses were performed in the SISVAR program, version 5.6 [20]. We considered the linear and quadratic regression model between the doses and the evaluated characteristic, and the criterion for choosing the regression model was the equation that resulted in the highest coefficient of determination (R^2).

3. RESULTS AND DISCUSSION

Significant interaction between fertilizer doses and potato plant genotypes was observed for LAI data at 45 DAE and light absorbance at 25 DAE in the crop year of 2013/14 (Table 1). Among the genotypes, for the LAI data, a significant difference occurred at 25 and 45 DAE in the agricultural year of 2013/14, and clone C0205 differed statistically with LAI higher than the cultivars Ágata and BRS Camila in both seasons. The plants responded in a quadratic manner to the fertilizer doses for the IAF data at 48 DAE in the agricultural year 2014/15, with the highest IAF dose being 8.5 t ha^{-1}. According to Andriolo et al. [21], the higher the N dose, the greater the leaf area of the plants and the greater the accumulation of nutrients in the leaves.

Table 1. Leaf area index (LAI) and percentage of light absorption (absorbance) of potato genotypes as a function of the doses (0, 2, 4, 6 t ha^{-1}) of NPK fertilizer 4-14-8 in two collection times at 25 and 45 days after emergence (DAE) of the plants in the agricultural year 2013/14 and at 28 and 48 DAE in the seasson 2014/15

Tratamentos	IAF				Absorbance (%)			
	2013/14		2014/15		2013/14		2014/15	
	25	45	28	48	25	45	28	48
Genotypes (G)								
Ágata	3,34b[1]	4,13b	2,15	2,17	33,7b	63,2	66,2	62,4
BRS Camila	5,09b	3,46b	1,12	2,11	30,5b	46,3	64,9	47,4
C0205	8,20a	5,55ª	-[2]	-	53,7a	68,1	-	-
Anova	*[3]	*	ns	ns	*	ns	ns	ns
CV1 (%)[4]	39,5	60,4	80,1	26,7	28,5	20,3	41	18,9
Doses (D)								
0	3,82	3,61	1,97	1,20	39,4	51,2	59,5	58
2	6,99	4,61	1,22	2,05	27,8	54,9	61,9	56,2
4	4,45	4,74	1,66	2,58	48,2	69,7	79,6	48,4
6	6,92	4,55	1,69	3,00	38,7	56,2	68,1	56,9
Regression	ns	*	ns	**/Q[5]	ns	ns	*/Q	ns
CV2 (%)	35,5	34,6	84,8	25,2	34,1	21,7	22,0	38,7
G x D	ns	*	ns	ns	*	ns	ns	ns

*[1] Means followed by the same letter did not differ significantly by the Tukey test at 5% probability; [2] in the second seasson the clone C0205 was not used in the experiment; [3] *, ** and ns represent statistical difference at 5% and 1% of probability, and absence of significant statistical difference, respectively; [4] CV_1 and CV_2 indicate the coefficient of variation of plot and subplot, respectively; [5] linear (L) and quadratic (Q) response of potato plants to fertilizer doses*

The plants responded quadratically to fertilizer doses for absorbance data at 28 DAE in the agricultural year 2014/15, and the dose that resulted in the highest absorbance was 4.2 t $ha^{-1.}$ For the other seasons, there was no difference in the response of the plants to the doses (Table 1). Betweem the genotypes for the tuber numbers, a significant difference occurred at 25 DAE in the agricultural year of 2013/14, and clone C0205 did not differ statistically from the cultivar BRS Camila, although both differed statistically from the cultivar Ágata, with a value of 28 % bigger For the other epochs it was verified that there were no differences between the genotypes. The number of tubers is dependent on the competition between the stems for resources, especially light conditions, nutrients and water. This characteristic, number of tubers, varies according to cultivar and environmental conditions [22].

The Fig. 1(A) shows the behavior of each genotype in relation to LAI as a function of the fertilizer doses at 45 DAE in seasson 2013/14, in which it is verified that each genotype responded differently to the doses of fertilizer, with the cultivar Ágata presenting a positive quadratic response, with lower LAI at 3.8 t ha^{-1}, the cultivar BRS Camila presents a quadratic negative response, with a higher LAI at the dose of 3.2 t ha^{-1} and clone C0205 presented positive linear response.

The Fig. 1(B) shows the behavior of each genotype in relation to the absorbance at 25 DAE in the agricultural year of 2013/14. It was verified that each genotype responded differently to fertilizer doses, with clone C0205 and the cultivar Ágata presented a quadratic positive response, with a higher absorbance at the dose of 4.3 and 2,6 t ha^{-1}, respectively, while the cultivar BRS Camila showed a quadratic negative response, with a lower absorbance at the dose of 3,3 t ha^{-1}.

