horticultura brasileira

Research

SORATTO, RP; YAGI, R; JOB, ALG; FERNANDES, AM. 2021. Fertilization management strategies for 'Agata' potato production. *Horticultura Brasileira* 39: 389-396. DOI: http://dx.doi.org/10.1590/s0102-0536-20210407

Fertilization management strategies for 'Agata' potato production

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ABSTRACT

Fluctuations in potato prices and invariably rising production costs need sustainable fertilization strategies. For this purpose, two experiments were conducted in the southwestern region of São Paulo state to evaluate fertilization management strategies for the 'Agata' potato cultivar. The treatments consisted of the producer's standard fertilization (1700 kg ha^{-1} NPK 4-30-10 at planting + 100 kg ha^{-1} urea and 150 kg ha^{-1} KCl at hilling) and combinations of two P rates at planting (standard rate and half of the rate), as monoammonium phosphate (MAP) with two forms of KCl application (total rate in the post-planting phase or half of the rate in the post-planting phase and half at hilling). The application of half the P rate (255 kg ha^{-1} P_2O_5) as the MAP at planting and the transfer of K from planting to applications in the post-planting phase or in the post-planting phase and at hilling, despite having provided a lower leaf P concentration, maintained the total tuber yield with higher operational yield of planting fertilization. It also increased the yield of tubers with a diameter >4.5 cm under conditions of lower water availability in the vegetative stages of the crop and soil with medium availability of P and K. Such a fertilization strategy is valuable for cost reductions and possible environmental liabilities.

Keywords: *Solanum tuberosum*, monoammonium phosphate, mineral nutrition, tuber yield, tuber dry matter.

RESUMO

Estratégias de manejo da adubação na produção de batata 'Agata'

Oscilações dos preços da batata e custos de produção invariavelmente crescentes demandam estratégias de adubação sustentáveis. Com esse objetivo, foram conduzidos dois experimentos no sudoeste do estado de São Paulo para avaliar estratégias de manejo da adubação na batata 'Agata'. Os tratamentos consistiram da adubação padrão do produtor (1700 kg ha^{-1} de NPK 4-30-10 no plantio + 100 kg ha^{-1} de ureia e 150 kg ha^{-1} de KCl na amontoa) e das combinações de duas doses de P no plantio (dose padrão e metade da dose), na forma de monoamônio fosfato (MAP), com duas formas de aplicação de KCl (dose total em pós-plantio ou metade da dose em pós-plantio e metade na amontoa). A aplicação de metade da dose de P (255 kg ha^{-1} de P_2O_5) como monoamônio fosfato (MAP) no plantio e a transferência do K do plantio para aplicações em pós-plantio ou em pós-plantio e amontoa, apesar de ter proporcionado menor teor de P nas folhas, manteve a produtividade total de tubérculos com maior rendimento operacional na adubação de plantio. Aumentou também a produtividade de tubérculos da classe especial em condições de menor disponibilidade hídrica nos estádios vegetativos da cultura e solo com disponibilidade média de P e K. Tal estratégia de adubação é válida para reduções de custos e de eventuais passivos ambientais.

Palavras-chave: *Solanum tuberosum*, monoamônio fosfato, nutrição mineral, produtividade de tubérculos, matéria seca de tubérculos.

Received on February 9, 2021; accepted on July 29, 2021

High rates of fertilizers, especially those containing phosphorus (P) and potassium (K), have been commonly used in potato (*Solanum tuberosum*) planting furrows in Brazil (Fernandes & Soratto, 2016a; Job *et al.*, 2019; Yagi *et al.*, 2019). These have been used supposedly to supply these nutrients and avoid yield and profitability losses, due to the high investment required by the crop. However, fertilizer costs in the potato crop have been above R$ 5,000.00 ha^{-1}, which is equivalent to 14 to 20% of the total production cost (Deleo & Boteon, 2020). High rates of nutrients per unit area associated with less concentrated formulas also decrease the operational yield of fertilizer application, due to the need for a greater number of stops for refilling the fertilizer applicator.

Phosphorus is taken up in relatively small amounts (32-41 kg ha^{-1} P_2O_5) by potato crops (Fernandes *et al.*, 2011) and, despite the occurrence of response to high rates of P fertilizer in soils with low P availability (Fernandes & Soratto, 2016a, 2016b), high P rates are not necessary in soils with medium or high P availability (Fernandes & Soratto, 2016a). The potato uptake is approximately 80% of its P requirement during the tuber bulking stage (Fernandes *et al.*, 2011). However, it is recommended to apply a high rate of P in the planting furrows, owing to the low P mobility in the soil and its importance to the initial plant growth (Lorenzi *et al.*, 1997; Fernandes *et al.*, 2014; Fernandes & Soratto, 2016a, 2016b).

