

Full Length Research Paper

Effect of base saturation and nitrogen dose on cultivation of crambe

J. M. Alves^{1*}, W. M. Leandro², S. A. S. O. Neto³, A. K. M. Leão³, C. C. F. Alves⁴ and E. L. Souchie¹

¹Field of Agronomy, Instituto Federal Goiano, Campus Rio Verde – GO, Brasil.

²School of Agronomy, Universidade Federal de Goiás, Brasil.

³Faculty of Agronomy Course, Instituto Federal Goiano, Campus Rio Verde – GO, Brasil.

⁴Area of Organic Chemistry, Instituto Federal Goiano, Campus Rio Verde – GO, Brasil.

Received 17 November, 2013; Accepted 17 December, 2014

The grain production potential of crambe reported in literature may vary from 1000 to 1500 kg ha⁻¹, but there are not yet any recommendations regarding specific nitrogen (N) fertilization for this crop. The objective of this study was to evaluate the effect of base saturation and the addition of N doses on plant development and productivity of crambe. This study was developed at the São Tomaz Jatobá farm in the municipality of Rio Verde, GO in a Distroferric Red Latosol. The experiment consisted of a factorial (4×3) design with four repetitions totaling 48 plots distributed in random blocks. Four levels of base saturation (V%) were evaluated as follows: 34 (natural soil), 40, 50 and 60. Moreover, the following three N doses were evaluated: Control (without application de N), 40 kg ha⁻¹ N and 80 kg ha⁻¹ N. The experimental plots were rectangular and measured 9 m² with five planted lines and a spacing of 0.45 m between rows. Planting was performed on March 8th, 2011 using the FMS Brilhante cultivar. The following variables were evaluated: Root dry mass and shoot dry mass in three distinct periods (35, 45 and 55 days after emergence); grain yield; and oil content. The addition of the N doses increased the root dry masses, shoot dry masses and yield, but N addition did not influence oil content. In general, the best N dose was 40 kg ha⁻¹. Base saturation linearly or quadratically influenced all parameters evaluated, and the best base saturation observed in this study was 50%.

Key words: FMS Brilhante cultivar, nitrogen fertilization, productivity, oil content, Brazil.

INTRODUCTION

Several plants have been studied with the objective of providing oil for biodiesel production. Among these plants, crambe (*Crambe abyssinica*) is notable. Crambe is a winter crop and can be grown late in the season during periods in which risks for other crops in the late off-season would be high in the Midwest region of Brazil

(Pitol et al., 2010). For these reasons, this plant has attracted interest as an alternative for the off-season and crop rotation (Panno and Prior, 2009). One of the main characteristics of crambe cultivation is its earliness, producing mature grains at 90 to 100 days with uniform maturation, which facilitates mechanical harvesting

*Corresponding author. E-mail: jmiltonalves@gmail.com.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](http://creativecommons.org/licenses/by/4.0/)

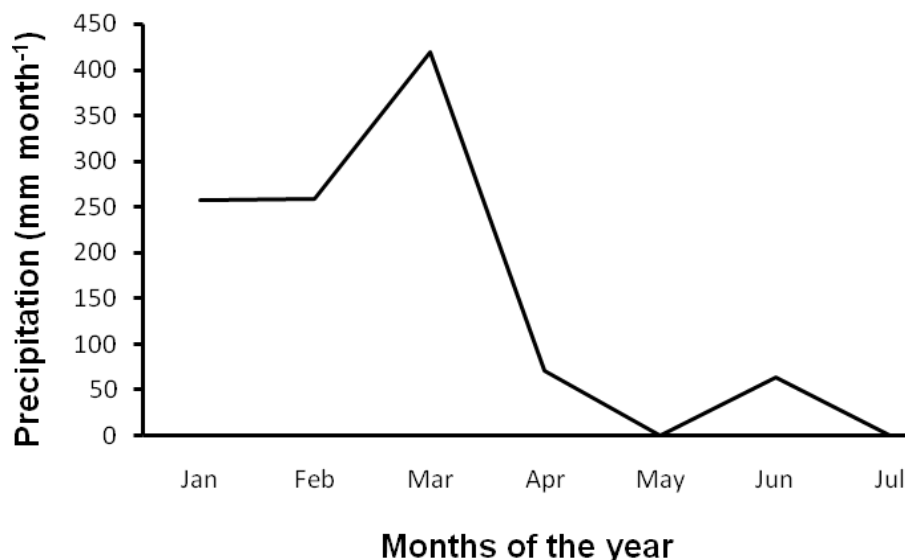


Figure 1. Accumulated precipitation (mm month⁻¹) during development of the crambe crop in the municipality of Rio Verde, GO during the year of 2011.

