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PRODUCTIVITY AND QUALITY OF POTATOES UNDER DIFFERENT POTASSIUM FERTILIZER SOURCES[1]

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ABSTRACT - The objective of this study was to evaluate potassium and chloride accumulation in, and the yield and quality of the potato tubers of the Asterix cultivar, under the application of two potassium fertilizer sources (KCl and $K_2SO_4.2MgSO_4$) and their combinations. The experimental design was a randomized complete block with five treatments and four replications in a factorial scheme with a subdivided plot. The presence of greater than 61.8% of the recommended dose of chloride in potassium fertilization affects potato plant growth, with less dry matter accumulation in the aerial part. This does not occur in the tubers because of lower nutrient translocation to the tubers. K accumulation varies between levels depending on the companion ions of the sources. Throughout the cycle, the amount of chloride increased in the aerial parts and tubers with an increase in the percentage of KCl. The total productivity is affected by the use of a combination of potassium sources in different proportions, with a maximum yield of 41.3 t ha^{-1} with a combination of 64.5% KCl and 36.5% $K_2SO_4.2MgSO_4$. Soluble solids did not vary with the sources at a dose of 180 kg ha^{-1} K_2O.

Keywords: *Solanum tuberosum* L. Chloride. Nutrient accumulation.

PRODUTIVIDADE E QUALIDADE DE BATATA SOB DIFERENTES FONTES DE FERTILIZANTES POTÁSSICOS

RESUMO - O objetivo deste trabalho foi avaliar o acúmulo de potássio e cloreto na produtividade e qualidade de tubérculos de batata, cultivar Asterix, sob aplicação de duas fontes de fertilizante potássico (KCl e $K_2SO_4.2MgSO_4$) e combinações destes. O delineamento experimental foi em blocos casualizados, com cinco tratamentos e quatro repetições, em esquema fatorial com parcela subdividida. A presença de cloreto na fertilização potássica acima de 61,8% da dose recomendada afeta o crescimento das plantas de batata, com menor acúmulo de matéria seca na parte aérea. Isso não ocorre nos tubérculos devido à menor translocação de nutrientes para os tubérculos. O acúmulo de K é variável entre os níveis, dependendo dos íons companheiros das fontes. Ao longo do ciclo, a quantidade de cloreto aumenta na parte aérea e tubérculos com o aumento da % de KCl. A produtividade total é afetada pelo uso da combinação das doses da fonte de potássio, com produtividade máxima de 41,3 t ha^{-1} com a associação entre 64,5% KCl e 36,5% KCl and $K_2SO_4.2MgSO_4$. Os sólidos solúveis não variaram com as fontes na dose de 180 kg ha^{-1} K_2O.

Palavras-chave: *Solanum tuberosum* L. Cloreto. Acúmulo de nutriente.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is a basic crop that provides phytonutrients, minerals, vitamins, and dietary fiber (BEALS, 2019; MISHRA et al., 2020). It is economically important worldwide and can be grown on a large scale (ZAHEER; AKHTAR, 2016). Therefore, knowledge about the conditions under which they grow and the impact of these conditions is important (BRAZINSKIENE et al., 2014).

In processed potatoes, tuber quality is essential; therefore, producers need to combine high yields with excellent quality. Some issues related to productivity and quality are at the heart of the search for new knowledge on potato production. The potato crop consumes the greatest amount of fertilizer, which has a significant impact on costs.

The nutrient absorbed in the greatest quantity by the potato plant is potassium (K) (FERNANDES; SORATTO, 2013). K is essential for starch synthesis, nitrogen metabolism, and respiration; it activates enzymes and helps plants adapt to environmental stress (ZELELEW et al., 2016). It also plays an important role in maintaining the tone and vigor of plants (LI et al., 2015).

Potassium is supplied in the form of chloride, nitrate, and sulfate of potassium, with chloride being the most commonly used because of its lower cost and higher concentration. Chlorine is considered a micronutrient and, like K, is absorbed by plants. There are several possible molecular mechanisms for Cl uptake and translocation in plants (SUN et al., 2014).