In relation to K, although the potato crop takes up the nutrient in greater amounts and responds to high K rates (Fernandes *et al.*, 2011; Job *et al.*, 2019), the K uptake occurs more intensely between 41 and 61 days after planting (DAP). Further, for the cultivar Agata, the most planted cultivar in Brazil for the fresh market, only 24% of the total K requirement is taken up until the initial stage of tuberization (Fernandes *et al.*, 2011). Potassium chloride (KCl) is the mineral source of K, most commonly used in agriculture and in Brazilian potato production. Nevertheless, high rates of KCl applied in the planting furrow are potentially harmful to the potato crop because they can increase the electrical conductivity of the soil (Reis Junior *et al.*, 1999).

Further, the chlorine (Cl) uptake by plants (Pauletti & Menarim, 2004) also reduces the uptake of some nutrients, such as P (Berger *et al.*, 1961), calcium (Ca), and magnesium (Mg) (Job *et al.*, 2019), in addition to reducing the yield and the percentage of dry matter (DM) in the tubers (Pauletti & Menarim, 2004). Thus, the splitting of KCl fertilization between planting and sidedressing, together with nitrogen (N) fertilization, has been suggested to increase tuber yield in relation to N and K applications only in the planting furrow (Cardoso *et al.*, 2007; Yagi *et al.*, 2020). However, in clayey soils, the splitting of K fertilization did not affect the marketable and total tuber yield of cultivar Agata, regardless of the exchangeable K concentration in the soil (Job *et al.*, 2019).

According to Job *et al.* (2019), in soils with low K concentrations, there may not be enough time for adequate K nutrition of 'Agata' plants with the split application of KCl in planting and sidedressing. This may be related to the low diffusion of the element against a weak gradient of concentration in the soil generated by the limited root system of potato plants (Trehan & Claassen, 1998). Thus, the application of KCl before planting or shortly after planting, removing it from the planting furrow, is another strategy that could increase the P uptake by plants, as it avoids their antagonistic interaction with chloride anions, increasing the tuber yield (Berger *et al.*, 1961; Pauletti & Menarim, 2004).

In order to reduce the rates of N and K, while maintaining the P rates in the planting furrow, and aiming to decrease production costs and increase the yield and profitability of the potato crop, fertilization strategies based on the use of more concentrated formulas (Yagi *et al.*, 2019), associated with the application of N and K at sidedressing (Yagi *et al.*, 2020), have also been studied. The exclusive use of monoammonium phosphate (MAP) at planting, as a source of more soluble P for potato plants, transferring the application of KCl to applications in the post-planting phase and/or in sidedressing together with N fertilization, can also favor plant nutrition, increase yield, and improve the quality of 'Agata' potato tubers.

The objective of this study was to evaluate the effect of fertilization management strategies, by applying MAP levels exclusively, as well as removing K from the planting furrow, and applying it at broadcast shortly after planting (post-planting) or splitting it between post-planting and hilling, in the nutrition and yield of 'Agata' potato tubers and in the operational yield of fertilizer application at planting.

MATERIAL AND METHODS

Two experiments were carried out on potato-producing farms in the São Paulo State, Brazil, one in Bernardino de Campos (23°01'S; 49°28'W; altitude 695 m) in the year 2013 and the other in Itaí (23°32'S; 49°02'W; altitude 661 m) in the year 2014. These two locations are about 60 km apart from each other in a Cwa climate (tropical with dry winter and hot and rainy summer). Rainfall and air temperature were measured during the experimental periods at nearby climatological stations. The total rainfall during the potato growing seasons was 202 mm in Bernardino de Campos-2013 (BC-2013) and 349 mm in Itaí-2014, while the total irrigation volumes were 136 and 92 mm, respectively. Average air temperatures during growing seasons were 17.1°C in BC-2013 and 16.8°C in Itaí-2014.

