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RESEARCH ARTICLE

FOLIAR CONTENTS AND ESTABLISHMENT OF DRIS INDEX FOR THE CUPID POTATO CULTIVAR

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ABSTRACT

Potatoes tend to have relatively short production cycle and high yield per area, hence they demand the presence of readily available nutrients in soil solution. Each potato cultivar has specific characteristics of its development. The objective of this study was to verify foliar contents and to establish Diagnosis and Recommendation Integrated System (DRIS) indices for the Cupid potato cultivar with the use of organo-mineral fertilizer. The experiment was conducted in Perdizes city, Minas Gerais, during the rainy season of 2014/2015. The experimental design had randomized blocks with factorial arrangement of 4 doses and 2 fertilization managements + control treatment (conventional mineral dose) with 3 repetitions. The organo-mineral fertilizer doses were 25, 50, 75 and 100% of a mineral dose, which were: 600 kg ha^{-1}of potassium sulfate, 850 kg ha^{-1}of phosphate monoammonium, and 300 kg ha^{-1} of ammonium sulphate. The management of fertilization consisted of either performing or nottop dressing 19 days after planting (DAP) with hilling. After 36 days, leaf samples were collected from each plot for foliar analysis. At the end of the experiments, the tubers were collected to calculate the productivity of the useful area on the plots. The order of insufficiency can be established using DRIS in the high productivity group through the following sequence: Fe>S>K>Mn>Cu>Zn>B> Mg>N>P>Ca, and the order of insufficiency in the low productivity group through the following sequence: Mn>P>N>Mg>Fe>Cu>Zn>S>K>B>Ca. On the basis of DRIS, the treatment with the dose of 75% and top dressing showed the best nutritional balance in the production of potato cv. Cupid.

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INTRODUCTION

The potato has a great economic importance in Brazil but it presents a constant challenge to all professionals involved in the production chain due to its uniqueness and complexity. According to the Ibge (2014), Brazil's average yield was 27.80 t ha^{-1}, with cultivated area of approximately 149,000 hectares, distributed throughout the following states: Minas Gerais (28%), São Paulo (19%), Rio Grande do Sul (15%), Bahia (6%), Goiás (5%). The potato crop is highly responsive to environmental changes, especially in relation to soil fertility. Potato cultivars for industrial purposes respond differently from the others due to accumulation of dry matter in the tubers, thus they present different behavior regarding absorption of nutrients. In the production if these cultivars the aim is to obtain high quality of raw material and yield (Bregagnoli, *et al*., 2006). Fertilization, in most cases, is based on empirical evidence rather than results of soil analysis, with much larger doses than those recommended by research (Andriolo *et al*., 2006). The organo-mineral fertilizers improve soil characteristics due to the presence of organic fractions in their composition. The benefits of these fractions in soil are: increased water and nutrient retention, reduced propensity to erosion, recovery of microbial flora, reduced acidification and need for liming (Novais *et al* 2007). Free amino acids in the organo-mineral fertilizers act as hormone precursors, essential in plant rooting process (Cardoso, Luz and Lana 2015). However, there is little information about the behavior of potato in response to this new technology. Fertilizer recommendations for potato crops are solely based on soil analysis. Recommendations regarding the amount of nutrients which are provided to plants through fertilization should be done by assessing the fertility of soil and supplemented with foliar analysis (Cogo *et al*, 2006; Malavolta, 2006). The amount of nutrients present in leaves reflect absorption of nutrients by plants which are available in soil.

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The Diagnosis and Recommendation Integrated System (DRIS) is considered a tool to identify nutritional status of plants since it identifies nutritional limitations which are not identified by soil analysis. In addition, DRIS indices show nutrients in deficiency and in excess. Therefore, their advantage is that they allow ordering nutrients from the most limiting to the most excessive, indicating the ones which are hampering production due to nutritional imbalance. DRIS uses as nutritional standard a population of reference based on high productivity of plants whose nutrition is in balance (Beaufils, 1973; Baldock and Schulte, 1996 Nziguheba *et al*., 2009). Thus, this study aimed to evaluate foliar levels and productivity of Cupido potato tubers under different doses and management of organo-mineral fertilizer, and consequently to establish productivity indices of DRIS.

