

EFFECT OF FERTILIZATION AT SOWING ON NUTRITION AND YIELD OF CRAMBE IN SECOND SEASON⁽¹⁾

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SUMMARY

The interest in crambe (*Crambe abyssinica*) cultivation in Brazil is on the rise, whereas information on the nutrient requirements for this crop is scarce. The objective of this work was to evaluate the effect of nitrogen-phosphorus-potassium (N-P₂O₅-K₂O formula 8:28:16) fertilization (0, 150, and 300 kg ha⁻¹) on crambe shoot biomass production, grain and oil yields, and nutrient extraction and exportation in the second growing season after soybean. The experiment with a Haplorthox (Dystroferric Red Latosol) was carried out for two years in Botucatu, São Paulo State, Brazil. A randomized complete block design with eight replications was used. Fertilization with NPK at sowing increased the shoot biomass production, grain yield, grain oil content, as well as nutrient extraction and exportation at harvest. In the fertilized treatments, the average amounts of nutrients extracted per hectare were 91 kg K, 71 kg N, 52 kg Ca, 9.4 kg P, 9.4 kg Mg, 7.9 kg S, 2,348 g Fe, 289 g Zn, 135 g Mn, and 18.2 g Cu; while the average values of nutrient exportation per hectare were 54 kg N, 20 kg K, 12.3 kg Ca, 10 kg P, 6.6 kg S, 3.2 kg Mg, 365 g Zn, 60 g Fe, 50 g Mn, and 7.3 g Cu, with NPK fertilizer application.

Index terms: *Crambe abyssinica*, yield components, nutrient extraction, nutrient exportation.

RESUMO: NUTRIÇÃO E PRODUTIVIDADE DO CRAMBE EM RAZÃO DA ADUBAÇÃO DE SEMEADURA NA SAFRINHA

Tem aumentado o interesse pelo cultivo do cambre (Crambe abyssinica) no Brasil; porém, são escassas as informações sobre as necessidades de nutrientes por essa cultura. Objetivou-se com este trabalho avaliar o efeito da adubação NPK (0, 150 e 300 kg ha⁻¹ da fórmula N-P₂O₅-

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K₂O 8-28-16) na produção de matéria seca, produtividade de grãos e de óleo, extração e exportação de nutrientes pela cultura do crambe cultivada na safrinha, em sucessão à soja. O experimento foi realizado durante dois anos num Latossolo Vermelho distroférrico, no município de Botucatu, SP. Utilizou-se o delineamento em blocos casualizados, com oito repetições. A adubação NPK na semeadura aumentou a produção de matéria seca, a produtividade de grãos, o teor de óleo nos grãos, a extração e a exportação de nutrientes pela cultura do crambe. As quantidades médias de nutrientes extraídas por hectare nos tratamentos adubados foram de 91 kg de K, 71 kg de N, 52 kg de Ca, 9,4 kg de P, 9,4 kg de Mg, 7,9 kg de S, 2348 g de Fe, 289 g de Zn, 135 g de Mn e 18,2 g de Cu. Já a exportação foi em média de 54 kg de N, 20 kg de K, 12,3 kg de Ca, 10 kg de P, 6,6 kg de S, 3,2 kg de Mg, 365 g de Zn, 60 g de Fe, 50 g de Mn e 7,3 g de Cu, quando se utilizou adubação NPK.

Termos de indexação: Crambe abyssinica, componentes da produção, extração de nutrientes, exportação de nutrientes.

INTRODUCTION

Crambe (*Crambe abyssinica* Hochst. ex. R.E. Fries) is an oilseed crop native to the Mediterranean region and is cultivated in the United States, Canada and Europe (Adamsen & Coffelt, 2005). Its seeds contain 30 to 45 % oil, making it a promising crop for industrial use or as biofuel (Adamsen & Coffelt, 2005; Souza et al., 2009; Toebe et al., 2010). In Brazil, this oilseed crop is rather unknown, but cultivation has steadily expanded since the establishment of the first cultivar in the country in 2007 (Roscoe & Delmontes, 2008).

