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Productivity and establishment of DRIS indexes for cultivation of potato cultivar Asterix tubers in a dystrophic Red Latosol

Angélica de Araújo Queiroz[1], Atalita Francis Cardoso[2], Carolina Oliveira da Silva*[3], Reginaldo de Camargo[3], Regina Maria Quintão Lana[3], José Magno Queiroz Luz[3]

[1]Federal Institute of the Minas Gerais Triangle/IFTM - Campus Uberlândia - Street Blanche Galassi, 150 - Morada da Colina - Uberlândia - MG - Brazil
[2]University Center of the Goiatuba/UNICERRADO - Campus Goiatuba - highway GO-320 - Jardim Santa Paula, Goiatuba - GO - Brazil
[3]Federal University of Uberlândia/UFU - Institute of Agricultural Science - Campus Umuarama Block 2E - Uberlândia - MG - Brazil

***Corresponding author: caroll_meyreles@hotmail.com**

Abstract

The potato culture has the highest relative demand for fertilizers per unit area, around 2.3 to 2.8 t ha^{-1}. The objective of this study was to evaluate the productivity of a potato Asterix cultivar subjected to different doses of nitrogen, phosphorus, and potassium, and to establish the DRIS index according to productivity results. The experimental design was randomized blocks, with 5 rates and 4 replicates for each nutrient totalizing 20 plots per experiment. The rates of nutrients were: nitrogen (0, 70, 140, 210 and 240 Kg ha^{-1}); phosphorus (0, 200, 400, 600 and 800 kg ha^{-1}) and potassium (0, 150, 300, 450 and 600 kg ha^{-1}). For leaf diagnosis by the DRIS index, 10 complete leaves of the third expanded trifoliate were collected. The DRIS standards calculations were based on populations of high productivity (or reference) and low productivity. Plants whose productivities were greater than 22 t ha^{-1} represented the groups of reference. It was concluded that productivity was not influenced by the P and K doses studied, with an increase in yield of tubers as a function of the N rates applied, up to the dose of 173 kg ha^{-1} of N. According to the DRIS index, it is possible to establish the order of limiting nutrients for failure in descending order in areas with high productivity Ca> Mn> P> S> Zn = Cu> K> N> B> Fe> Mg, and the order of limiting nutrients in areas of low productivity Ca> Cu> Mg> P> S> Mn> Zn> K> Fe = B> N. The results showed that productions above 22 t ha^{-1} need adjustments of the soil fertility managements.

Keywords: economy; fertilizers; nutrients; soil; *Solanum tuberosum*.
Abbreviations: B_boron; Ca_calcium; Cu_cuprum DRIS_Integrated System of Diagnosis and Recommendation; Fe_ferum; IBN_nutritional balance index; K_potassium; Mg_magnesium; Mn_manganese; N_nitrogen; P_phosphorus; S_sulfur; Zn_ zinc.

Introduction

The potato (*Solanum tuberosum* L.) is the fourth most consumed food in the world, with a Brazilian production in 2015 reached to 3.627.053 million tons and a harvested area of 129.269 thousand hectares, resulting in an average yield of 28.58 t ha^{-1} (Agrianual, 2016).
Among the vegetables, the potato has the highest relative demand of fertilizers per unit area, around 2.3 to 2.8 t ha^{-1}. The amount of nutrients to be incorporated in the soil should be made by means of results obtained in soil analysis and additionally with leaf analysis results (Malavolta, 2006).
The nutritional diagnosis in cultivated plants has evolved interpretation of the nutritional contents in plant tissues with methods that relate nutrient contents to each other such as the Diagnosis and Recommendation Integrated System (DRIS) (Beaulfils, 1973). DRIS is used to calculate indices for each nutrient. It is considered a tool for the identification of nutritional limitations that are not diagnosed by soil analysis, such as macro and micronutrients, and is a support to other methods (Nziguheba et al., 2009).
Critical level and sufficiency range methods are generally the most used criteria for the evaluation and interpretation of the nutritional status of plants and have been applied in several annual or perennial crops (Prado et al., 2008).
The calculation of the DRIS indices enables classification of nutrients, such as deficiency, excess or balance, indicating production that is limited due to a nutritional imbalance. It uses a standard or reference population with high productivity, where nutrition is at 80% and the maximum production is attributed to them (Beaufils, 1973).
The DRIS system allows modeling of the biological response of crops to variation in nutrient availability (Wadt et al., 2007). The DRIS does not indicate which nutrient is deficient or in concentration of toxicity, but which nutrient is the most limiting and the order of nutrient limitation (Faquin, 2002). Thus, it presents the advantages of the scale of

interpretation of the method as being continuous and the nutrients are ordered from the most limiting to the most excessive. It presents the indication of cases, in which the production is being limited due to a nutritional imbalance (Baldlock; Schulte, 1996).