The IAF is an important morphological parameter of the plant [23]. Plants with higher LAI have greater interception of light, which allows, according to Silva et al. [4], that the plant remain for a longer period of time with photosynthetically active leaves.

In addition, the vegetative growth is directly related to the fertilizer doses in the plants, greater availability N, the main nutrient responsible for the vegetative growth. It was observed in Table 2 that there was no significant interaction between fertilizer doses and potato plant genotypes, number of tubers and fresh mass of tubers in both agricultural years.

Between the genotypes for fresh tuber mass data, there was a significant difference at 25 and 45 DAE in the agricultural year of 2013/14, with the cultivar BRS Camila differing from genotypes C0205 and 'Agate' with a 39% to C0205 and 82% higher in relation to 'Agate' at 25 DAE. At 45 DAE 'BRS Camila' differed statistically from the other genotypes with an 11% higher value than clone C0205 and 'Agate' For the other epochs it was verified that there was no difference between the genotypes.

The fact that the cultivar Agate has a lower fresh mass of tubers when compared to clone C0205 can be explained by the higher number of primary stems of 'Agate' when compared to the other genotypes tested, since according to Fernades et al. [24] cultivars that present larger numbers of stems per area, have a smaller average size of tubers.

The plants responded in a quadratic manner to the fertilizer doses for the number of tubers at 25 and 45 DAE in the seasson 2013/14, and the doses that resulted in a larger number of tubers were, respectively, the doses of 3.1 t ha^{-1} and 3.8 t ha^{-1}. For the other epochs it was verified that there was no difference in the number of tubers of the plants in relation to the doses.

The plants responded in a quadratic manner to the fertilizer doses for the data on the fresh mass of tubers at all times for both agricultural years (Table 2), and the doses that resulted in a higher fresh mass of tubers were 7.2 t ha^{-1}, 2,9 t ha^{-1} for the 25 and 45 DAE in the seasson 2013/14. Plants that present higher height, number of nodes and stems and LAI, tend to produce more tubers, and these characteristics are determined according to the genetic potential of plants, as well as the nutrition to which they are submitted.

The increase in the number of tubers is related to the increase of the fresh mass of tubers, in the case of this experiment, the genotypes 'BRS Camila' and C0205 presented greater number of tubers, when compared to 'Agata'. The increase in NPK doses results in higher tubercle production, as well as in fresh mass [24].

Table 2. Number of tubers (no pl^{-1}) and fresh mass of tubers (g pl^{-1}) of potato genotypes as a function of the doses (0, 2, 4, 6 t ha-1) of NPK fertilizer 4-14 -8 in two collection seasons at 25 and 45 days after emergence (DAE) of the plants in the seasson 2013/14 and at 28 and 48 DAE in the seasson 2014/15

Treatments	Number of tubers (nº pl^{-1})				Fresh mass of tubers (g pl^{-1})			
	2013/14		2014/15		2013/14		2014/15	
	25	45	28	48	25	45	28	48
Genotypes (G)								
Ágata	4,98b[1]	8,96	3,92	6,65	23,1c	466,1b	37,3	480,4
BRS Camila	7,19a	8,88	3,25	4,85	127a	539,0a	45,0	438,2
C0205	6,38a	8,33	-[2]	-	76,8b	492,3b	-	-
Anova	*[3]	ns	ns	ns	*	*	ns	ns
CV1(%)[4]	57,1	20,5	22,4	42,2	53,8	38,6	39,1	15,6
Doses (D)								
0	5,13	6,97	2,46	4,17	47,5	480,9	29,5	329,3
2	7,79	10,5	2,88	5,92	44,1	525,3	33,1	532,3
4	5,74	8,03	4,58	6,38	117,7	514,1	67,5	484,1
6	6,08	9,35	4,42	6,50	93,9	476,2	34,5	544,7
Regression	*/Q[5]	*/Q	ns	ns	*/Q	*/Q	*/Q	*/Q
CV2 (%)	28,6	23,6	51,8	34,9	60,9	24,7	50,9	30,2
G x D	ns	ns	ns	ns	ns	ns	ns	ns

*[1] Means followed by the same letter did not differ significantly by the Tukey test at 5% probability; [2] in the second agricultural year the clone C0205 was not used in the experiment; [3] *, ** and ns represent statistical difference at 5% and 1% of probability, and absence of significant statistical difference, respectively; [4] CV_1 and CV_2 indicate the coefficient of variation of plot and subplot, respectively; [5] linear (L) and quadratic (Q) response of potato plants to fertilizer doses*

Table 3. Number of primary stems (number pl^{-1}) and number of secondary stems (pl^{-1}) of potato genotypes as a function of the doses (0, 2, 4, 6 t ha^{-1}) of NPK fertilizer 4- 14-8 in two collection seasons at 25 and 45 days after emergence (DAE) of the plants in seasson 2013/14 and at 28 and 48 DAE in seasson 2014/15