This crop is tolerant to drought and low temperatures, has a short growing cycle ranging from 83 to 105 days, as well as low production costs and characteristics that allow mechanized harvesting (Falasca et al., 2010). Due to these characteristics, crambe is an interesting alternative for cultivation after soybean, in the fall-winter growing season, the so-called second growing season, especially in early-fall periods, when the climate risks in the Midwest of Brazil make the sowing of crops such as corn and sunflower unfeasible (Marin et al., 2000; Roscoe & Delmontes, 2008; Heinemann et al., 2009; Pereira et al., 2009).

For an adequate development of crambe, fertility in the topsoil (0-0.20 m) must be amended and Al³⁺ saturation must be low in the subsurface (0.20-0.40 m) (Pitol et al., 2010). The crop is nutrient-demanding, especially in terms of K and N (Heinz et al., 2011), indicating the need to supply these nutrients by fertilization. Due to the high P-fixation capacity of most Brazilian soils, the inclusion of this nutrient in fertilization can increase crambe growth and grain yield (Cihacek et al., 1993; Silva et al., 2011).

Studies on crambe fertilization for the conditions in Brazil are still very limited and controversial. Broch et al. (2010) found no effect of nitrogen-phosphorus-potassium fertilization (NPK formula 7:24:24 + 3.0 % S), which, according to the authors, was a consequence of the high organic matter, P and K content in the soil. However, these authors observed an increase in yield due to an increased availability of N in the soil, either by fertilization or by a crop rotation

system. Silva et al. (2011) found that P application at sowing increased grain weight, oil content and grain yield of this oilseed crop.

During the second growing season, because of the scarce and erratic rainfall, farmers prefer to use very little or no fertilizer at sowing, which can hamper the crop performance (Bicudo et al., 2009). Furthermore, as a relatively new crop in Brazil, there are still doubts about the need for NPK fertilization of second-season crambe, as well as about nutrient extraction and exportation by this crop.

The purpose of this study was to evaluate the effect of NPK fertilization on shoot biomass production, grain and oil yields, and nutrient extraction and exportation of crambe in the second growing season, after soybean.

MATERIAL AND METHODS

A field experiment was carried out in Botucatu, São Paulo State, Brazil (48° 26' W, 22° 51' S; 740 m asl), on a Haplorthox (dystroférric red latosol). The climate of the region is Cwa according to the Köppen classification, which is a tropical climate with dry winters and hot, rainy summers. The experimental rainfall and temperature data are presented in figure 1.

In each year, before sowing crambe, the chemical properties of the surface layer (0-0.20 m) were determined according to Raji et al. (2001). In 2010, the soil characteristics were as follows: organic matter (OM), 26.0 g dm⁻³; pH (CaCl₂), 4.9; P (resin), 9.0 mg dm⁻³; K, Ca, Mg, and H+Al, 4.4, 42, 18.5, and 55.9 mmol_c dm⁻³, respectively; and base saturation of 54 %; S-SO₄²⁻, Cu, Fe, Mn, and Zn, 25.3, 3.4, 15.4, 5.6, and 1.8 mg dm⁻³, respectively. In 2011, the analysis results were as follows: OM, 28.5 g dm⁻³; pH (CaCl₂), 5.5; P (resin), 32.0 mg dm⁻³; K, Ca, Mg, and H+Al, 3.7, 47.3, 26.4, and 51.0 mmol_c dm⁻³, respectively; base saturation 60 %; S-SO₄²⁻, Cu, Fe, Mn, and Zn, 27.6, 1.3, 12.8, 3.9, and 1.0 mg dm⁻³, respectively.

The plants in the area were desiccated with 1,981 g ha⁻¹ a.i. of glyphosate, after the soybean