The Asterix cultivar is the most commonly planted potato and is characterized by producing oval-elongated tubers with yellow flesh and red skin. The tubers with high dry mass, low sugar and high soluble solids are ideal for industrial purposes. In addition, the tubers of this cultivar have good post-harvest characteristics as they are tolerant to browning (Figueiredo, 2011).

The aim of this study was to evaluate the Asterix potato culture productivity as a function of the applied nitrogen (N), phosphorus (P) and potassium (K) levels, and to establish the DRIS indexes based on yields tubers. DRIS has stood out among traditional methods of interpreting the results of plant tissue analysis, and foliar analysis has been identified as an efficient method for fertilizer recommendation.

Results and Discussion

Tuber productivity

Effect of increasing doses of phosphorus on total tuber production

The Asterix cultivar did not present a significant difference in the yield of tubers, when increasing doses of P_2O_5 were applied to the soil in the planting (Supplementary Table 2).

In this study, the maximum yield obtained was 23.7 t ha^{-1} of tubers (Table 4), a productivity close to the average of the state of Minas Gerais, which recorded harvest of 1.1 million tons of harvested tubers in the 2010, with a yield of 28 t ha^{-1} (Agencia Minas, 2011). The lowest productivity found in the study is most likely due to the presence of bacterial wilt (*Ralstonia solanacearum*) in the cultivated area.

The lack of productivity responses can also be attributed to the difficulty that potato plants have in assimilating P. It is important that the presence of P in the soil occurs under a readily available source in sufficient quantities. Moreover, it can be attributed to the fact that only about 20% of the phosphorus applied to the soil is actually assimilated by the plants, and the rest usually can be fixed by the solid fraction of the soil (Silva et al., 2013).

The P has a significant influence on the reduction of the vegetative cycle and on the increase of the number of tubers per potato plant, but it does little to increase the productivity and to the size of the tuber (Fontes, 1999).

Arrobas and Rodrigues (2009) did not find a significant response for the production of tubers with the application of phosphorus in the doses of 0, 50, 100 and 200 kg ha^{-1} of P_2O_5.

In the production of seed potato tubers, there were significant interactions between nitrogen and phosphate fertilization. Supply of these nutrients increased the production of tubers. The doses of P_2O_5 for maximum technical efficiency were 775, 820 and 690 kg ha^{-1} (Nava et al., 2007).

Effect of increasing doses of potassium on the total production of tubers

The total yield of tubers was not affected by the increasing doses of potassium applied in the planting groove (Supplementary Table 2). The maximum productivity obtained was 23.05 t ha^{-1}, when the dose of 300 kg ha^{-1} applied (Table 5).

The possible absence of response in the study and the potassium fertilization may have been due to the initial K content found in the soil of about 180 kg ha^{-1} of K.

The results of the effect of K doses on tuber yields are contradictory in the literature, showing absence of responses and positive responses (Pauletti and Menarin, 2004). These contradictory results can be attributed to the chemical composition or excess nutrients of the soil, affecting the nutrient availability of the plants. In calcareous soils with high levels of Ca^{+2} and Mg^{+2}, the lack of response to K was attributed to the antagonistic interactions between the three elements (Manolov et al., 2015).

According to Pauletti and Menarin (2004), the excess of potassium supplied to potato increased its absorption and accumulation in the plant. The same authors did not observe any influence on the total productivity of tubers by the increase of K contents, when the source was potassium sulphate, but was reduced with the application of chloride.