Treatments	Number of primary stems (nº pl^{-1})				Number of secondary stems (nº pl^{-1})			
	2013/14		2014/15		2013/14		2014/15	
	25	45	28	48	25	45	28	48
Genotypes (G)								
Agata	3,04	3,53	2,28	2,9	3,28	4,85b[1]	1,40	2,42
BRS Camila	3,77	4,25	1,40	1,48	3,00	3,52b	2,13	2,21
C0205	4,38	4,40	-[2]	-	7,60	8,40a	-	-
Anova	ns[3]	ns	*	ns	ns	*	ns	ns
CV1 (%)[4]	135	32,5	32,6	38,6	22,3	55,2	105	70,3
Doses (D)								
0	4,38	4,38	2,17	1,76	7,17	2,51	0,63	1,47
2	4,18	4,81	1,38	2,00	4,49	4,73	1,83	1,17
4	3,63	3,63	2,00	1,75	4,97	5,51	3,38	1,75
6	3,40	3,78	3,04	2,13	3,65	7,84	3,25	2,88
Regression	ns	*/Q[5]	ns	ns	ns	**/L	*/Q	**/Q
CV2 (%)	157	22,9	48,8	32,5	27,1	27,9	53,1	41,7
G x D	ns	ns	ns	ns	ns	ns	ns	ns

*[1] Means followed by the same letter did not differ significantly by the Tukey test at 5% probability; [2] in the second seasson the clone C0205 was not used in the experiment; [3] *, ** and ns represent statistical difference at 5% and 1% of probability, and absence of significant statistical difference, respectively; [4] CV_1 and CV_2 indicate the coefficient of variation of plot and subplot, respectively; [5] linear (L) and quadratic (Q) response of potato plants to fertilizer doses*