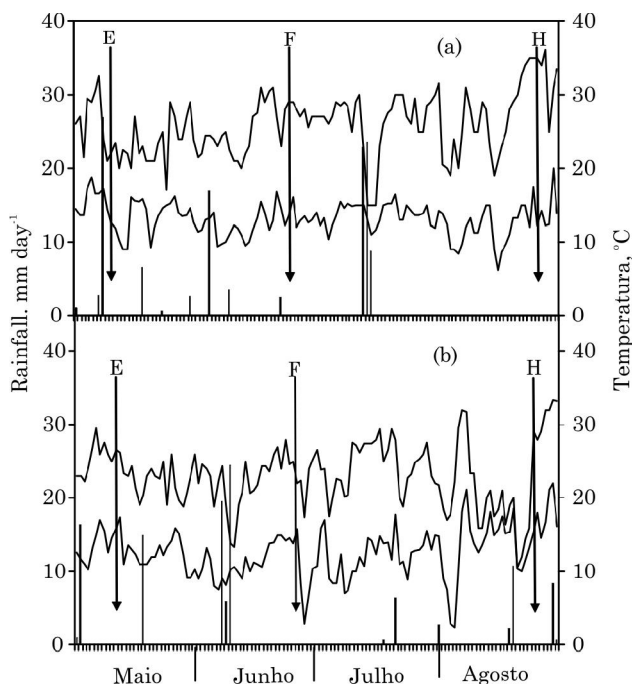


Figure 1. Rainfall (|), maximum (—) and minimum temperature (—) in the experimental area during the months of May to August of 2010 (a) and 2011 (b), and dates of seedling emergence (E), flowering (F) and harvesting (H) of crambe. (Information provided by the Department of Rural Engineering, FCA/UNESP).

harvest. The crambe cultivar FMS Brilhante was mechanically sown in a no-tillage system on 29/04/2010 and 03/05/2011, at a spacing of 0.34 m between rows and about 34 seeds m^{-2} (12 kg seeds ha^{-1}).

The experiment was carried out in a randomized block design with eight replications. The treatments consisted of three doses (0, 150, and 300 kg ha^{-1}) of N-P₂O₅-K₂O (8:28:16) fertilizer applied in the sowing furrow. Thus, the treatments received the following respective amounts of nutrients: 0, 12, and 24 kg ha^{-1} N; 0, 42, and 84 kg ha^{-1} P₂O₅; 0, 24, and 48 kg ha^{-1} K₂O. Each experimental plot consisted of ten 4 m-long rows, of which the eight central rows were evaluated, without the borders of 0.5 m at either end of each row. Seedling emergence occurred on 09/05/2010 and 13/05/2011.

Weeding was carried out by hand in the first year only (01/06/2010). There was no need to control pests and diseases.

Flowering began 46 days after emergence (DAE) in both years, i.e., on 24/06/2010 and 28/06/2011. One week after flowering (02/07/2010 and 07/07/2011), the plants from 2 m of the rows of each plot were counted, harvested, washed, and dried to constant weight in a forced air dryer at 70 °C. After drying, the samples were weighed and ground, and the concentration of the nutrients N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn were determined according to Malavolta et al. (1997).

Based on the number of plants, nutrient concentration and shoot dry matter (DM), the amounts of nutrients extracted per hectare were calculated.

At harvest, 108 and 103 DAE, respectively, in 2010 and 2011, 20 plants per plot were collected to determine the number of grains per plant and the 1,000 grain weight (unhusked grain). In the four rows of each plot, plants were counted to determine the final plant population and the grains were harvested and threshed manually to determine grain (unhusked grain) yield. The grain yield was calculated for a moisture content of 0.13 kg kg^{-1} .

After harvest, samples of unhusked grain were oven-dried at 70 °C for 24 h, and the oil content was measured by nuclear magnetic resonance, according to the method described by Colnago (1996).

In addition, samples of unhusked grain from each plot were oven-dried at 70 °C for 24 h before grinding, and analyzed to determine the concentrations of N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn (Malavolta et al., 1997). The amounts of nutrients exported were estimated using the data of nutrient concentrations and yield (dry basis).

The data were subjected to analysis of variance using the statistical software package SISVAR (Ferreira, 2008), and the means were compared by the LSD test at 0.05 probability.

RESULTS AND DISCUSSION

The shoot DM production of crambe was influenced by fertilization in both study years; highest values were observed after application of 300 kg ha^{-1} of the fertilizer N-P₂O₅-K₂O (08:28:16) (Table 1). In 2010, the shoot DM production at the intermediate fertilization rate (150 kg ha^{-1}) did not differ from the DM production in the other treatments. In 2011, shoot DM production with the intermediate fertilization rate increased in comparison with the control treatment (no fertilizer), but decreased in comparison with the highest fertilization rate. In the first year, despite the low soil P availability, the application of 150 kg ha^{-1} fertilizer increased shoot DM production by 40 % over the control treatment, whereas in the second year, the increase was 123 %. These results show that the biomass yield of second-season crambe can be increased by the application of fertilizer at sowing. The higher water availability in the second year improved the effect of fertilization. Miranda et al. (2000) found a higher response of common bean to P fertilization when grown at adequate water availability levels. Moreover, due to the lower plant population in 2011, the individual growth of crambe plants increased, reflecting the higher fertilization effect (Table 1). Cihacek et al. (1993) also observed significant increases in crambe DM production when the crop was treated with P fertilizer. In a study by Heinz et al.