MATERIALS AND METHODS

The experiment was conducted in Perdizes, Minas Gerais, (19°21'10"S and 47º17'34" O) at an altitude of 1000 m, between December 10, 2014 and March 29, 2015, using Cupido potato cultivar. The climate is classified as Aw (megathermal), according to KOPPEN classification, with cold and dry winters and hot and humid summer. Results of soil analysis from the 0-20cm layer of the experimental area are presented in Table 2.

The experimental design had randomized blocks in a factorial design (4x2+1), with eight treatments, a control treatment and three repetitions, totaling 27 installments. Each plot consisted of 6 rows spaced 0.8 cm apart and 6 m long, totaling 28.8 m^2 of total area per plot. Treatments consisted of four ratios: 25, 50, 75, 100% of doses of a conventional mineral fertilizer with organo-mineral source and with or without top dressing (Table 3). The dose of mineral fertilizer applied at planting was 600 kg $ha^{-1}$of K_2SO_4 (xx% of K_2O) and 850 kg ha^{-1} of $NH_4H_2PO_4$ (xx% of N and xx% of P_2O_5) and 300 kg $ha^{-1}$of NH_2SO_4 (xx% of N), applied viatop dressing. The doses of organo-mineral fertilizer applied in treatments in the form of top dressing, which was held 19 DAP with hilling, were proportional to doses of a conventional mineral fertilizer. Soil preparation was performed according to recommendations for potato crop, i.e. plowing followed by roller/leveler harrowing and subsequently opening furrows to a depth of 15 cm. Seed tubers used in this experiment were type III class (30 to 40 millimeters in diameter). Per plot, 120 seed tubers were sown. The irrigation system had central pivot 71.58 mm, with the optimal range for the development of 450 to 500 mm of water throughout the production cycle. However, there were constant rains during the period of the experiment, totaling 883.4 mm, setting an excess of 504.9 mm. To asses nutritional status of plants by DRIS, 10 complete leaves (limbo + petiole) of the third fully developed trifoliate were collected (Cfsemg, 1999) 36 DAP.

Table 1. Rainfall, maximum and minimum temperatures of the study area

Months	Precipitation (mm)	Day		Night	
		T. mín. (ºC)	T.max (ºC)	T.mín (ºC)	T.max (ºC)
December	122.8	22.46	23.80	19.96	20.72
January	97.6	24.79	26.38	20.97	22.14
February	349.2	22.16	23.55	19.50	20.33
March	313.8	21.71	23.15	19.09	19.58

Source: Weather Station Gupo Rochetto (2015)

Table 2. Results of soil chemical analysis from the 0-20 cm layer of the experimental area

pH	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	T	SB	OM	V	m
H_2O (1:2.5)	$mgdm^{-3}$		$cmol_cdm^{-3}$					g dm^{-3}	%	
6.0	29.5	63	3.8	0.6	0	8.05	4.55	-	56	0

P and K- Extrator Mehlich-1 (HCl 0.05 mol L^{-1}; + H_2SO_4) 0.025 mol L^{-1}); Ca, Mg and Al – Extrator KCl 1 mol L^{-1}; T-CTC potencial (pH 7.0); V- base saturation; OM (organic matter - colorimetric method) (Embrapa, 2011).

Table 3. Description of treatments used in the experiment

Proportion of organo-mineral fertilizer	Doses kg ha^{-1}			
	Planting			Topdressing
	00.00.30	06.30.00	18.03.00	18.03.00
25%	240	368.3	83.5	-
25%	240	368.3	-	83.5
50%	480	736.5	167	-
50%	480	736.5	-	167
75%	720	1105	250.5	-
75%	720	1105	-	250.5
100%	960	1473	334	-
100%	960	1473	-	334

No fertilizer application.