The soils of the experimental areas, classified as Oxisols with clayey texture, were sampled (0-20 cm depth) for chemical and textural analyses. In BC-2013 and Itaí-2014, the results of chemical and textural analyzes of soils were, respectively: pH($CaCl_2$) 5.0 and 4.8, 27 and 28 mg dm^{-3} P-resin, 35 and 32 g dm^{-3} organic matter, 35 and 36 $mmol_c$ dm^{-3} Ca^{2+}, 20 and 8 $mmol_c$ dm^{-3} Mg^{2+}, 1.6 and 1.6 $mmol_c$ dm^{-3} K^+, 114 and 93 $mmol_c$ dm^{-3} cation exchange capacity, 49 and 50% base saturation, 449 and 527 g kg^{-1} clay, and 406 and 291 g kg^{-1} sand. Both soils showed medium concentrations of P and K for potato cultivation (Lorenzi *et al.*, 1997).

In both site-years, the experimental design used was randomized blocks with five treatments and four replications. The treatments consisted of the standard fertilizer used by the potato producer, with 1700 kg ha^{-1} of formula NPK 4-30-10+Ca+S at planting plus 100 kg ha^{-1} urea and 150 kg ha^{-1} KCl in sidedressing immediately before hilling, in addition to four other treatments (Table 1). The treatments that were compared with the potato producer standard fertilization were formed by combining two rates of MAP+Ca+S (1275 and 638 kg ha^{-1}) with two forms of applying a rate of 430 kg ha^{-1} KCl, i.e., the total rate broadcast applied in the post-planting phase or half of the rate broadcast applied in the post-planting phase and half in the sidedressing immediately before hilling. Thus, as the standard treatment of the producer (T1), all other treatments received 45 kg ha^{-1} N (urea; 45% N) in sidedressing before the hilling and all treatments with MAP+Ca+S rates and KCl splitting also received phosphogypsum (15% S and 20% Ca) in the post-planting phase, in order to equalize the amounts of applied S.

In both the experiments, the soil was tilled with two heavy disk harrowing operations, chiseling, and light harrowing, which occurred on the day prior to planting. The furrows were mechanically opened using a furrower-planter, and the spacing between the furrows was 0.80 m. The plots comprised five 5-m long rows with 0.80-m row spacing. Planting fertilizers were applied manually in the furrows, according to the respective treatments, and lightly incorporated into the soil with a hoe simulating the potato planters used by producers.

Table 1. Description and nutrient amounts in the fertilization treatments. Botucatu, UNESP, 2013-2014.

Treatment	Application time(1)	Sources	Rate (kg ha^{-1})					
			Sources	N	P_2O_5	K_2O	Ca	S
T1	Planting	4-30-10, 8.3% Ca, 4% S	1700	68	510	170	141	68
	Hilling	KCl	150	0	0	90	0	0
	Hilling	Urea	100	45	0	0	0	0
			Total	**112**	**510**	**260**	**141**	**68**
T2	Planting	MAP (07-40-00, 5.5% Ca, 3% S)	1275	89	510	0	70	38
	Post-planting	KCl	430	0	0	258	0	0
	Post-planting	Phosphogypsum	200	0	0	0	40	30
	Hilling	Urea	100	45	0	0	0	0
			Total	**134**	**510**	**258**	**110**	**68**
T3	Planting	MAP (07-40-00, 5.5% Ca, 3% S)	1275	89	510	0	70	38
	Post-planting	KCl	280	0	0	168	0	0
	Post-planting	Phosphogypsum	200	0	0	0	40	30
	Hilling	KCl	150	0	0	90	0	0
	Hilling	Urea	100	45	0	0	0	0
			Total	**134**	**510**	**258**	**110**	**68**
T4	Planting	MAP (07-40-00, 5.5% Ca, 3% S)	638	45	255	0	35	19
	Post-planting	KCl	430	0	0	258	0	0
	Post-planting	Phosphogypsum	333	0	0	0	67	50
	Hilling	Ureia	100	45	0	0	0	0
			Total	**90**	**255**	**258**	**102**	**68**
T5	Planting	MAP (07-40-00, 5.5% Ca, 3% S)	638	45	255	0	35	19
	Post-planting	KCl	280	0	0	168	0	0
	Post-planting	Phosphogypsum	333	0	0	0	67	50
	Hilling	KCl	150	0	0	90	0	0
	Hilling	Ureia	100	45	0	0	0	0
			Total	**90**	**255**	**258**	**102**	**68**

(1) Planting, planting furrow; Post-planting, broadcasted after planting; Hilling, sidedressed immediately before hilling.