(2011), in soil containing $5 \text{ mg dm}^{-3} \text{ P}$ and $4.9 \text{ mmol}_c \text{ dm}^{-3} \text{ K}$ at 56 % base saturation, even without fertilization, crambe accumulated $2,688 \text{ kg ha}^{-1}$ of shoot DM until the flowering phase, similarly to the results obtained at higher rates of NPK fertilization. The difference in DM production between these studies can be attributed to weather conditions, soil conditions or plant population, as these authors used almost twice the plant population of the present study. The lower DM production observed in 2011 was probably due to the lower plant population (Table 1), which was caused by less favorable weather conditions during the crop establishment (Figure 1). The results demonstrate the potential of crambe to produce a higher yield of shoot biomass even when grown at low water availability levels, given that the amounts of rainfall between sowing and flowering were 62 and 71 mm, respectively, in 2010 and 2011.

The final plant population was influenced by fertilization in both years (Table 1). In 2010, the treatment with 300 kg ha^{-1} NPK fertilizer resulted in a higher plant population than in the control treatment (no fertilizer). However, the plant population at the intermediate fertilizer rate (150 kg ha^{-1}) did not differ from the control treatment. In 2011, the fertilized treatments provided higher final plant populations than the control treatment. Kikuti et al. (2005) observed higher final plant populations of common bean in response to increasing rates of P_2O_5 applied in the sowing furrow. According to these authors, the increase in soluble P in the soil in the initial phase of crop establishment, provided by the phosphate fertilization, improved the nutrition and initial growth of the seedlings, mainly in the roots, leading to a greater tolerance to the saline effect caused by the application of higher N and K_2O rates. This fact probably also played a role in our study. The lower plant population observed in 2011 was related to the lower water availability during the crop establishment phase in this year (Figure 1).

The N and K concentrations in the crambe shoots were not influenced by fertilization in either year (Table 2). The reason for the absence of any effect on the N concentration may be the preceding soybean crop. According to Broch et al. (2010), soybean residues provide successive crops with N remaining from biological fixation. Even though N exportation in soybean is relatively high, the N balance in the soil is positive after growing this leguminous crop (Alves et al., 2006). The K concentration was not affected by fertilization, probably because of the initial soil K contents of $4.4 \text{ mmol}_c \text{ dm}^{-3}$ in 2010 and $3.7 \text{ mmol}_c \text{ dm}^{-3}$ in 2011 in the experimental area, which is considered high (Raij et al., 1997). Moreover, the higher production of shoot DM caused by NPK fertilization may have resulted in a dilution effect in the N and K concentrations (Tables 1 and 2), i.e., although the plants absorbed large amounts of these nutrients, there was no increase in the plant nutrient concentrations after fertilization.

In both years, only fertilization at the highest rate (300 kg ha^{-1}) increased the P concentration in the plant shoots (Table 2). This means that, aside from promoting higher growth, P fertilization may also increase the concentration of this nutrient in the plant (Cihacek et al., 1993). In each year, the Ca and Mg concentrations decreased after fertilization (Table 2), probably due to a dilution effect caused by the increased DM production in response to fertilization (Table 1). With regard to S levels, the concentration of this nutrient in plants after NPK fertilization increased only in the second year, regardless of the fertilizer rate. In both years the soil S-SO_4^{2-} concentrations were considered high (Raij et al., 1997).