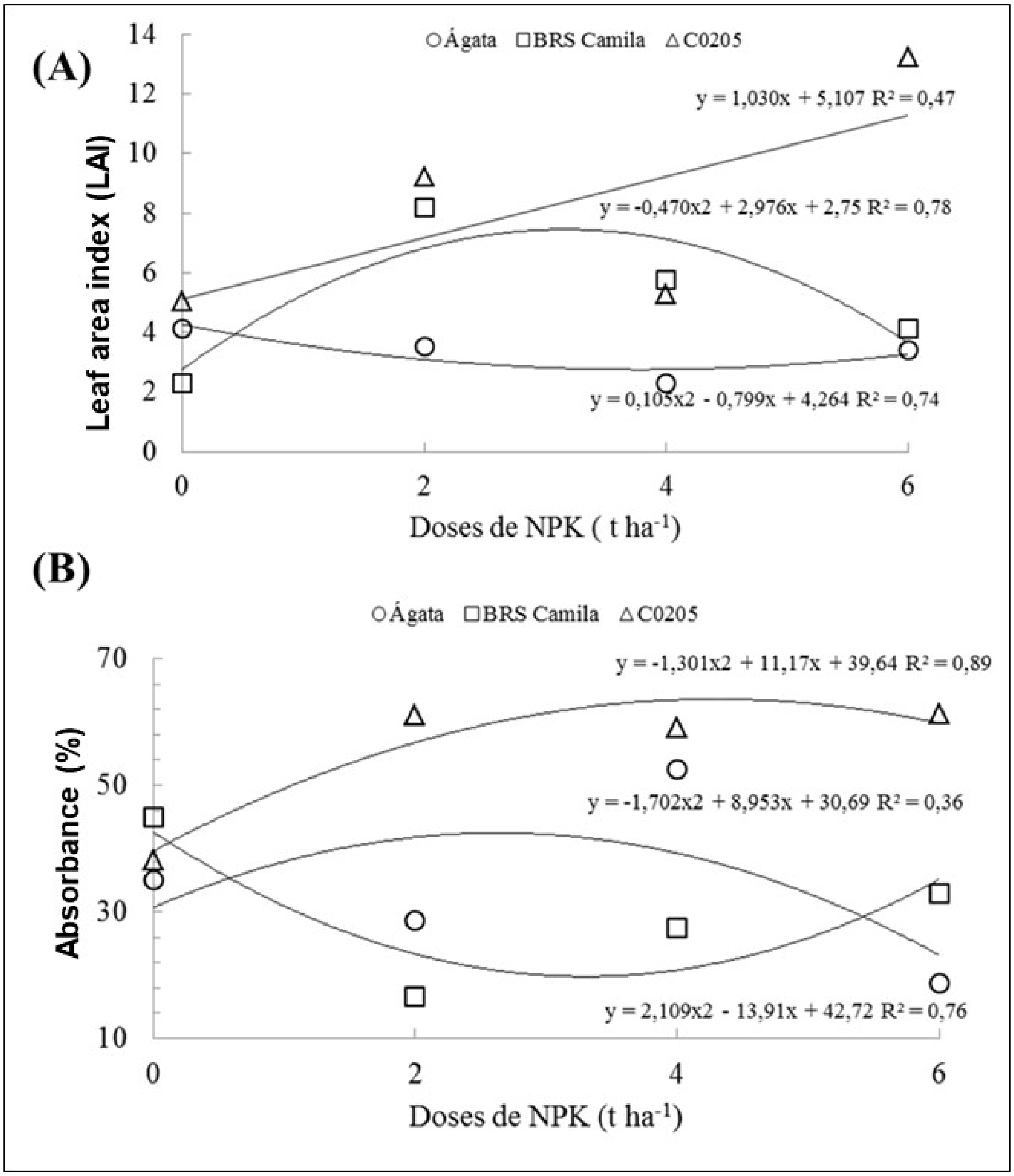

Fig. 1. Depletion between doses (0, 2, 4, 6 t ha^{-1}) of NPK fertilizer 4-14-8 and potato plant genotypes: (A) leaf area index at 45 days after emergence in the seasson 2013/14; (B) for absorbance (%) at 25 days after emergence (AED) in the seasson 2013/14

This increase in NPK dose increases the fresh mass of tubers because of the higher LAI of the plants, and plants with higher LAI tend to intercept more solar radiation, so that it may result in a greater amount of fresh mass of tubers, since increase in the availability of N, promotes the growth and increase of the photosynthesizing area and increased photoassimilates production, which are translocated and stored in the tuber [9].

There was no significant interaction between fertilizer doses and potato plant genotypes for the data on number of primary stems and number of secondary stems in both seassons (Table 3). Among the genotypes for the data concerning the number of primary stems, a significant difference occurred in 28 DAE in the agricultural year of 2014/15, and the cultivar Ágata differed statistically with a number of primary stems 48% higher than the 'BRS

Camila'. For the other epochs of evaluations, no difference occurred.

These results agree with those of Fernades [24], who report that the cultivar Ágata has a high number of stems when compared to other genotypes, showing that this characteristic is influenced by the cultivar [25]. Among the genotypes, for the secondary stem number data, a significant difference was observed in the 45 DAE in the agricultural year of 2013/14, and clone C0205 differed statistically with a number of secondary stems 51% higher than the average of the cultivars Ágata and 'BRS Camila', Silva et al. [26] highlighted the greater vegetative potential of this clone when compared to BRS Clara and Ágata; showing that C02-05 has greater potential for "in natura" consumption compared to agate cultivation already established in the market. However, for the other epochs there was no difference between the genotypes. The plants responded quadratically to the fertilizer doses for the primary stem number data at 45 DAE in seasson 2013/14, with the dose that resulted in the largest number of primary stem was 0 t ha^{-1}. For the other epochs of evaluations, no significant difference occurred. At 45 DAE in seasson 2013/14, the plants responded in a linearly positive way to the doses of fertilizers, for the data referring to the number of secondary stems. At 28 DAE and 48 DAE in the agricultural year of 2014/15, the plants responded in a quadratic manner, and the doses that resulted in a larger and smaller number of secondary stem were 5.8 and 1.6 t ha^{-1}, respectively.

When evaluating the productive potential of a plant, this is achieved as a function of the different contributions of plant growth [5]. Decision making at the time of use and management of certain cultivars will be influenced by the morphological characteristics of the plants. According to Feltran and Lemos [27], the greater number of stems of a plant can lead to higher yields. Potato breeders face the challenge of providing genotypes that meet the needs of producers and consumers. The need of the producers is for early-cycle cultivars, allied to the high yield, while for the consumer the need is for quality tubers [8].

The increase in NPK doses results in higher tuber production [28] (NAVA et al., 2007) as well as in fresh mass [24]. This increase in NPK dose increases the fresh mass of tubers because of the higher LAI of the plants, and plants with higher LAI tend to intercept more solar radiation, so that it may result in a greater amount of fresh mass of tubers, since increase in the availability of N, causes it to promote the growth and increase of the photosynthesizing area and greater production of photoassimilates, which are translocated and stored in the tuber [9].

4. CONCLUSION

Potato genotypes respond differently to increased NPK fertilizer doses 4-14-8 applied.

The genotypes responded to the light absorption percentage, with C0205 presenting the best results, so that plants with greater leaf area presented greater light absorption.

The genotype C0205 presents greater productive capacity when compared to the Agata and Camila genotypes, being evident the greater number and fresh mass of tubers produced.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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