In order to characterize the productivity, tubers from two central lines were harvested about 120 days after planting, disregarding two lines on each side of the blocks and the first and the final meter of each block, forming auseful area of 6,4m^2. After harvesting of the experiment, a soil sample from each plot was collected from 0-20cm layer for soil analysis. The following characteristics, according to the methods described in Embrapa (1997), were determined,: pH (H_2O); extractable P and K by Mehlich^{-1}and determined, respectively, by flame photometry and colorimetry; exchangeable Ca, Mg and Al by KCl 1 mol L^{-1}, with Ca and Mg determined by atomic absorption spectrophotometry and Al by titration with NaOH 0,025 mol L^{-1}; and H+Al with calcium acetate 0,5 mol L^{-1}at pH 7,0. Total N was determined by the Kjeldahl method and organic carbon by oxidation with $K_2Cr_2O_7$ 1,25 mol L^{-1}in acid medium (Anderson and Ingram, 1993). The calculations for the establishment of standards of DRIS were based on high productivity populations (or reference population) and low productivity. Treatments whose yields were higher than 15.50 t ha^{-1} were established as reference populations. Productivity spreadsheets of the experiments, DRIS indices and Index of Nutritional Balance (IBN) were obtained using Excel software (Microsoft) and calculations using the original method proposed by Beaufils (1973) (Equations 1; 2; 3 e 4)

If: $Y/X_{\alpha} < Y/X_{n}$

Then: $$\int(X/Y_n) = [1-(Y/X_n/Y/X_{\alpha})]x(100xk/CV) \quad (1)$$

If $Y/X_{\alpha} = Y/X_{n}$

Then: $$\int(X/Y) = 0(zero) \quad (2)$$

If $Y/X_{\alpha} \geq Y/X_{n}$

Then: $$\int(X/Y_n) = [(Y/X_{\alpha}/Y/X_n)-]x(100xk/CV) \quad (3)$$

Where: $\int(Y/X)$ = calculated function of nutrients ratio Y and X; Y/X_{α} = nutrients-to-sample ratio; $Y/X\,n$ = nutrients-to-norm ratio; s= standard deviation ratio $Y/X\,n$; CV= coefficient of variation (%) of the relation $Y/X\,n$; k=constant of sensitivity.

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

Where: I_y: DRIS index for the Y nutrient; Y: nutrient to calculate the index; X: other nutrient; *m*: number of functions whose nutrient Y is the denominator of the function; *n*: number of functions whose nutrient Y is in the numerator of the function.

Parameters related to nutrients are calculated using DRIS formula establishing which nutrients are negative, positive or zero. The negative and positive parameters indicate deficiency and excess, respectively; values near zero indicate adequate levels. Nutritional balance index (IBN) was established after the calculation of the index of each nutrient according to the original method proposed by Beaufils (1973).

$$\text{IBN} = [\text{índex A}] + [\text{índex B}] + \text{K} + [\text{índex N}]$$

After harvesting, the tubers were weighed and sorted. Three classes were created according to the diameter of tubers: tubers with a diameter bigger than 45 mm (special), bigger than 36 mm (1x) and smaller than 36 mm (lollipop). Tubers damaged by disease, rotten or deformed by physiological abnormalities and cracks were separated and formed a fourth class (disposal). Each class was weighed and the data were converted into productivity per hectare.