The action of chlorine on plants varies among species. Lam et al. (2015) observed that within a single family of plants, there were species that showed a positive response to the presence of chlorine, while in others, no evidence was found.

Salinity can cause serious damage that directly affects plant growth and productivity. These damages can be of osmotic or ionic origin, through the reduction of the osmotic potential of the soil, affecting the water absorption capacity of the roots, or due to the toxicity of ions, such as Na^+ and Cl^- (NÓBREGA et al., 2018; WANDERLEY et al., 2018).

Mallmann, Lucchesi, and Deschamps (2011) reported that excess chloride reduced the chlorophyll content in some oleraceae and, consequently, affected their photosynthetic activity and productivity. As a result, nutrient sources that do not contain chlorine have been adopted by large potato farmers who plan their production for processing, especially in combination with chloride, in order to dilute the high cost of sulfate.

The double sulfate of potassium and magnesium is an example of a sulfate-containing fertilizer, with the advantage that in addition to providing magnesium, it also increases the availability of sulfur and phosphorus. Sulfur (S) is necessary for the synthesis of many metabolites, including proteins, co-enzymes, prosthetic groups, vitamins, amino acids, and secondary metabolites (GIGOLASHVILI; KOPRIVA, 2014). The uptake of P and the yield of tubers increased with S application, irrespective of the dose and form of S fertilizer (KLIKOCKA et al., 2015).

However, sulfur deficiency has become a problem in agriculture over the last decades in many areas, and sulfur fertilization is required to ensure the yield, quality, and health of crops (SAUTER et al., 2013, KOPRIVA et al., 2016).

The objective of this study was to evaluate potassium and chloride accumulation, yield, and quality of potato tubers of the Asterix cultivar, under the application of two sources of potassium fertilizer (KCl and $K_2SO_4.2MgSO_4$) and their combinations.

MATERIAL AND METHODS

The experiment was carried out in the municipality of Perdizes (latitude: 19°21′10″S and longitude: 47°17′34″W), in the state of Minas Gerais, between May and October of 2011, using the Asterix variety of potatoes (intended for industry).

The soil in the area was classified as yellow latosol with a clayey texture. Soil chemical analysis performed before soil preparation at 0–20 cm depth showed the following results: P = 38.72 mg dm^{-3}; K = 0.18 $cmol_c$ dm^{-3}, pH = 5.7; Ca^{2+} = 1.70 $cmol_c$ dm^{-3}; Mg^{2+} = 0.39 $cmol_c$ dm^{-3}, Al^{3+} = 0 $cmol_c$ dm^{-3}, CTC = 5.8 $cmol_c$ dm^{-3}, T = 2.27 $cmol_c$ dm^{-3}, and SB = 2.27 $cmol_c$ dm^{-3} (EMBRAPA, 1999).

The experimental design was a randomized block with five treatments and four replications in a factorial scheme with subdivided plots. The plots refer to the treatments, and the subplots to the plant collection times (26, 41, 56, 71, 86, 101, and 116 days after planting [DAP]). Each plot consisted of six 6 m long rows, spaced 0.75 m apart, totaling 27 m^2 of the total area per plot. Seed tubers, spaced 0.30 m apart, formed a population of approximately 44.444 plants ha^{-1}.

The treatments consisted of combinations of two potassium fertilizer sources (potassium chloride—KCl, and potassium and magnesium double sulfate—$K_2SO_4.2MgSO_4$) (Table 1). The quantity of nutrients (N, P, and K) was based on the physical and chemical soil analyses and according to the recommendations of the Commission of Fertility of the Soils of Minas Gerais (RIBEIRO; GUIMARÃES; ALVAREZ, 1999). A total of 90 kg ha^{-1} of N, 180 kg ha^{-1} of KCL, and 750 kg ha^{-1} of triple superphosphate, with 55% of the nitrogen, were applied, and potassium was added to the soil at the time of planting. The remaining 45% of the nitrogen was applied at the time when the ridging was carried out, 26 DAP.