The fertilization of crambe at sowing did not affect the Cu concentration in the shoots in either year, or the Fe concentration in the second year (Table 2). There was a decrease in the Fe concentration in 2010 and in the Mn and Zn concentrations in both years after NPK fertilization at sowing, which can be

Table 1. Shoot dry matter production at flowering and final plant population of crambe treated with different rates of the fertilizer N- P_2O_5 - K_2O (8:28:16)

NPK fertilizer kg ha ⁻¹	Shoot dry matter		Final plant population
	g/plant	kg ha ⁻¹ 2010	plants ha ⁻¹
0	2.7 b	1,525 b	572,610 b
150	3.6 ab	2,134 ab	612,132 ab
300	4.2 a	2,639 a	631,302 a
CV (%)	29.6	29.0	8.6
		2011	
0	2.5 c	815 c	329,832 b
150	3.8 b	1,819 b	463,925 a
300	5.2 a	2,283 a	443,771 a
CV (%)	20.2	20.8	5.8

Values followed by different letters, in the column, were significantly different by the LSD test ($p \leq 0.05$).

Table 2. Nutrient concentration and extraction in shoots of crambe treated with different rates of the fertilizer N-P₂O₅-K₂O (8:28:16)

NPK fertilizer	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Concentration in shoot										
kg ha ⁻¹	g kg ⁻¹					mg kg ⁻¹				
2010										
0	31.4 a	3.4 b	41.7 a	28.4 a	5.3 a	3.4 a	12.2 a	1,377 a	83.3 a	229 a
150	31.4 a	3.8 b	41.8 a	25.4 ab	4.5 b	3.3 a	11.3 a	1,107 b	68.2 b	155 b
300	33.1 a	4.6 a	42.5 a	24.0 b	4.4 b	3.4 a	10.3 a	1,047 b	62.6 b	138 b
CV (%)	7.4	11.6	8.9	11.8	9.2	6.7	27.0	17.2	15.9	12.0
2011										
0	29.2 a	3.5 b	37.5 a	27.5 a	4.8 a	3.5 b	6.1 a	1,111 a	74.6 a	162 a
150	30.6 a	3.6 b	39.6 a	23.3 b	3.8 b	3.7 a	5.0 a	1,040 a	57.7 b	125 b
300	31.8 a	4.6 a	40.6 a	20.7 b	4.1 b	3.8 a	4.8 a	1,086 a	56.9 b	106 b
CV (%)	9.2	10.0	16.0	14.5	12.5	4.6	29.7	25.0	15.5	24.2
Amount extracted										
	kg ha ⁻¹					g ha ⁻¹				
2010										
0	48.1 b	5.2 b	63.9 b	44.3 b	8.1 b	5.2 b	17.9 b	2,092 a	128.2 a	352 a
150	67.2 ab	8.2 b	89.5 ab	54.0 ab	9.6 ab	7.1 ab	24.0 ab	2,337 a	141.6 a	328 a
300	88.9 a	12.2 a	110.7 a	62.5 a	11.7 a	9.1 a	28.6 a	2,747 a	164.9 a	366 a
CV (%)	34.6	35.6	27.5	26.2	29.5	29.5	38.2	29.5	28.6	31.6
2011										
0	23.6 c	2.8 c	30.5 c	22.3 b	3.9 c	2.8 c	4.9 b	886 c	60.2 c	131 b
150	55.4 b	6.6 b	72.0 b	42.5 a	6.9 b	6.8 b	9.1 a	1,875 b	105.1 b	223 a
300	72.6 a	10.5 a	91.0 a	47.2 a	9.5 a	8.7 a	11.1 a	2,431 a	128.4 a	238 a
CV (%)	20.8	27.3	19.2	27.0	32.3	23.4	37.6	21.9	18.5	15.8

Values followed by different letters, in the column, were significantly different by the LSD test ($p \leq 0.05$).

explained by the dilution effect due to the higher DM production by the fertilized plants (Table 1). The initial levels of the soil micronutrient contents were considered medium to high (Raij et al., 1997).

In each of the two years, the amounts of macronutrients extracted by crambe were influenced by fertilization, with increasing values according to the increasing fertilization rates (Table 2). In the control treatment (no fertilizer), the macronutrient requirements of cultivar FMS Brilhante in the flowering phase in both years were, in decreasing order: K > N > Ca > Mg > P = S. In the treatment with 150 kg ha⁻¹ NPK fertilizer applied at sowing, P was extracted in higher amounts than S in 2010, and inversely in 2011. However, with the application of 300 kg ha⁻¹ of NPK fertilizer, more P was absorbed than Mg and S in both years. This shows that when P-containing fertilizer is applied, crambe increases P uptake (Cihacek et al., 1993), and may even change the order of extraction. Heinz et al. (2011), in a study with crambe grown without fertilization, reported the following decreasing order of macronutrient accumulation in crambe shoots in the flowering phase: K > N > Ca > S > P > Mg. These differences in the

extraction of Mg, S, and P are due to differences in the weather and soil conditions, as well as to the kind of fertilization.