RESULTS AND DISCUSSION

The average yield of a group rated as high productivity group(>15,5 t ha^{-1}) and low productivity (<15,5 t ha^{-1}),and the average levels of macro and micronutrients in leaf tissue of Cupid potato cultivar are presented in Table 9. Potassium is the most required nutrient by the majority of vegetables (Ferreira; Castellane and Cruz, 1990), followed by N, P, Ca and Mg (Embrapa, 1997). Foliar potassium levels (Table 8) in both groups of high and low productivity were in deficiency according to Reis Junior (1995), which are 74 to 89 g kg $^{-1}$ K. This may be due to leaching of K^+ cations by rain which may have diminished the level of this nutrient in soil. As for the contents of N, P, Ca, Mg, S, B, Cu, Zn found in the leaves of theplants (Table 8), they were considered adequate (Reis Junior, 1995). Levels of Fe and Mn were above suitable for a potato crop. However, there were not visual symptoms of toxicity or any other effects of these nutrients which could cause physiological changes to the plants with negative impact on growth.(Bakery Walker, 1989; Reis Junior1995). Excess of Mg interferes with the activity of key enzymes involved in plant respiration process by slowering it and decreasing the amount of auxin in plant cells, a hormone responsible for the growth of plants (Foy; Chaney and White, 1978). Regarding the mobility of Mg, it is considered mobile in the plant and it is mainly concentrated in the region of the roots, particularly when the soil is rich in organic matter and pH is lower or equal to 5.5 (Wallace; Alexander and Chaudhry, 1977). Mn and Fe are classified as heavy metals because their density is greater than 4.5 g cm^3 (Ernst, 1996). These nutrients cause a reduction in plant photosynthesis as they inhibit biosynthesis of chlorophyll by reducing the proportion of total chlorophylls a and b (Krupa; Baranowska and Orzol, 1996). Under conditions of excessive rainfall, as in this study, iron is in the form of trivalent Fe^{3+}cation which is reduced to Fe^{2+}, which is an assimilable form by plants (Ponnamperuma; Bradfield and Peech, 1995). Absorption of P, K, Ca and Mg was reduced with increasing concentration of Fe, which inhibited formation of new active roots causing nutritional disorders (Fageira Filho and Carvalho, 1981).

The excess of iron may block the absorption of nutrients by the ferric oxide layer formed in the roots (Howeler, 1973). The decreasing capacity of oxidation of the root system occurs when the levels of K and P accentuate the iron toxicity (Trolldenier, 1977). The surplus of iron may be excessively accumulated in plants or precipitated on the surface of roots (Silveira *et al*, 2007). The precipitation in the region of the roots may alter absorption of essential nutrients to plants generating multiple nutritional deficiencies (Zhang, Zhang and Mao, 1999). When DRIS index is negative it indicates that the nutrient is below the optimum level, and when it is positive it indicates that the nutrient is above the optimal level. Thus, negative values (-) indicate deficiencies, while positive values (+) indicate excess of nutrients in relation to others (Baldock and Schulte; 1996).

The relationship between nutritional balance and productivity is evident. DRIS indices for the high productivity group have lower values than for the low productivity group (Table 5 e 6). The deficient nutrients in the low productivity group were Mn, P and S, whereas Ca presented excess. Araujo (2011) states that maximum absorption of P, K, Mg and S is generally observed between 40 and 50 days after planting. However, P and Ca are absorbed throughout the crop cycle, reaching absorption peak between 90 and 110 days after planting. In the low productivity group P presented deficit, which significantly reduced growth cycle and increased number of potato tubers per plant, but had small effect on productivity and the size of the tubers (Fontes, 1999; Zaag, 1993).

Within the low productivity group, the lowest productivity was observed in the treatment which received 100% of organ-mineral fertilizer without top dressing, presenting IBN of 94.10, with P as the most limiting nutrient, and DRIS index of -18,54 (Tables 5 and 7). DRIS allowed the order of limitations of nutrients, assessing the adequacy of relations between all the nutrients. Nevertheless, it did not allow calculation of their amount which should be applied; it just stated the order and if the limitation were due to deficiency (minus sign) or to excess (plus sign) in relation to other nutrients. According to what can be seen in Table 7, it was possible to establish nutrient deficiency indices with productivity above 15.5 t ha^{-1} and below 15.5 t ha^{-1}.