Table 1. Percentage (%) of potassium fertilizer sources (KCl and $K_2SO_4.2MgSO_4$) used in each treatment, in planting and cover, in potato cv. Asterix.

Treatments	Planting	
	KCl (%)	$K_2SO_4.2MgSO_4$ (%)
1	0	100
2	25	75
3	50	50
4	75	25
5	100	0

The nitrogen sources used were urea (45% N) and ammonium nitrate (35% N). The phosphorus source was triple superphosphate (45% P_2O_5), and the potassium sources were potassium chloride (KCl) (58% K_2O) and K_2SO_4.2 $MgSO_4$ (21% K_2O, 11% Mg, and 22% S). All sources were weighed separately, in proportion for each 6 m line of the plots, using an analytical balance, packed in plastic bags, and homogenized.

The experiment was performed according to the recommendations for potato crops: plowing, dewatering/leveling, and opening of the grooves. The fertilizer distribution in the planting groove was performed manually, and the mechanized distribution of seed potatoes type 3 (tubers 30–40 mm in diameter) was carried out along with the application of protective fungicides and insecticides.

Cover fertilization was also performed manually, and piling was subsequently carried out at 26 DAP. Plants were collected every 15 days after piling during the cycle, with seven collection points at 26, 41, 56, 71, 86, 101, and 116 DAP. For each collection, the sampled plants were stored in plastic bags to be weighed using an analytical balance in the laboratory, to measure the dry matter of the leaves and tubers.

The K and Cl amounts contained in the leaf and tuber samples were determined. The material was washed, and after removing excess water, the samples were placed in paper bags and dried in a stove with forced air circulation. After drying, the samples were processed and subjected to nutrient content analysis, according to Embrapa (2009).

Nutrient accumulation was determined by multiplying the nutrient content (K and Cl) with the dry matter at each stage of plant development. The absorption curve and nutrient accumulation data were plotted once the data were procured for all the stages.

At the end of the cycle at 116 DAP, the tubers from the plants in the two central rows of each plot, at 0.5 m from each end of the plot, were collected manually, classified, and weighed on an electronic scale. The productivity data obtained for the useful areas were extrapolated by estimating the productivity in kilogram per hectare.

Classification was carried out according to the February 23, 1995 Ministerial Order No. 69, by the Ministry of Agriculture, Livestock and Food Supply (MAPA), and the tubers were classified according to their diameter as follows: special (>45 mm), commercial (≥33 mm and <45 mm), and non-standard (<33 mm). The tubers damaged by impact or diseases were separated and constituted the fourth class (discard), and the deformed tubers with physiological anomalies formed the fifth class.

Soluble solid content was determined using the densimeter technique. In this technique, a sample of 3.63 kg of tubers was randomly collected from the tubers harvested in each plot. The material was immersed in a tank with a capacity of 100 L of water and the submerged weight was measured. The specific weight of each sample was calculated and then related to the content of soluble solids, reported as a percentage (GOULD, 1999).

The results were subjected to variance analysis. The productivity and quality of the tubers were compared using Tukey's test at a 5% probability. Data related to biweekly collections were subjected to polynomial regression analysis for the quantitative factors and Tukey's test for the qualitative factors. The statistical program SISVAR (FERREIRA, 2019) was used for all analyses.

RESULTS AND DISCUSSION

There was no correlation between the proportions of potassic fertilizers and the periods evaluated for any of the aerial part variables (accumulation of dry matter, accumulation of potassium, and chlorine) and dry matter of tubers (Table 2).

Table 2. Analysis of variance for the following variables: DMAAP: Dry matter accumulation in potato aerial part; KAPA: Potassium accumulation in potato aerial part; CLAPA: Chlorine accumulation in potato aerial part; DMAT: Dry matter accumulation in potato tubers; KAT: Potassium accumulation in potato tubers; and CLAT: Chlorine accumulation in potato tubers.