The extraction of the micronutrients Fe, Mn, and Zn were not affected by fertilization in the first year, which was due to higher concentrations of these nutrients in the crop shoots in the control treatment (Table 2). The Cu extraction were increased by NPK fertilization in both years. In 2011, the Cu and Zn amounts extracted were increased, but only in the treatment with 150 kg ha⁻¹ NPK fertilizer. Higher fertilizer rates were not followed by a corresponding increase in extracted Cu and Zn amounts. However, the amounts of Fe and Mn increased with increasing fertilization rates. Regardless of the NPK fertilizer utilized and the cropping year, the following decreasing order of micronutrient contents was observed in the flowering phase: Fe > Zn > Mn > Cu (Table 2).

Generally speaking, the nutrient extraction was higher in the first year, which can mostly be attributed to the higher DM yield (Tables 1 and 2). In the average of both years, without fertilization, crambe extracted 47 kg K, 36 kg N, 33 kg Ca, 6 kg Mg, 4 kg S, 1,489 g Fe, 241 g Zn, 94 g Mn and 11 g Cu per ha (Table 2).

However, the application of 300 kg ha⁻¹ of the N-P₂O₅-K₂O (8:28:16) fertilizer in the sowing furrow led to higher nutrient extraction, with average amounts per hectare of 101 kg K, 81 kg N, 54 kg Ca, 11 kg P, 11 kg Mg, 9 kg S, 2,589 g Fe, 302 g Zn, 147 g Mn and 20 g Cu. In the treatment with application of 150 kg ha⁻¹ of the NPK fertilizer, the most nutrients were extracted at intermediate levels.

In both years, the number of grains per plant was higher when a higher amount of NPK fertilizer was applied (Table 3); however, as observed for the shoot DM production (Table 1), the fertilization effect was more intense in the second year. This was probably due to the lower plant population in 2011, which may have favored individual plant growth with higher levels of fertilization, resulting in a larger number of grains per plant (Tables 1 and 3).

The weight of 1,000 crambe grains was increased by NPK fertilizer application in the sowing furrow, with values ranging from 6.8 to 9.3 g (Table 3). Silva et al. (2011) obtained a weight increase of 1,000 crambe grains by P application in the sowing furrow. The values of 6.3 to 7.7 g obtained by Silva et al. (2011) were slightly below those observed in this study, but within the range reported by Falasca et al. (2010), which is between 6 and 10 g.

The grain yield was increased by fertilization with NPK in both years, according to the increasing fertilizer rates (Table 3). Broch et al. (2010) observed no effect in the grain yield of crambe sown after corn and soybean when using the fertilizer N-P₂O₅-K₂O (7:24:24) + 3 % of S at different rates (0, 100, 200, and 300 kg ha⁻¹). According to these authors, this occurred as a result of the high concentrations of organic matter, P, and K in the soil. However, Silva et al. (2011) observed an increase in crambe grain yield, especially with the application of 40 kg ha⁻¹ of P₂O₅. In this study, the effect of applying NPK fertilizer in the sowing furrow was more pronounced in the second

crop year, probably as a result of lower water availability in the initial development phase of the crop (Figure 1) hampering plant establishment without fertilization (Tables 1 and 3). The results demonstrate the importance of fertilization with NPK in the sowing furrow to ensure satisfactory growth and yield of second-season crambe grown after soybean, even in soil with high P and K concentrations (Raij et al., 1997). Moreover, it is noteworthy that fertilization promoted yields of over 1,500 kg ha⁻¹, despite only 80 mm rain was recorded from crop emergence to maturation (Figure 1).