Table 4. Average foliar contents and yield of high and low productivity group of potato cultivar Cupido due to the use of organo-mineral fertilizer

Productivity (t ha^{-1})	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	g kg^{-1}						mg kg^{-1}				
Above 15,5 t ha^{-1}											
18.03	40.92	3.70	42.17	16.72	4.48	3.17	33.01	11.98	673.51	279.66	71.04
Below15.5 t ha^{-1}											
14.89	40.50	3.70	41.83	17.67	4.67	3.20	33.87	12.46	661.05	269.94	73.59

Table 5. DRIS indices of macronutrients (g kg^{-1}) and IBN of Cupido potato cultivar due to the use of organo-mineral fertilizer

Treatment	Productivity (t ha^{-1})	Highproductivity (>15,50 t ha^{-1})						
		N	P	K	Ca	Mg	S	IBN
75% without top dressing	18,84	-2,74	-2,39	5,06	-2,49	-3,59	-12,64	49,72
mineral	18,5	-1,18	6,56	1,30	-1,54	-4,70	1,80	50,85
25% withtop dressing	17,56	-2,87	-1,39	-9,98	3,61	7,99	9,86	75,17
75%withtop dressing	17,36	6,76	-2,69	2,90	0,06	0,39	0,91	36,83
Treatment	Productivity (t ha^{-1})	Low productivity (<15,50 t ha^{-1})						
25%withouttop dressing	15,37	6,07	6,59	4,67	16,02	4,96	1,69	125,19
50% withtop dressing	15,26	-11,35	-0,41	-3,43	12,45	-22,85	-7,53	104,18
50% withouttop dressing	14,89	3,01	11,47	8,11	-2,36	21,17	7,16	125,22
100% withtop dressing	14,69	-20,96	-47,63	-6,21	5,99	1,88	-3,68	187,03
100% withouttop dressing	13,94	1,21	-18,54	3,54	16,55	-7,61	-4,38	94,10

Without top dressing= fertilization at planting; withtop dressing= top dressing19 DAP.

Table 6. DRIS indices of micronutrients (mg kg-1) of the potato cultivar Cupido due to the use of organo-mineral fertilizer

		High productivity (>15,50 t ha^{-1})				
		B	Cu	Fe	Mn	Zn
75% without top dressing	18,84	8,14	-1,01	9,35	0,00	2,31
Mineral	18,5	-5,98	-12,02	0,24	5,71	9,82
25% with top dressing	17,56	2,49	13,63	-14,69	-6,57	-2,08
75% with top dressing	17,36	-5,03	0,79	6,39	0,21	-10,69
		Low productivity (<15,50 t ha^{-1})				
25%without top dressing	15,37	15,86	3,93	4,50	15,35	-6,51
50% with top dressing	15,26	-5,37	11,42	-13,47	-41,41	0,27
50% without ttop dressing	14,89	-3,85	-11,18	1,54	75,56	8,55
100% with top dressing	14,69	11,71	-9,97	3,03	-6,56	11,00
100% without top dressing	13,94	8,14	-1,01	9,35	0,00	2,31

Without top dressing= fertilization at planting; with top dressing= top dressing 19 DAP.

Table 7. Deficiency and excess indices of macro and micronutrients of the high and low productivity group of potato tubers due to the use of organo-mineral fertilizer

Order	Deficiency indices				Excess indices			
	>15,5 t ha^{-1}		<15,5 t ha^{-1}		>15,5 t ha^{-1}		<15,5 t ha^{-1}	
1°	Fe	-14.7	Mn	-32.0	Cu	7.2	Mn	45.4
2°	S	-12.6	P	-22.1	N	6.8	Ca	12.7
3°	K	-10.0	N	-16.1	P	6.6	B	10.6
4°	Mm	-6.6	Mg	-15.2	Zn	6.0	Mg	9.3
5°	Cu	-6.5	Fe	-13.9	B	5.3	P	9.0
6°	Zn	-6.4	Cu	-10.6	Fe	5.3	Zn	8.6
7	B	-5.5	Zn	-6.5	S	4.2	Cu	6.3
8°	Mg	-4.1	S	-5.2	Mg	4.2	K	5.4
9°	N	-2.2	K	-4.8	K	3.1	S	4.4
10°	P	-2.1	B	-4.6	Mn	2.9	N	3.4
11°	Ca	-2.0	Ca	-2.4	Ca	1.8	Fe	3.0