	DMAAP	KAPA	CLAPA	DMAT	KAT	CLAT
Treatments	0.038*	0.212 ns	0.005*	0.006*	0.496 ns	0.003*
Time	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
Treatments* Time	0.257ns	0.217 ns	0.006*	0.007*	0.002*	0.000*
CV1	31.90	37.62	46.62	22.89	26.89	28.68
CV2	23.11	27.99	37.65	25.04	28.80	44.69
Average	40.43	1.88	1.52	192.45	4.95	1.28

* Significant at 5% probability by F-test. ns not significant at a 5% probability. CV1, coefficient of variation for the plot; CV2, coefficient of variation for the subplot.

The dry matter of the aerial part increased at 61.8% of the recommended rate of KCl, with a maximum accumulation of 43.6 g plant^{-1}, after which it decreased. These values indicated lower growth, possibly because at higher rates, the chloride interfered with dry matter accumulation (Figure 1A).

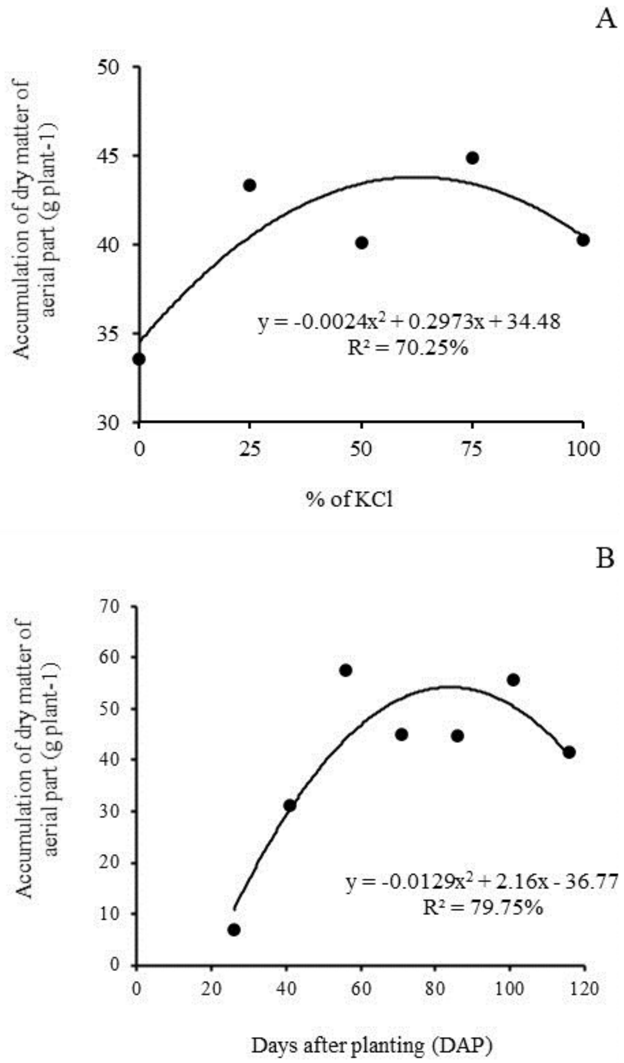

Figure 1. Dry matter accumulation in the aerial part of the potatoes of the Asterix cultivar, plotted with respect to (A) % of K supplied by KCl and supplemented with $K_2SO_4.2MgSO_4$, and (B) days after planting, throughout the growth cycle.

Studies have shown that the chloride contained in fertilizers promotes dry matter reduction, which was corroborated in this study. These disadvantages attributed to chloride are critical in the choice of potassium fertilizer source, especially when the production is on an industrial scale, such as for the Asterix cultivar.

Asterix potato plants accumulated dry matter gradually up to 83.5 DAP, with a maximum accumulation of 53.9 g plant^{-1} (Figure 1B). This is because at the beginning of development, potato plants invest primarily in their vegetative growth, and after full growth, most of the plant energy is diverted to tuber reserves.

According to Fernandes et al. (2010), the accumulation of dry matter can be observed at the beginning of development, when the reserves contained in the seed tubers are transported upward to support the initial establishment of the plants. At the end of the cycle, there was a reduction in the dry matter in the aerial part due to leaf fall during the process of natural senescence of the plants.