Following this, seed tubers-type III (diameter between 30 to 40 mm) of the cultivar Agata were distributed every 0.30 m in the planting furrow on 04/25/2013 and 04/18/2014 in Bernardino de Campos and Itaí, respectively. Subsequently, the agrochemicals thiamethoxam (155 g a.i. ha^{-1}), metiram (220 g a.i. ha^{-1}), pyraclostrobin (22 g a.i. ha^{-1}), boscalid (112.5 g a.i. ha^{-1}), and streptomycin (17 g a.i. ha^{-1}) were applied to the seed tubers. The furrows were then closed and the respective treatments with K fertilization were applied post-planting (Table 1). In both site-years, 1.7 kg ha^{-1} B (boric acid) was applied at 7 DAP by center pivot irrigation.

Crop management was carried out in accordance with regional practices employed by potato producers, including sprinkler irrigation, pest and disease control with phytosanitary products registered for the crop. At 22 and 26 DAP, respectively, in BC-2013 and Itaí-2014, 45 kg ha^{-1} N was applied in the form of urea accompanied by the respective treatments with K fertilization in sidedressing (Table 1). Immediately after this, the hilling was carried out.

Diagnostic leaves were sampled at 50 and 49 DAP, respectively, in BC-2013 and Itaí-2014. The third fully expanded leaf was collected from the apex of the plants in 12 plants per plot, that were selected randomly. The leaves were washed with deionized water, dried in an oven with forced air circulation at 65°C for 72 h, ground, and chemically analyzed to determine the macronutrient concentrations (Malavolta *et al.*, 1997).

In BC-2013, potato plants were desiccated and harvested at 93 and 117 DAP, respectively, and in Itaí-2014, they were desiccated and harvested at 106 and 115 DAP, respectively. In the harvests, the tubers of two 1.5-m long rows (10 plants) of the useful area of each plot were collected, counted, and weighed. These tubers were separated into two classes of tubers (with a diameter greater than 4.5 cm, classified as special class, and with a diameter less than 4.5 cm), which were also counted and weighed. The proportion of tuber yield in the special class was also calculated. A sample of tubers from each treatment was collected randomly, weighed, sliced, and dried in an oven with forced air circulation at 65°C for 96 h to estimate the percentage of DM in the tubers.

The obtained results were subjected to analysis of variance by the F test, using a grouped analysis of experiments. The means were compared using the least significant differences (LSD) test at 5% probability. In addition, technical information on the farmer's fertilizer applicator (four-row Hennipman model WH-B with, Agro Industrial Hennipman Ltda., Castro-PR, Brazil), area fertilized with each fertilizer refilling, and fertilizer refilling time were collected. Simple calculations were performed in order to compare the operational yield of fertilizer application at planting in each fertilization management.

RESULTS AND DISCUSSION

There was a significant interaction between fertilization management and site-years for P concentration in the leaves (Table 2). Only the T5 treatment (255 kg ha^{-1} P_2O_5 in the MAP form at planting and KCl split between post-planting and hilling) showed values 12.2% lower than that of the T1 treatment (510 kg ha^{-1} P_2O_5 as NPK 4-30-10 at planting plus N and K complementation at hilling) in BC-2013 (Figure 1). In Itaí-2014, application of the highest MAP rate at planting combined with KCl in the post-planting phase (T2) showed a higher leaf P concentration than that of all other treatments, especially those with a reduced rate of P at planting (T4 and T5). MAP stands out in relation to other simple phosphate fertilizers due to its greater solubility in water (Raij, 1997; Nascimento *et al.*, 2018). In the soil, MAP granules are invaded by water flow by capillarity, quickly forming several soluble forms of ammonium phosphate that are expelled to their exterior (Fixen & Bruulsema, 2014). Even though the nitrification of the dissociated ammonium can acidify the medium, favor the P fixation in the clays, and restrict the P mobility around the MAP granules, it is still more labile than the P from the dissolution of the triple superphosphate (Nascimento *et al.*, 2018). Thus, in more clayey soils, application of MAP results in P concentrations similar or higher than other simple phosphate fertilizers (Oliveira *et al.*, 2017). Compared to treatment with the NPK formula at planting (T1), the greater N input (21 kg ha^{-1} N more) in the higher MAP rates (T2 and T3) may also have favored the P uptake by plants, since potato plants show greater P use efficiency with the application of a higher N rate (Hailu *et al.*, 2017).