In excessive fertilization of potassium, there is a greater absorption and accumulation in the plant. This reduces osmotic potential and increases water uptake, which causes dilution of the starch due to increased moisture of tubers (Pauletti and Menarin, 2004), which is undesirable for industry cultivars. Although potassium is required in high quantities, its excessive use in potato cultivation at doses above the required can reduce tubercle production, raise production costs, and cause environmental impacts. It is interesting to note that high doses of potassium fertilization raise the electrical conductivity of K^+ / (Ca^{2++} Mg^{2+}) 1/2 ratio of the soil, damaging the production of tubers (Reis Junior and Fontes, 1999).

Effect of increasing doses of Nitrogen on total tuber production

Tuber productivity was influenced by increasing N rates applied to the soil, conforming a quadratic model (Fig 1).

Tuber productivity increased with the N rates studied up to 173 kg ha^{-1}, where yield was 21.8 t ha^{-1} of tubers (Fig 1). The 173 kg ha^{-1} dose is within the N fertilization dose of 70 to 330 kg ha^{-1} of N, found by Kolbe and Beckmann (1997), and 60 to 250 kg ha^{-1} of N, quoted by Lorenzi et al. (1997). For the state of Minas Gerais, the recommendation is 190 kg ha^{-1} of N (Fontes, 1999).

Silva et al. (2007), studied statistical models to describe potato productivity as a function of nitrogen fertilization. They found that in the quadratic model, the maximum estimated N dose was 178 kg ha^{-1}, and provided the maximum physical productivity of 40,720 kg ha^{-1} of Monalisa cultivar tubers. The maximum economic dose of N was lower, about 163 or 171 kg ha^{-1}, in the unfavorable or favorable scenario of potato prices, respectively. Thus, the maximum dose found in this study corroborates with studies

Table 1. Chemical characterization of soil at 0-2.0 m depth.

pH H_2O	P	K	Ca^{2+}	Mg^{2+}	Al^{+3}	T	SB
	----mg dm^{-3}----		-------$cmol_c$ dm^{-3}-------				
5.7	19.8	90	3.2	0.9	0.0	7.7	4.3

P, K = (HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}) P available (extractor Mehlich-1); Ca, Mg, Al, (KCl 1 mol L^{-1}); SB = Sum of basis; T = CEC in pH 7.0; V = Saturation for basis; m = Saturation for aluminum (EMBRAPA, 2009).

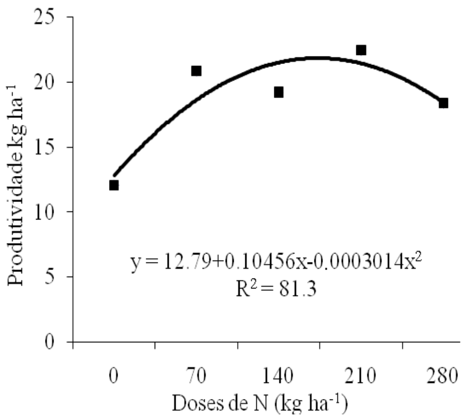

Fig 1. Productivity of potato tubers, Asterix cultivar, as a function of the N rates applied in the planting groove.

Table 2. Doses of N, P and K used.

Doses (kg ha^{-1})		
N	P_2O_5	K_2O
0	0	0
70	200	150
140	400	300
210	600	450
280	800	600

Table 3. Average yield of tubers of Asterix cultivar, as a function of N doses applied in the planting groove.

Doses de N	Means observed
Kg ha^{-1}	t ha^{-1}
0	12.08
70	20.81
140	19.18
210	22.31
280	18.36

Table 4. Average yield of tubers of Asterix cultivar, as a function of P_2O_5 doses applied in the planting groove.

Doses de P_2O_5	Means observed
Kg ha^{-1}	t ha^{-1}
0	20.31
200	18.26
400	20.96
600	21.05
800	23.70

Table 5. Average yields of tubers, observed in t ha^{-1} of Asterix cultivar, produced in Perdizes, as a function of the K_2O doses used.

Doses of K_2O	Means observed
Kg ha^{-1}	t ha^{-1}
0	21.51
150	19.01
300	23.05
450	21.02
600	21.82

Table 6. Mean values of foliar nutrients and productivity of the high productivity (> 22 t ha^{-1}) and low yield (<22 t ha^{-1}) potatoes of Asterix.