There was a significant correlation between the proportions of K fertilizers and the periods evaluated for the dry matter of tubers (Table 2). No polynomial equation fitted the dataset for the tested rates. The mean dry matter accumulation of the tubers ranged from 49 to 62, 11 to 150, 165 to 214, 231 to 278, and 246 to 463 g plant^{-1} at 56, 71, 86, 101, and 116 DAP, respectively (Figure 2; Table 2).

Although the chloride in the potassium fertilizer interfered with the vegetative development of the plant, the same was not observed for the tubers. Cl may indirectly affect plant growth through stomatal regulation, as a mobile counter ion for K^+. Moreover, in the photochemical steps of photosynthesis, compensation by Cl instead of malate plays an important role in the balance of loads within plant cells (KIRKBY; RÖMHELD, 2007).

The toxic effect on the leaves comes from the direct action through metabolic and physiological processes that occur in tissues exposed to light. With respect to translocation and the tubers, the action is diluted, which can be related to the concentration gradient. Therefore, at rates higher than those tested in this study, the result may be more pronounced in demonstrating the toxic effect on aerial parts and tubers.

The accumulation of dry matter in the tubers gradually increased during the cycle at all rates. The maximum accumulation obtained at 116 DAP was 261.99, 314.53, 352.70, 420.41 and 311.68 g plant^{-1} for 0%, 25%, 50%, 75%, and 100%, respectively, of the recommended rate of the KCl source (Figure 2).

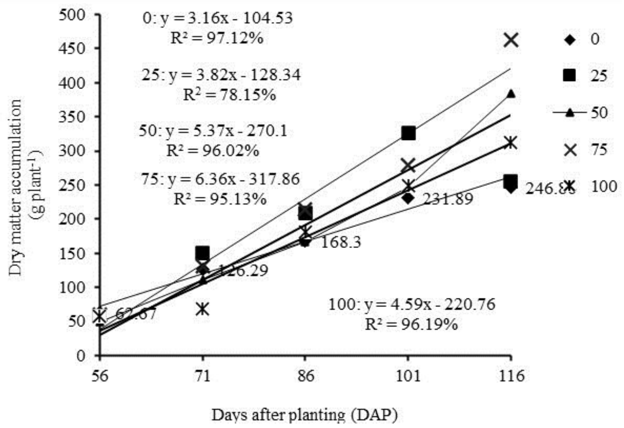

Figure 2. Dry matter accumulation in the potato tubers of the Asterix cultivar throughout the growth cycle.

Tuber accumulation occurs continuously because, after tuberization, the reserve organs become the main drains of plants, with all the photoassimilates gradually being drawn to the tubers (FERNANDES et al., 2010).

The availability of nutrients, such as K, differs with soil type (ZÖRB; SENBAYRAM; PEITER, 2014) and soil dynamics not only with respect to the presence of chloride ions but also the interactions with magnesium cations present in the sulfate source.

Competition between magnesium (Mg^{2+}) and potassium (K^+) occurs during the absorption at the root because these elements use the same absorption sites (VETTERLEIN et al., 2013; SCHNEIDER et al., 2013). A balance between these nutrients can be a viable option for improving the nutrition management of crops (CHOUDHARY; THAKUR; SURI, 2013). The proportion of K in relation to the other cations should be monitored because lower accumulation of one of these elements can cause some interference in the plant metabolism.

However, according to Kirkby and Römheld (2007), chloride is widely distributed in nature and approximately 100–200 mg kg^{-1} is required in some species for optimum growth. Chloride is neither trapped nor adsorbed by the soil particles and is easily absorbed by the root system next to the soil water that accumulates by perspiration. Thus, higher the amount of chloride ions in the solution, greater its translocation and accumulation, as observed in this study.

Crop sensitivity to Cl is quite variable in sensitive species, with some fruits manifesting damages at concentrations above 0.3% of chloride. Tolerant species accumulate up to 4.0 to 5.0% of chloride. According to Gheyi, Dias, and Lacerda (2010), the first symptom of over-accumulation of chloride ions is the burning in the apex leaves, which, in advanced stages, reaches the edges and promotes their premature fall.