In treatments with the highest P rate (T1, T2, and T3), leaf P concentrations were higher in Itaí-2014 than in BC-2013 (Figure 1). From planting to the time when the diagnostic leaves were sampled, rainfall and irrigation volumes recorded were 71% higher (130 mm) in Itaí-2014 than in BC-2013, which possibly favored the greater P uptake in the treatments with greater nutrient supply. According to Sun *et al.* (2015), greater water availability increases the P concentrations in the potato leaves, regardless of the application of P fertilizers. However, in none of the treatments, the leaf P concentration was below the range (2.5 to 5.0 g kg^{-1} P) considered suitable for a potato crop (Lorenzi *et al.*, 1997), or below the minimum limit (2.9 g kg^{-1} P) suggested for the cultivar Agata by Fernandes & Soratto (2016b).

There was only an effect of fertilizer management on leaf Ca concentrations (Table 2). Leaf Ca concentration in the T2 treatment was, on average, 18.1% lower than that in treatments with the lowest P rate (T4 and T5), even lower than the sufficiency range of 10 to 20 g Ca kg^{-1} (Lorenzi *et al.*, 1997). On the other hand, there was no difference in the leaf Ca concentrations between treatments with the highest P rate, regardless of the source used. In lightly acidic soils, phosphate anions from MAP can form phosphate minerals with Fe and Al or precipitate with Ca (Fixen & Bruulsema, 2014), while the complexation of Al^{3+}, concomitantly with the formation of Ca phosphates, may have been favored by the application of phosphogypsum in plots with MAP to equalize the amounts

Table 2. Leaf concentrations of macronutrients (N, P, K, Ca, Mg, and S) of potato cultivar Agata as affected by fertilization management (FM) in two site-years (SY) and analyses of variance. Botucatu, UNESP, 2013-2014.

Fertilization management (FM[1])	Leaf concentration (g kg^{-1})					
	N	P	K	Ca	Mg	S
T1	49.9	4.2	42.0	10.1ab	3.6	2.7
T2	50.1	4.7	37.9	9.3b	3.2	2.9
T3	50.3	4.3	38.3	10.1ab	3.7	2.8
T4	49.5	3.4	38.7	11.3a	3.8	2.8
T5	46.4	3.3	44.3	11.4a	4.0	2.7
Site-year (SY)						
BC-2013	47.7	3.7	43.7	10.5	3.4b	2.8
Itaí-2014	50.8	4.2	36.8	10.4	3.9a	2.7
Source of variation	ANOVA (P>F)					
FM	0.428	0.317	0.697	0.046	0.093	0.340
SY	0.074	0.283	0.101	0.696	0.021	0.101
FM × SY	0.706	<0.001	0.133	0.743	0.579	0.806
CV(%)	10.1	7.2	17.6	13.2	13.0	11.9

[(1)]Description of fertilization treatments is shown in Table 1. [(2)]Values within a column for a particular factor (fertilization or site-year) followed by different letters are significantly different at p≤0.05 according to LSD test. BC-2013 = Planting in Bernardino de Campos-SP in 2013; Itaí-2014 = Planting in Itaí in 2014.

of S supplied by NPK fertilizer (Table 1). When phosphate fertilizer is applied, the P mobility around the granule is restricted because cations such as Ca, for example, move into the granule by mass flow, forming dihydrated calcium phosphates (Nascimento *et al.*, 2018). Additionally, these lower leaf Ca concentrations may also have been affected by the massive supply of K in the treatment with full application in the post-planting phase (T2), since the supply of this nutrient in planting is also antagonistic to the Ca uptake, decreasing its concentration in the diagnostic leaves of the cultivar Agata (Job *et al.*, 2019).

Leaf Mg concentrations were affected only by the site-year, and in Itaí-2014, the values were 14.5% higher than those in BC-2013 (Table 2), consistent with the Mg concentration in the soils of the evaluated site-years. Concentrations of N, K, and S in the leaves were not affected by treatments or site-years (Table 2), which indicates that the K removal from the planting furrow did not negatively affect the K nutrition of the plants. In all treatments, the concentrations of N, Mg, and S in the leaves were within the ranges considered suitable for the crop (Lorenzi *et al.*, 1997), while the leaf K concentrations in some treatments were slightly below the critical limit; however, the difference was not significant.