Productivity (t ha^{-1})	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	-----------------dag kg^{-1}-----------------						------------mg kg^{-1}---------------				
> 22 (22.000)	61.1	6.2	39.7	9.4	3.9	2.6	47.7	16.3	434.8	249.5	73.4
< 22 (19.000)	60.9	6.4	38.8	8.8	4.0	2.9	30.8	14.0	465.8	216.9	70.1

Table 7. DRIS indexes for macro and micronutrients population of plants of high productivity (> 22 t ha^{-1}) and low productivity (<22 t ha^{-1}) of potato of the cultivar Asterix.

Doses (Kg ha^{-1})			Treatments	Productivity (t ha^{-1})	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	IBN
N	P_2O_5	K_2O			DRIS indices for high productivity group											
140	800	300	800 P_2O_5	24.000	0.9	1.5	-0.6	-1.5	0.9	1.6	-0.6	-2.2	-1.5	1.8	1.5	14.6
140	400	300	800 P_2O_5	23.000	0.2	-1.6	-0.4	0.8	0.4	1.6	-0.9	1.5	3.2	-2.4	-1.9	14.8
140	400	0	800 P_2O_5	21.517	0.2	0.4	-0.7	1.2	-0.3	-1.8	-0.8	1.2	-0.6	1.0	0.0	8.20
140	400	150	150 K_2O	21.942	0.1	-0.6	0.0	0.4	-0.7	-1.6	-1.1	-0.1	0.6	2.1	1.0	8.44
140	400	600	600 K_2O	21.860	0.2	0.4	-0.5	0.2	-0.2	0.4	-0.4	0.5	-0.5	1.8	-1.9	6.90
210	400	300	210 N	22.392	5.0	-5.8	6.0	-5.5	5.5	-4.2	4.2	-3.2	2.9	-3.1	3.6	49.1
					DRIS indices for low productivity group											
140	400	450	450 K_2O	21.022	0.0	-1.3	2.2	3.3	2.9	0.6	-1.2	-3.1	-0.5	-2.4	-0.5	17.0
0	400	300	0 N	12.088	2.2	4.7	-2.8	-11.6	-4.1	4.1	-1.3	-0.6	9.6	0.2	-0.4	41.5
70	400	300	70 N	20.816	6.9	3.6	-1.4	-7.3	-1.5	6.4	-1.0	-0.7	-1.7	0.8	1.0	32.3
140	400	300	140 N	19.187	1.9	4.7	-0.6	-10.7	-3.7	6.0	-1.1	0.9	-0.5	-0.3	0.4	31.0
280	400	300	280 N	18.365	4.9	-1.5	-0.7	2.2	2.0	2.6	0.5	-4.9	-1.6	-1.0	-1.1	27.7
140	0	300	0 P_2O_5	20.317	0.1	0.8	0.6	2.4	1.2	1.1	-0.7	-4.5	1.4	-1.8	-2.2	16.6
140	200	300	200 P_2O_5	18.267	1.6	1.2	-0.2	1.4	2.9	2.6	-0.7	-1.5	-0.5	-1.6	-1.8	19.6
140	400	300	400 P_2O_5	20.997	1.8	1.0	-0.4	0.8	2.1	2.9	-0.6	-5.1	-0.7	-1.5	-0.8	17.7

Table 8. Macro and micronutrient deficiency index in high productivity (> 22 t ha^{-1}) and low productivity (<22 t ha^{-1}) potatoes of Asterix.

Order	Disability índices			
	>22 (t ha^{-1})		<22 (t ha^{-1})	
1º	Ca	-3.5	Ca	-7.9
2º	Mn	-2.8	Cu	-3.2
3º	P	-2.7	Mg	-3.1
4º	S	-2.5	P	-1.8
5º	Zn	-1.9	S	-1.5
6º	Cu	-1.9	Mn	-1.3
7º	K	-0.6	Zn	-1.1
8º	N	-0.4	K	-1.0
9º	B	-1.0	Fe	-0.9
10º	Fe	-0.9	B	-0.9
11º	Mg	-0.4	N	-0.1

already carried out regarding nitrogen fertilization in potato crop.

Silva (2007), evaluated application of nitrogen in the from zero to 300 kg ha^{-1} on cultivar Monalisa in Viçosa-MG and found that doses close to 200 kg ha^{-1} can provid higher total production and production commercial production of tubers.