Nutrient accumulation in the aerial parts followed a quadratic equation throughout the cycle. There was an increase in absorption, and consequent K and Cl accumulation up to 78.81 and 74.07 DAP, which comprised 2.75 and 1.99 g plant^{-1}, respectively (Figure 3).

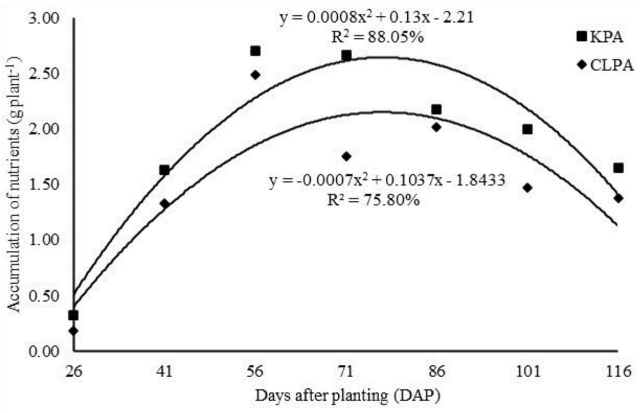

Figure 3. Potassium and chlorine accumulation in aerial parts of the potato plants of the Asterix cultivar throughout the growth cycle.

Fernandes, Soratto, and Silva (2011) obtained the data for K accumulation in tubers adjusted to sigmoid regression models. Nutrient accumulation, according to the authors, occurred from the beginning of tuberization till close to 83 and 90 DAP, with a maximum of 3.64 g plant^{-1} for the Asterix cultivar values similar to those found in the present study.

The K accumulation in tubers increased gradually during the cycle for 0%, 25%, and 100% KCl, which showed maximum accumulations of 9.01, 8.10, and 8.75 g plant^{-1}, respectively, at 116 DAP (Figure 4). At the 50% and 75% rates, the maximum K accumulation (1.84 and 1.59 g plant^{-1}, respectively) occurred at 60.8 and 65.4 DAP (Figure 4).

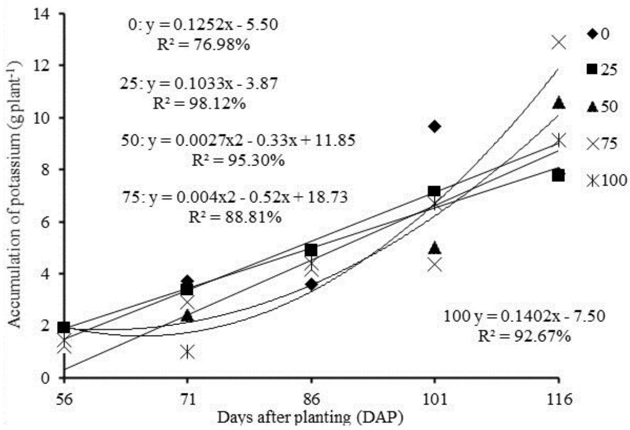

Figure 4. Potassium accumulation in potato tubers of the Asterix cultivar throughout the growth cycle.

The Cl accumulation in Asterix tubers increased throughout the cycle as expected, because the nutrients and other compounds were distributed among the tubers throughout plant development. The maximum accumulations observed were 2.57, 2.39, 3.11, 3.68, and 2.31 g plant^{-1} for the rates of 0%, 25%, 50%, 75%, and 100% KCl, respectively (Figure 5).

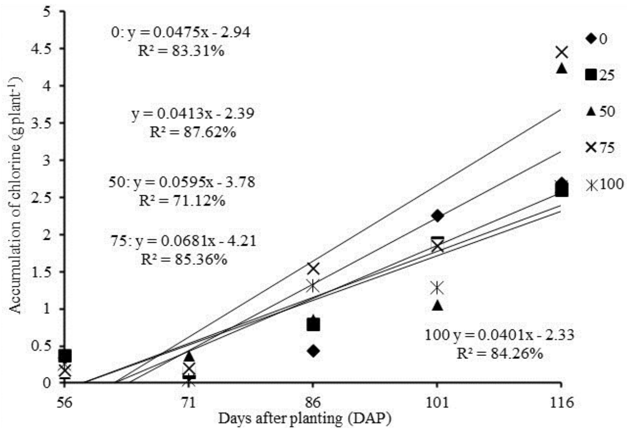

Figure 5. Chlorine accumulation in potato tubers of the Asterix cultivar throughout the growth cycle.