The average number of tubers per plant and the total tuber yield were affected only by the site-year (Table 3). Water restrictions in the first 30 DAP of the ‘Agata’ potato are crucial in defining crop yields, causing decreases in the number of stems per plant, total shoot DM of the plants, and in the tuber number and yield (Jadoski *et al.*, 2017). In this study, the water volumes of rain and irrigation during the first 30 DAP of the potato crop grown in Itaí-2014 were 113.8% (82 mm) higher than that in BC-2013. This higher water availability in Itaí-2014 was possibly responsible for the number of tubers per plant and total

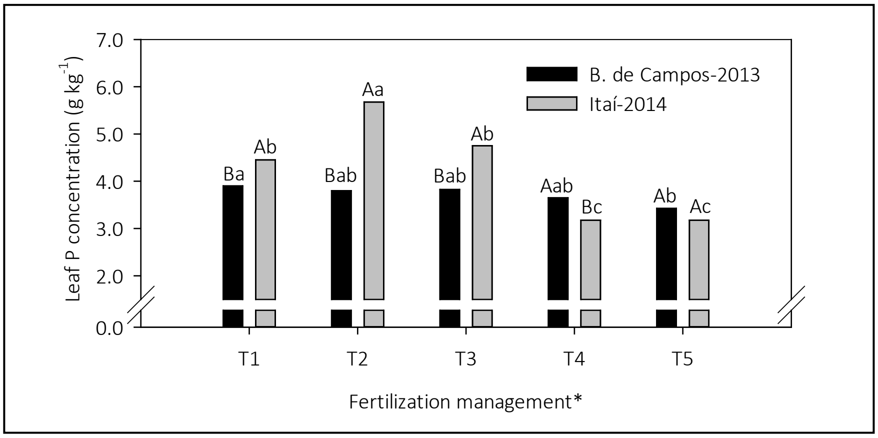

Figure 1. Leaf phosphorus concentracion of potato cultivar Agata as affected by fertilization management in two site-years. *Description of fertilization managements is shown in Table 1. Different lowercase letters indicate a significant difference among fertilization managements in the same site-year, whereas different uppercase letters indicate a significant difference among site-year in the same fertilization management, at p≤0.05 according to LSD test. Botucatu, UNESP, 2013-2014.

Table 3. Number of tubers per plant, tuber mean weight, tuber yield [total and special (>4.5cm)], proportion of tuber yield >4.5 cm, and percentage of dry matter (DM) in the tubers of potato cultivar Agata as affected by fertilization management (FM) in two site-years (SY) and analyses of variance. Botucatu, UNESP, 2013-2014.

Fertilization management (FM[1])	Tuber number per plant (no. plant^{-1})	Tuber mean weight (g)	Tuber yield (t ha^{-1})		Proportion of tuber yield >4.5 cm (%)	Tuber DM (%)
			Total	>4.5cm		
T1	12.4	79.4	40.8	28.8	69.7	14.1
T2	12.0	81.3	40.3	30.1	74.5	14.9
T3	12.1	76.8	38.8	29.2	75.2	15.0
T4	11.9	76.7	37.8	28.1	73.7	14.4
T5	12.5	76.8	39.2	29.6	76.0	14.6
Site-year (SY)						
BC-2013	9.8b	79.0	32.2b	23.5b	73.2	14.9
Itaí-2014	14.5a	77.3	46.6a	34.7a	74.4	14.8
Source of variation			ANOVA (P>F)			
FM	0.522	0.445	0.523	0.947	0.698	0.202
SY	<0.001	0.385	<0.001	0.003	0.702	0.752
FM × SY	0.821	0.802	0.310	0.057	0.010	0.534
CV(%)	9.6	10.4	7.8	10.8	5.9	6.6

[(1)]Description of fertilization managements is shown in the Table 1. [(2)]Values within a column for a particular factor (fertilization or site-year) followed by different letters are significantly different at p≤0.05 according to LSD test. BC-2013 = Planting in Bernardino de Campos-SP in 2013; Itaí-2014 = Planting in Itaí in 2014.

tuber yield, with values of 46.8% and 45.0%, respectively, which were higher than that in BC-2013 (Table 3).

There was no effect of the studied factors on tuber mean weight (Table 3). However, there was an interaction between fertilizer management and site-year on the tuber yield of the special class (diameter >4.5 cm), as well as on the proportion of tuber yield contained in that class. In BC-2013, T5 treatment resulted in tuber yield of the special class 27.1% (5.8 t ha^{-1}) higher than that of the T1 treatment (Figure 2A), due to the higher proportion of special size tubers (Figure 2B), as no differences were observed in the total tuber yield (Table 3). On the other hand, in Itaí-2014 there was no difference between treatments for tuber yield and proportion of tubers in the special class (Figure 2). Only in the T5 treatment, there was no difference in the tuber yield of the special class between site-years, due to the high proportion of tubers of special size obtained in BC-2013. However, in the other treatments, tuber yield of the special class in Itaí-2014 was, on average, 56.4% (12.8 t ha^{-1}) higher than in BC-2013 (Figure 2A). Only in the T1 treatment, the percentage of tubers of the special class in BC-2013 was lower than in Itaí-2014 (Figure 2B).