The grain oil content was influenced by fertilization in the second year only, with high concentrations being observed in the fertilized crops, irrespective of the amount of NPK fertilizer (Table 3). Souza et al. (2009) observed average grain oil contents of 44.1 % in samples of unhusked grain of the crambe cultivar FMS Brillhante in the states of Mato Grosso and Mato Grosso do Sul. However, Adamsen & Coffelt (2005) observed crambe seed oil contents varying between 33.8 and 39.5 % in a study in Arizona, USA. These values are similar to those observed in this study. In view of the increases in the grain yield and in the grain oil content (Table 3), it is clear that fertilization with NPK improved the oil yield per area.

The P concentration in the grains increased with NPK fertilization (Table 4). Only in 2010, the Ca concentration in crambe grains was higher in the control than in the treatment with fertilization of 300 kg ha⁻¹ NPK. The N concentrations in the grains were similar to those reported by Souza et al. (2009). The K concentrations in the first year were higher than those observed by Souza et al. (2009) and Vargas-Lopez et al. (1999), but lower in the second year (Table 4). The P concentrations were similar to those values found by Vargas-Lopez et al. (1999). The Ca concentrations assessed in this study were higher than those reported by Souza et al. (2009) and lower than

Table 3. Number of grains per plant, 1,000 grain weight, grain yield and grain oil content in crambe treated with different rates of the fertilizer N-P₂O₅-K₂O (8:28:16)

NPK fertilizer	Grains per plant	1,000 grain weight	Grain yield	Grain oil content
kg ha ⁻¹	n ^o /plant	g	kg ha ⁻¹	%
2010				
0	296.9 b	8.6 b	1,307 c	35.2 a
150	361.6 ab	8.8 ab	1,584 b	35.4 a
300	373.8 a	9.3 a	1,850 a	36.2 a
CV (%)	17.5	4.6	10.4	4.3
2011				
0	238.0 c	6.8 b	539 c	34.4 b
150	551.6 b	7.7 a	1,986 b	36.2 a
300	703.4 a	7.3 ab	2,209 a	36.4 a
CV (%)	10.7	8.1	9.1	4.6

Values followed by different letters, in the column, were significantly different by the the LSD test (p<0.05).

Table 4. Nutrient concentration and exportation in crambe grains treated with different rates of the fertilizer N-P₂O₅-K₂O (08:28:16)

NPK fertilizer	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Concentration in grains										
kg ha ⁻¹	g kg ⁻¹					mg kg ⁻¹				
2010										
0	34.5 a	5.1 c	17.5 a	8.7 a	2.2 a	4.0 a	2.6 a	40.2 a	25.4 b	231.9 a
150	32.4 a	6.4 b	18.0 a	7.9 ab	2.4 a	4.0 a	2.9 a	36.6 a	37.9 a	231.9 a
300	32.6 a	7.1 a	17.9 a	7.0 b	2.4 a	4.3 a	2.1 a	24.4 b	30.4 b	234.3 a
CV (%)	8.7	9.9	13.0	16.5	18.1	8.4	44.1	28.5	19.6	6.5
2011										
0	33.6 a	5.0 b	7.9 a	7.0 a	1.3 a	4.3 a	5.8 a	53.1 a	24.5 a	232.2 a
150	32.7 a	5.6 a	7.3 a	7.5 a	1.4 a	3.7 a	5.6 a	40.0 b	28.0 a	215.1 b
300	32.5 a	5.5 a	7.3 a	7.4 a	1.5 a	3.9 a	6.3 a	42.4 b	26.0 a	204.5 b
CV (%)	5.7	8.2	13.9	13.4	20.5	7.6	21.7	23.1	13.7	6.9
Amount exported										
	kg ha ⁻¹					g ha ⁻¹				
2010										
0	39.3 b	5.8 c	19.9 b	9.9 a	2.5 b	4.5 c	2.9 a	45.0 a	29.0 b	263.5 c
150	44.7 b	8.8 b	24.8 a	10.8 a	3.3 a	5.5 b	4.0 a	50.6 a	52.2 a	319.8 b
300	52.7 a	11.4 a	28.6 a	11.1 a	3.9 a	6.9 a	3.4 a	38.6 a	48.4 a	378.7 a
CV (%)	14.8	14.1	15.6	17.3	20.5	11.5	39.9	26.1	24.5	13.0
2011										
0	16.6 c	2.3 b	3.7 b	3.3 b	0.6 c	2.0 c	2.7 c	24.1 c	11.5 b	108.1 b
150	54.4 b	9.7 a	12.6 a	13.1 a	2.4 b	6.4 b	9.6 b	68.8 b	48.7 a	371.2 a
300	62.5 a	10.6 a	14.2 a	14.1 a	3.0 a	7.4 a	12.1 a	80.8 a	49.7 a	392.7 a
CV (%)	12.5	13.8	18.8	19.5	24.8	8.9	25.2	18.6	20.2	11.7

Values followed by different letters, in the column, were significantly different by the LSD test ($p \leq 0.05$).

those observed by Vargas-Lopez et al. (1999). The Mg and S concentrations were however lower than those cited by these authors.