Previous studies have shown that chloride promotes a reduction in dry matter and starch content (BEUKEMA; VAN DER ZAAG, 2021), in addition to affecting the quality of the tubers produced. The choice of this source should be restricted to potatoes produced on an industrial scale, such as Asterix. This study illustrated that an application of 67.2% of the recommended rate of KCl results in a reduction in K accumulation, which is undesirable in tubers, as potatoes are one of the major sources of K in human nutrition.

Productivity and soluble solids

The total tuber yield increased at 64.5% KCl with a yield of 41.3 t ha^{-1} (Figure 6A; Table 3). In general, it was observed that a combination of K sources yielded positive results associated with the beneficial effects of each source.

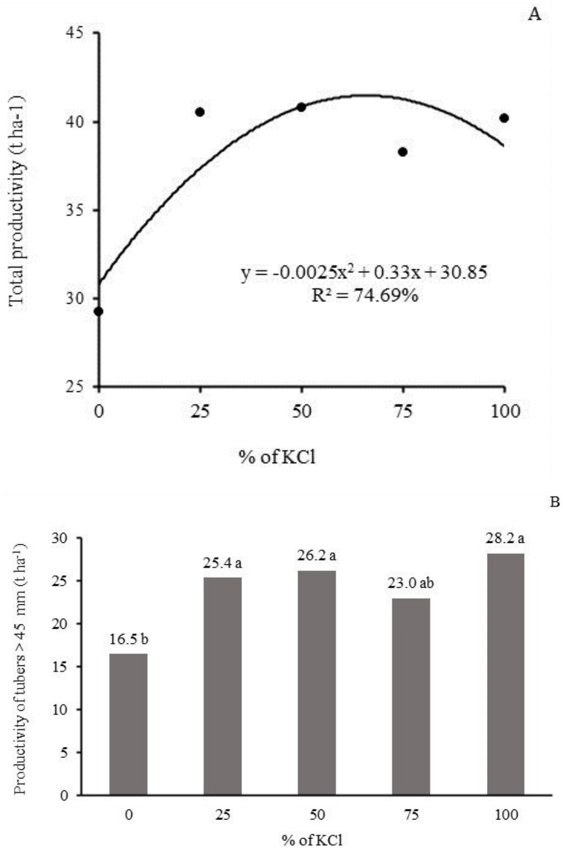

Figure 6. Productivity (t ha^{-1}) of the potato tubers of the Asterix cultivar according to the potassic fertilizer treatments (% of K supplied by KCl, supplemented with $K_2SO_4.2MgSO_4$). (A) Total productivity, and (B) productivity of potatoes with diameter > 45 mm (special).

Table 3. Productivity of potato tubers (t ha^{-1}) total, special (diameter >45 mm), commercial (≥33 mm and <45 mm), non-standard (<33 mm), discard (tubers damaged by impacts or diseases), and solid soluble (%).

	Total	Special	Commercial	Discard	Non-standard	Solid soluble
Treatments	0.019*	0.004*	0.228 ^{ns}	0.875 ^{ns}	0.193 ^{ns}	0.115 ^{ns}
CV	12.19	14.77	17.17	55.26	37.93	11.05
Average	37.81	23.90	12.59	0.81	0.51	19.3

*Significant at 5% probability by F-test. ^{ns}, not significant at a 5% probability. CV, coefficient of variation.

The tuber yield with a diameter greater than 45 mm (special) was lower under sulfate form (0% KCl). The other rates did not differ significantly (Figure 6B). Considering that larger tubers have higher commercial value and the sulfate source has a higher cost, the combination of sources is an alternative to be considered by farmers.