However, in the case of the BRS Ana cultivar, the authors observed that nitrogen doses above 100 kg ha^{-1}, applied as ammonium sulphate at planting, do not result in large increases in productivity (Silva, 2007).

Assessment of nutritional status

Nutritional diagnosis

The average productivity of the group classified as high productivity (> 22.00 t ha^{-1}) and low productivity (<22.00 t ha^{-1}) and the average levels of macros and micronutrients evaluated in the leaf tissue of the Asterix are described in Table 6.

The levels of calcium, magnesium, sulfur, boron, copper, manganese and zinc were within the range, while nitrogen, phosphorus and iron levels were higher, and potassium levels were below adequate levels (Lorenzi et al., 1997; Jones Junior, 1991).

The foliar potassium content in both groups was deficient according to Lorenzi et al. (1997), which found a range from 40 to 65 g kg^{-1} K. The potassium in the soil solution was in the form of cation K^+, which was susceptible to losses by leaching, and its accumulation did not occur in the system (Teixeira, 2013).

The higher content of leaf iron in both groups may be due to the low pH of the soil, which increases the availability of cationic micronutrients such as iron.

The treatments that obtained averages classified as high productivity, produced more than 22 t ha^{-1} of potato tubers. These were treatments with fertilization in planting furrow at the doses of 800 kg ha^{-1} of P_2O_5, 150, 300, 600 kg ha^{-1} K_2O, 210 kg ha^{-1} N and to fertilizer (Table 7).

As there was variation in N, P and K doses, in populations considered to be of high productivity (> 22 t ha^{-1}) the dose of 140 kg of N combined with 800 kg of P_2O_5 and 300 K_2O provided the highest yield of tubers. However, treatment with 150 kg ha^{-1} of K_2O provided similar productivity, where half the phosphorus and potassium doses were used.

According to the chemical characterization of the soil, the content of phosphorus and potassium available as a function of soil clay content is classified as very good and good, respectively (Table 1). The calcium content was classified as good, magnesium as low, cation exchange capacity at pH 7 and medium aluminum content. This small difference in productivity between treatments is related to the nutrient content already present in the soil (Rosen et al., 2014).

The recommendation of doses depends on the level of productivity, cultivar, population, and level of soil element, as they react with each other and compete with the added nutrients, soil type, climate, irrigation and efficiency of the fertilizer used (Fernandes; Soratto, 2012).

The DRIS indices of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn, which present negative values (-) indicate deficiencies and those with positive (+) values indicate excess nutrients in relation to the other (Table 7). The values varied among the treatments of the experiment and showed that the fertilization treatments significantly affected the nutrition and, consequently, the production of the crop (Ribeiro et al., 2016).

The relationship between nutritional balance and productivity is evident. The values of the DRIS indexes (Table 7) for the high productivity group were lower than low productivity group, because when the value of the index is closer to zero, the more balanced the nutrient content is compared to others (Junior et al., 2003).

The comparison of the nutritional balance between the treatments was made by the nutritional balance index (IBN), which is the sum of the absolute values in models of the DRIS index (Table 7), in which the lower value provides better nutritional balance for the crop (Bangroo et al., 2010). Thus, in this case, it is observed that the treatments of the high productivity group presented a better nutritional balance than the group of low productivity.

In high-productivity group a higher yield of 24 t ha^{-1} was observed, when 800 kg ha^{-1} of P_2O_5 was used. But we observed that the dose of 400 kg ha^{-1} P_2O_5 provided similar productivity. This represents a saving of 400 kg ha^{-1} in the fertilization of the crop. Therefore, we found that the DRIS index for phosphorus of this treatment was in excess.

The dose of 600 K_2O presented the lowest IBN (6.90) indicating that the plants of this treatment had a better nutritional balance.

Within the high productivity group, the nutrient that most limited the productivity was P, in the treatment in which 210 Kg ha^{-1} N of all nutrients were analyzed, with DRIS index of 5.8.

Within the low productivity group, the treatment with the lowest productivity was the one with the absence of N in the fertilization, but the one with the lowest IBN among the IBN values was the treatment with absence of P_2O_5. The nutrient Ca was also a limiting factor having a DRIS index of 11.6.