This is due to the fact that the closer to zero the value of the index is, the more balanced nutrient concentration is in relation to the others. Within the high yield group (> 15.5 t ha^{-1}), it was observed that the treatment with the proportion of 75% of organo-mineral fertilizer based on the mineral fertilizer used as a control (600, 850 and 300kg $ha^{-1}$of: K_2SO_4, $NH_4H_2PO_4$, $(NH_4)_2SO_4$, respectively) with top dressing, presented IBN of 36.83, the lowest in the high productivity group. In general, IBN showed values higher than those found by Araújo *et al*. (2014) who tested NPK doses on cv. Agata and obtained productivity of 52.79 t ha^{-1} at a dose of 140 N, 400 P_20_5 and 450 K_2O with IBN of 8,6. IBN increased to 69.62 in low productivity of 30.897 t ha^{-1} with the dose of 0 N, 400 P_20_5 and 300 K_2O. The authors argue that smaller DRIS indices, near zero, lead to nutritional balance which is directly reflected by increased productivity. White *et al*. (2009) state that the levels of nutrients present in the tubers and leaves are influenced by environmental and genetic factors. IBN found in this study was not close to zero, which again was probably due to adverse environmental conditions of the experiment, favoring infestation by pests and diseases, causing nutritional and physiological disorders. Bangroo *et al*. (2010) state that DRIS standards should be developed for specific conditions, in which all other factors ought to be correlated with productivity as: cultivar, climate, soil and crop, weather conditions, soil type, nutrient adsorption capacity and ability to remove nutrients by crops, or the production system as a whole. Within the high yield group and among the proportions of organo-mineral fertilizers, N, P and Zn limited productivity the most. Nitrogen is important forthe synthesis of proteins and compounds such as chlorophyll, hormones, and vitamins. It is also the precursor of amino acids which are associated with susceptibility or resistance to diseases, and it is also highly redistributed via phloem (Marschner, 1995). Nitrogen can increase dry matter production of the aerial part, without increasing the production of tubers due to the alteration of the drain-to-sourceratio (Bebendo, 1995). Regarding the mineral fertilizer, nutrients which limited the most were Cu, B and Mg. The macronutrient P in the organo-mineral fertilizer composition was in excess when it was compared with the organo-mineral fertilizers. Among the studied nutrients, Fe showed the highest rate of deficiency in the high productivity group. In the low productivity group, Mn showed the highest deficiency. Thus, the order of insufficiency maybe established for the area of high productivityas: Fe>S>K>Mn>Zn>B> Mg>N>P>Ca, and the order of insufficiency for area of low productivity as: Mn>P>N>Mg>Fe>Cu>Zn>S>K>B>Ca.

Conclusion

In high rainfall conditions and without good thermo periodicity for the potato crop, smaller doses (25%) of organo-mineral fertilizer without top dressing had the same effect as higher doses (50, 75, 100%) of organo-mineralfertilizer and mineral fertilization on the development and productivity of tubers. Fertilization with organo-mineral fertilizer can be entirely carried out at planting, reducing production costs by eliminating top dressing. The order of insufficiency can be established using DRIS in the high productivity group through the following sequence: Fe>S>K>Mn>Cu>Zn>B>Mg> N>P>Ca, and the order of insufficiency in the low productivity group through the following sequence: Mn>P>N>Mg>Fe>Cu> Zn>S>K>B>Ca. On the basis of DRIS, the treatment with the dose of 75% and top dressing showed the best nutritional balance in the production of potato cv. Cupid.

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