Productivity of tubers with a diameter greater than 36 mm (commercial), less than 36 mm (non-standard), and of the discard class did not differ for different potassium fertilizer rates (% KCl and $K_2SO_4.2MgSO_4$), and ranged from 11.2 to 13.8, 0.3 to 1, and 0.5 to 0.9 t ha^{-1}, respectively (Table 3).

Fernandes et al. (2010) obtained a total productivity of 40.0 t ha^{-1} for the Asterix cultivar, which is within the range found in this study. Luz et al. (2020) used potassium chloride fertilization of potatoes in Atlantic and Ágata cultivars and obtained a productivity of 32.3–37 t ha^{-1} for the Atlantic cultivar cultivated in Unaí, which did not respond to the increase in potassium fertilizer dose. In soils with high levels of K, such as in the present study, the influence of the sources on productivity occurs through an increase in the dynamics between the ions in the soil solution, which correlates to combinations and rates of sources, which alleviates the negative effects on productivity.

Mallmann, Lucchesi, and Deschamps (2011) analyzed N, P, and K fertilization in the Monalisa cultivar and observed that in the case of potassium fertilizers, rates above 400 kg ha^{-1} KCl resulted in a productivity reduction, which may be due to an excessive amount of Cl, which impairs plant development. In treatments with sulfate application, the authors observed a positive effect with rates as high as 500 kg ha^{-1} of sulfate, indicating a favorable response to the absence of Cl and the presence of S.

Sulfate uptake and integration into cysteine and methionine are the core processes that direct the oxidized and reduced forms of organically bound S to their various functions, such as electron transport, structure, and regulation (CAPALDI et al, 2015). Therefore, application of K in the form of sulfates, under some conditions and for some cultivars, may be potential alternatives for nutritional management.

Luz et al. (2020) did not observe an increase in total productivity with an increase in potassium chloride fertilization. Instead there was reduction in productivity, possibly because of excess chlorine. It is worth remembering that deleterious effects occur when the levels of chloride absorbed by plants exceed their tolerance capacity.

The soluble solids content ranged from 19.1 to 19.5% among potassic fertilizer combinations, with no differences between treatments (Figure 7).

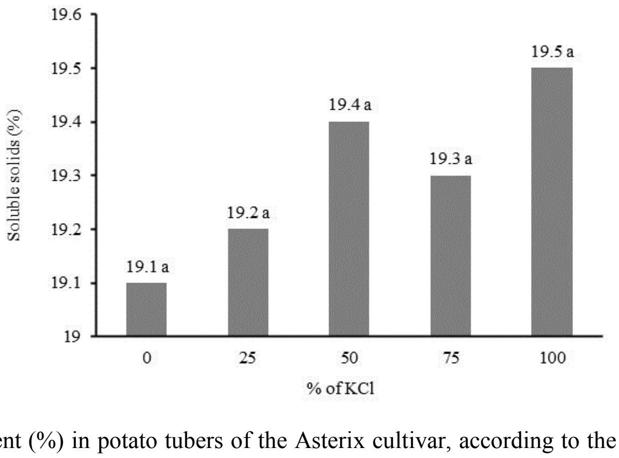

Figure 7. Soluble solids content (%) in potato tubers of the Asterix cultivar, according to the potassic fertilizer treatments (% of K supplied by KCl, supplemented with $K_2SO_4.2MgSO_4$).

Bansal and Trehan (2011) observed improved quality in tubers fertilized with potassium sulfate (reduction in reducing sugars in the tubers of four cultivars before and after storage at 10 °C). However, there is no evidence that sulfate is better than chloride, since factors such as K of the site soil, climatic conditions, and type of cultivar influence the nutrient uptake dynamics (SILVA; FONTES, 2016).

CONCLUSIONS

The presence of chloride in potassium fertilizers above 61.8% of the recommended dose affects potato plant growth, and a combination of 64.5% KCl and 36.5% $K_2SO_4.2MgSO_4$ provides the maximum total yield.

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