In 2010, the application of 300 kg ha⁻¹ of NPK fertilizer decreased the Fe concentrations in the crambe grains in comparison with the other treatments, whereas in 2011, the fertilization, regardless of the rate, resulted in lower Fe concentrations than in the control treatment (Table 4). The Mn grain concentrations were higher in the treatment with intermediate NPK fertilizer rate than in the other treatments in 2010. No effect of fertilization on Mn grain concentration was observed in 2011 (Table 4). However, NPK fertilization decreased the grain concentrations of Zn only in the second year of the study. The Cu and Fe concentrations in crambe grain observed in this study were lower than those reported by Vargas-Lopez et al. (1999) and Souza et al. (2009). However, the Mn concentration was similar to the values cited by these authors, and the Zn values found here were considerably higher than those reported by Souza et al. (2009). These variations between studies in nutrient concentrations in the crambe grains can be explained by differences in the growth conditions.

With regard to nutrient exportation, for only Ca, Cu, and Fe in the first year, no effect of fertilization was observed (Table 4). In general, the NPK fertilization produced an increase in nutrient exportation by crambe grains. In the second year, less nutrients were exported in the control treatment than in the first year, which can be attributed mainly to the lower grain yield in this treatment (Tables 3 and 4).

Taking the average of the two years, in the absence of NPK fertilization of crambe, the amounts of nutrients per hectare exported by grains were 28 kg N, 12 kg K, 6.6 kg Ca, 4.1 kg P, 3.3 kg S, 1.6 kg Mg, 186 g Zn, 35 g Fe, 20 g Mn, and 2.8 g Cu (Table 2). But after fertilizer applied in the sowing furrow, the average exportation per hectare was 54 kg N, 20 kg K, 12.3 kg Ca, 10 kg P, 6.6 kg S, 3.2 kg Mg, 365 g Zn, 60 g Fe, 50 g Mn, and 7.3 g Cu. Thus, in an average of treatments and years, the nutrient exportation was, in decreasing order: N > K > Ca > P > S > Mg > Zn > Fe > Mn > Cu. This exportation order is different from that observed for soybean, for example, where: N > K > P > S > Ca > Mg > Fe > Zn > Mn > Cu (TPS, 2011). It is worth mentioning that in some treatments the

exportation of P and Zn by grains was higher than the amounts extracted by crambe until the flowering phase (Tables 2 and 3), indicating that these nutrients in particular are absorbed at higher amounts by crambe at the end of the growth cycle. On average, 82 % of S and 77 % of N accumulated in crambe shoots until flowering were exported in the grains, whereas for Cu this value was 52 %, for Mg and Mn it was approximately 31 %, for K and Ca it was 22 %, and for Fe it was only 2.6 %.

CONCLUSIONS

1. Even in soils where soybean had been cultivated before, with high concentrations of P and K, the application of NPK fertilizer in the sowing furrow increased biomass production, grain yield and oil content in grains of second-season crambe.

2. The NPK fertilization induced a higher nutrient uptake in second-season crambe until flowering (average values after fertilization of 91 kg K, 71 kg N, 52 kg Ca, 9.4 kg P, 9.4 kg Mg, 7.9 kg S, 2,348 g Fe, 289 g Zn, 135 g Mn, and 18.2 g Cu).

3. The nutrient exportation by crambe was higher after NPK fertilization and, on average in the treatments with fertilization, the export quantities per hectare were 54 kg N, 20 kg K, 12.3 kg Ca, 10 kg P, 6.6 kg S, 3.2 kg Mg, 365 g Zn, 60 g Fe, 50 g Mn, and 7.3 g Cu.

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