In relation to the N doses studied, we verified that yield was low in the absence of nitrogen fertilization (12 t ha^{-1}) and Ca was the most limiting nutrient. With application of 70 kg ha^{-1} N supplement, there was a considerable productivity increase of 41% and the DRIS index of Ca fell. This was not observed at the dose of 140 kg ha^{-1} of N, in which the productivity dropped and the Ca index rose again. At the dose of 210 kg ha^{-1} of N, the productivity rose again and the Ca index falled, while P was considered as most limiting element. At the dose of 280 kg ha^{-1} of N, the productivity decreased again and Cu was the most limiting element.

Nitrogen fertilization in potato crop favored vegetative growth (Zheng et al., 2016).

Regarding the doses of K_2O, there were no significant increases in productivity as a function of the doses used, with the lowest IBN values. Queiroz et al. (2014) also did not observe a significant result for yield of potato tubers with the increase of the doses of K used in the fertilization. Therefore, even expecting high productivity, potassium fertilization may be unnecessary when the initial exchangeable K content of the soil is high.

The nutrients that most limited productivity were S, Mn, Cu and Zn.

In general average of all treatments within the low productivity group, the nutrient that most limited productivity was Ca, followed by B.

The DRIS allowed one to know the order of nutrient limitations in the studied potato fields and to evaluate the adequacy of the relationships among the nutrients. However, it did not allow the calculation of the amount of the nutrients that should be applied, providing only the order and whether the limitation occurs due to deficiency (negative sign) or excess (positive sign) in relation to the other nutrients (Bangroo et al., 2010).

Among the nutrients studied, Ca was the element that had the highest deficiency index in the group of high productivity and low productivity. The nutrient that had the highest excess index in the high productivity group was the B and in the low productivity group was the Fe (Table 8).

Thus, we can establish the order of insufficiency in the high productivity areas as follows: Ca> Mn> P> S> Zn = Cu> K> N> B> Fe> Mg, and the order of insufficiency in the areas of Low: yield Ca> Cu> Mg> P> S> Mn> Zn> K> Fe = B> N.

The data show that the studied areas, although producing above 22 t ha^{-1}, require adjustments in their soil fertility management system to reach higher production levels.

Materials and Methods

Plant material

For the calculation of the DRIS, the population of high productivity (or reference population) consisted of the areas where yields were greater than 22 t ha^{-1} of tubers.

To establish DRIS standards, the database was separated into a high productivity population and another with a low productivity,

The calculations of the standards, DRIS indexes, IBN and Nutritional Balance (IBN) were made using the DRIS worksheet and the Microsoft Excel software, using the original method proposed by Beaufils (1973).

The DRIS considers the nutritional balances, which are initially established standards, constituting the calculation of average, variance and coefficient of variation of nutrient relations, taken two by two.

Location of the experiment

The experiment was conducted in the county of Perdizes, Minas Gerais (19° 21' 10"S and 47° 17' 34" W) from June 12 to September 17, 2010. The regional climate is classified as tropical at altitude, according to the classification of Köppen, with annual average of 20.4 °C and average 119.8 mm.
Prior to the installation of the experiment the soil chemical analysis was carried out according to EMBRAPA´s methodology (1999) with the following results (Table 1).
The soil where the experiment was conducted is classified as a dystrophic Red Latosol (LVd) of clay texture, with 60% clay (Ferreira, 2010).

Experimental design

The experimental design was a randomized block design, with 5 doses and 4 replicates for each nutrient, including 20 plots. Three experiments were conducted simultaneously, one for each nutrient, nitrogen (N), phosphorus (P) and potassium (K), and the control was represented by the zero dose (Table 2).
The experiment had a total of 20 plots per nutrient, each plot consisted of 6 lines, spaced 0.75 cm between rows, with 6 m of length, totaling 27m^2 of total area per plot. The evaluations were carried out on the two central lines, which comprised the useful area of the plot, neglecting two lines on each side of the blocks and a half meters from each block, which were the borders, having a useful area of 7.5m^2.