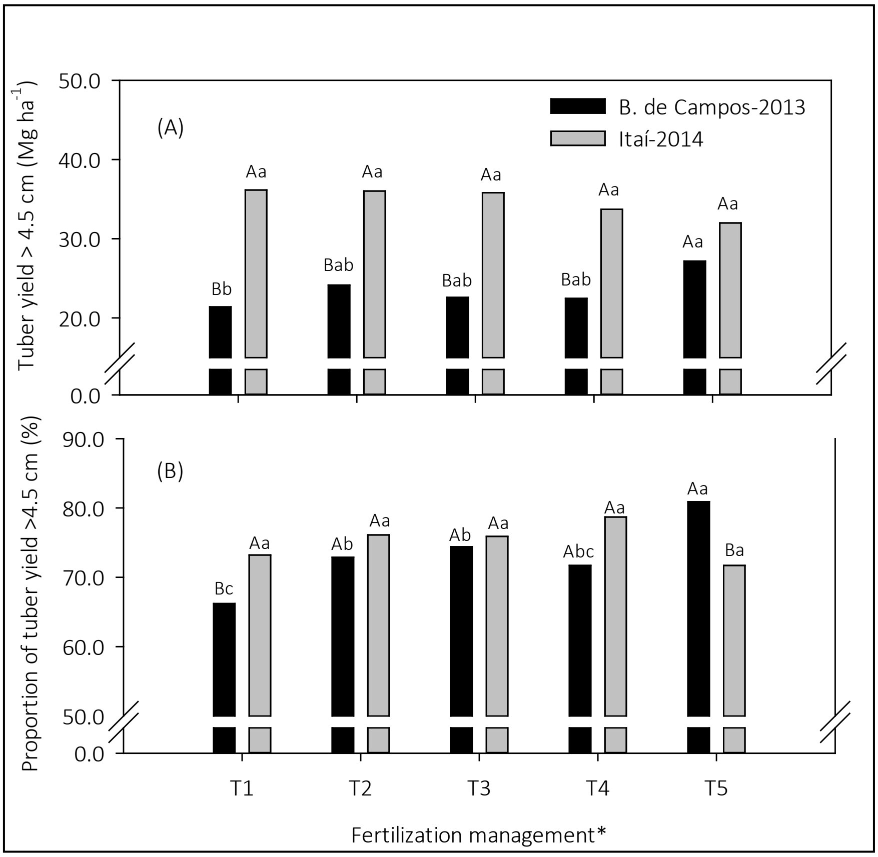

Figure 2. Yield of tubers >4.5 cm (A) and proportion of tuber yield >4.5 cm (B) of potato cultivar Agata as affected by fertilization management in two site-years. *Description of fertilization treatments is shown in Table 1. Different lowercase letters indicate a significant difference among fertilization managements in the same site-year, whereas different uppercase letters indicate a significant difference among site-year in the same fertilization management, at p≤0.05 according to LSD test. Botucatu, UNESP, 2013-2014.

The results indicate that the exclusive use of MAP and the total removal of K fertilizer (KCl) from the potato planting furrow presents itself as a management alternative, with maintenance of tuber yield of the cultivar Agata even in soil with medium K concentration, corroborating the results obtained by Panique *et al.* (1997). Evaluating the sources and rates of K in the planting furrow with a fixed rate of MAP, they observed that K fertilization increased the total tuber yield only in 5 out of 11 evaluated site-years, which was attributed particularly to water limitations and high K concentrations in the studied soils. In addition, the results obtained with half P rate as MAP confirm the inefficiency of applying more than 250 kg ha^{-1} P_2O_5 during planting of 'Agata' potato grown in soil with medium P concentration (Fernandes & Soratto, 2016a). Yagi *et al.* (2017) found that, in soil with high concentrations of P and K, the replacement of 420 kg ha^{-1} P_2O_5 using the formula NPK 4-14-8 with MAP fertilizer did not alter the marketable tuber yield; however, in soil with low P and medium K concentrations, there was a reduction of 6.6 t ha^{-1} (18.5%) in the tuber yield of the special class. Lower rates of P and N at planting furrow and the redirection of K from planting to post-planting and sidedressing showed greater yield of larger tubers in the year with less water availability in the initial stage of crop development (Figure 2). This can be explained by the lower saline effect of MAP at planting due to its greater solubility (Raij, 1997; Nascimento *et al.*, 2018), associated with the decrease in N supply and the absence of KCl in the planting furrow.

In the same condition of the BC-2013 experiment (adjacent area), Job *et al.* (2019) did not find an effect of the split application of K in the planting furrow and in the sidedressing for tuber yield of the special class of 'Agata' potato compared to the application of the same K rate totally in the planting furrow. This was attributed to the slow diffusion of K in the soil after application before hilling and to the nutritional imbalance observed in the concentrations of K, Ca, and Mg in the leaves. Thus, with the K application in the post-planting phase, there was possibly enough time for its uptake before the maximum demand period, which is from 45 to 56 DAP (Fernandes *et al.*, 2011), as evidenced by the absence of differences between leaf K concentrations in the treatments (Table 2). Thus, under these conditions of lower water availability, the split application of K possibly favored its adequate function in the translocation of carbohydrates to the tubers (Westermann, 2005), providing larger and heavier tubers (Karam *et al.*, 2009), and increasing the tuber yield of the special class (Figure 2A).

Table 4. Fertilizer rate, information on the fertilizer application capacity and operation, and estimated operational yield of fertilizer application at potato planting according to fertilization management. Botucatu, UNESP, 2013-2014.

Information	Treatments grouped by planting fertilization		
	T1[(1)]	T2 and T3	T4 and T5
Fertilizer rate (kg ha^{-1})	1700	1275	638
Fertilizer applicator capacity (kg)	2000	2000	2000
Working speed of fertilizer applicator (km h^{-1})	10	10	10
Area fertilized with each fertilizer refilling (ha)	1.18	1.57	3.13
Fertilizer refilling time (min)	5.8	5.8	5.8
Fertilizer refilling time per working hour (min)	15.7	11.8	5.9
Area fertilized per working hour (ha)	2.36	2.57	2.88
Relative operational yield (%)	100	109	122

[(1)]Description of fertilization managements is shown in Table 1.

Considering only planting fertilization, the non-application of K fertilizer, due to the use of MAP (formula more concentrated in P), increased the operational yield by 9%, compared to standard NPK fertilization (Table 4). The reduction in the P rate also increased the efficiency of the fertilizer application capacity in the planting furrow. This is due to the need for less downtime for refilling the fertilizer applicator when lower rates of fertilizer are used per area. It is important that the exclusive use of formula with only N and P at planting, such as MAP, may require complementary fertilization to supply other nutrients, such as Ca and S.

The studied factors did not affect the percentage of DM in the tubers, which was on average 14.8% (Table 3). Fernandes *et al.* (2015) also found no changes in the percentage of DM in the tubers of the cultivar Agata as a function of the rates of P applied in soil with medium nutrient concentration, even with a marked response in the tuber yield. Job *et al.* (2019) did not verify the effect of splitting K fertilization on the specific gravity of the ‘Agata’ potato.

The phosphate nutrition of potato cultivar Agata was favored by the exclusive use of MAP in the planting and KCl in the post-planting phase in Itaí-2014, with greater water availability until leaf sampling. This was observed despite the leaf P concentrations being slightly reduced by treatments with half the P rate at planting with MAP and with K at post-planting and sidedressing, in both site-years (Figure 1). Contrasting this, in BC-2013, this fertilization strategy increased the tuber yield of special class compared to the standard NPK fertilization, but without changing this variable in Itaí-2014 (Figure 2A). Furthermore, the total tuber yield and the percentage of tuber DM were not affected by the exclusive use of MAP at planting, regardless of the form of KCl application (Table 3). Thus, the application of 255 kg ha^{-1} P_2O_5 as the MAP at planting and the transfer of K from planting to applications in the post-planting phase or in post-planting phase and at hilling, increases the operational yield of planting fertilization and maintains total tuber yield. It also increases the tuber yield of the special class of ‘Agata’ potato under conditions of lower water availability in the vegetative stages of the crop grown in soils with mean availability of P and K (Figure 2A; Tables 3 and 4).

ACKNOWLEDGMENTS

The authors thank to the potato grower (Grupo Ioshida), who provided the area and logistical support for the experiments, and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for granting an award for excellence in research to the first and fourth authors.

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