Installation and conduction of the experiment

Soil preparation was performed according to the recommended for potato cultivation, by means of plowing followed by trenching / leveling and then opening of the grooves.
About 30 days after planting (DAP), hilling was done, where 80% of the N doses were added in cover and incorporated.
The irrigation system used was the central pivot where the plants received approximately 500 mm during the cycle, being close to the volume of water indicated for cultivation, which varies from 450 to 550 mm.
The phytosanitary treatment was the same used in the commercial crop, with only registered products for the potato crop applied in recommended doses. About 18 sprays were made throughout the crop cycle.
The NPK sources used were: Urea, with 43% N; Super simple phosphate, with 17% P_2O_5; And Potassium chloride with 57% K_2O. A 30 kg ha^{-1} of a source of micronutrients composed of 2.7% of Ca (calcium), 8.2% of S (sulfur), 12% of Zn and 6% of B (boron) was added.
The doses of N were split, with 20% applied in the groove at the time of planting and 80% applied in cover, together with the heap.
The liming was performed according to the soil analysis results and recommended according to the Ribeiro et al. (1999). Dolomitic limestone was incorporated into the soil and, after incorporation of limestone the doses of the studied elements were added in the planting groove.

Characteristics evaluated and statistical analysis

Productivity of tubers

At the end of the experiments, the tubers were harvested, weighed and the productivity of the plot area was calculated and converted into kg ha^{-1}.
The data were submitted to analysis of variance to verify the existence of differences between treatments. For the comparison of the means, the F test was applied at 5% and submitted to polynomial regression analysis. For the analyses, the statistical program SISVAR (Ferreira, 2003) was used.

Nutritional diagnosis

For the diagnosis of the nutritional status of the plants by the DRIS index, 10 complete leaves (limbus + petiole) from the third fully developed trefoil were harvested at 36 days after planting (DAP) (Ribeiro et al., 1999). We evaluated the foliar levels of nitrogen, phosphorus, potassium calcium, magnesium, sulfur, boron, copper, iron, manganese and zinc.
The calculations for the establishment of DRIS standards were based on populations of high productivity (reference population) and low productivity. The reference populations were established as being the treatments where productivities were superior to 22 t ha^{-1}.
With the formula of DRIS, indices were calculated for the nutrients that are positive or negative. The positive and negative indices indicate deficiency or excess, respectively, and number equal or near zero indicate adequate levels.
The datasets of the productivity experiments, as well as the DRIS indexes and the Nutritional Balance Index (IBN) were obtained using Excel software (Microsoft) and calculations following the original method proposed by Beaufils (1973). Eq. 1; Eq. 2; and Eq. 3.

If: $Y/X_a < Y/X_n$

So:

O $f(Y/X) = [1 - (Y/X_n)/(Y/X_a)] \cdot 1000/CV$ (1)

Se $Y/X_a = Y/X_n$

So:

$f(X/Y) = 0$ (2)

Se $Y/X_a \geq Y/X_n$

$f(Y/X) = [(Y/X_a)/(Y/X_n) - 1] \cdot 1000/CV$ (3)

Where; calculated function of the nutrient ratio Y and X; - nutrient ratio of the sample; - nutrient ratio of the standard; S - standard deviation of the relation; CV - coefficient of variation (%) of the relation; K - sensitivity constant. Eq. 4.

$$I_y = \frac{\sum_{i=1} f(Y/X_i) - \sum_{j=1} f(X_j/Y)}{m+n} \quad (4)$$

Where; Iy - DRIS index for nutrient Y; Y - nutrient for index calculation; X - other nutrient; M - number of functions whose nutrient Y is in the denominator of the function; N -

number of functions whose nutrient Y is in the numerator of the function.

Using the DRIS formula, the relative indices for the nutrients were calculated, which were negative, positive or equal to zero. Negative and positive indices indicate deficiency and excess, respectively, and values close to zero are indicative of adequate levels (Junior et al., 2003).

After calculating the index of each nutrient, the nutritional balance index (IBN) was established according to the original method proposed by Beaufils (1973). Eq. 5.

[illegible] (5)

Conclusion

The yield of tubers Asterix cultivar was not influenced by the increasing doses of P_2O_5 and K_2O. However, there was an increase in yield of tubers as a function of N rates applied, up to the 173 kg ha^{-1} dose of N, where yield was 21.8 t ha^{-1} of tubers. According to DRIS, the descending order of limiting nutrients for failure in areas with high productivity, had the following sequence: Ca> Mn> P> S> Zn = Cu> K> N> B> Fe> Mg, as well as, the lower productivity areas: Ca> Cu> Mg> P> S> Mn> Zn> K> Fe = B> N.

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