(Lazzeri et al., 1995; Falasca et al., 2010). Jasper et al. (2010a) reported that the crambe culture has lower production costs than other oil crops, such as canola, sunflower and soybean. According to Heinz et al. (2011), crambe litter presents greater persistence than other crops used as ground cover, and potassium (K), phosphorus (P) and magnesium (Mg) are the nutrients most rapidly released for the subsequent culture. The potential yield of crambe reported in literature varies from 1000 to 1500 kg ha⁻¹ (Pitol et al., 2010; Rogério et al., 2012; Santos et al., 2012). Regarding oil quality, data indicates an average production of 38% for total oil content, and this rate may vary according to the climate and soil conditions (Silva et al., 2011). The oil is composed of approximately 57% erucic acid, which can cause liver and kidney damage as well as loss of appetite in monogastric animals cited by Carlsson et al. (2007).

Regarding soil fertility, there are no specific recommendations of nitrogen (N) doses for the crop, and only a few studies on this subject have been published. In plants, mineral N is absorbed in the nitrate or ammonium forms, and it preferably comes into contact with the roots by mass flow (Malavolta et al., 1997). N makes up amino acids and nucleotides, and it is the primary nutrient for obtaining high yields in annual cultures (Castro et al., 1999). According to Soratto et al. (2013), N is the nutrient most exported in crambe production under field conditions reaching 54 kg ha⁻¹ N. According to the results obtained by Souza et al. (2009), the crude protein obtained in crambe cake (31.7%) indicates crambe crops demand N under high productivity conditions. Therefore, it is important to know the response potential of the crambe crop to this nutrient to enable more environmentally and financially efficient fertilization.

Considering base saturation, reports have suggested

that the crambe culture develops better and achieves better grain yields in eutrophic soils (Broch and Roscoe, 2010). According to these authors, crambe is quite tolerant to water stress, but this tolerance is directly linked to its deep rooting ability, which in turn depends on a corrected soil profile for acidity and aluminum toxicity. According to Janegitz et al. (2010), base saturation suitable for crambe development and production in medium textured soils is between 50 and 65%. Broch and Roscoe (2010) stated that the conditions of soil acidity used for crambe production are the same as the main summer crops. Only a few results are available on the ideal level of base saturation for good development of crambe. Thus, it is important to obtain information on the development of this crop in different levels of soil base saturation and in different weather conditions.

The objective of this study was to evaluate the effect of increasing soil base saturation and addition of N on vegetative growth, grain yield and oil content of crambe.

MATERIALS AND METHODS

This study was performed at the São Tomaz Jatobá farm (17° 49' 22.63" S and 50° 56' 21.87" W; elevation of 725 m) in the municipality of Rio Verde, GO in Brazil. The area was being cultivated in a succession of soybeans and maize where soybean was the culture used in the previous season (2010/2011), which was harvested in January 2011. According to the Köppen classification, the climate in the region is Aw, which is defined as humid tropical with a rainy season in the summer and dry in the winter. The annual average temperature varies between 20 and 35°C, and the annual precipitation ranges from 1,500 to 1,800 mm. Intensities of precipitation occurring during culture development are shown in Figure 1, and the average temperature is shown in Figure 2. Temperature and precipitation data were obtained from the meteorological station located in the University Campus of Fesurv

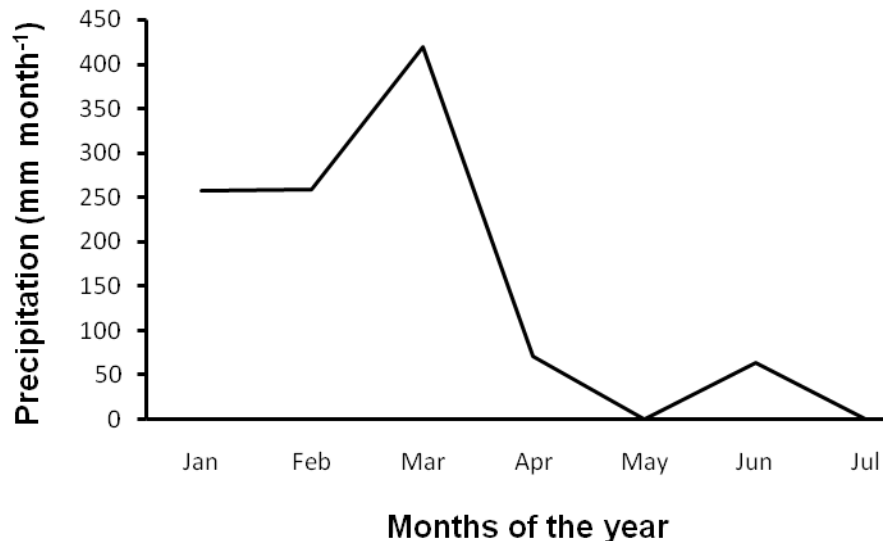


Figure 2. Average monthly temperature (°C) during crambe crop growth in the municipality of Rio Verde, GO during the year of 2011.

(University of Rio Verde) in Rio Verde, GO. The average monthly temperature (°C) was also monitored during crambe growth, as shown in Figure 2.

The undulated relief (8% slope) and soil classified as Distroferric Red Latosol (Embrapa, 2006) presented the following chemical and textural characteristics at depths of 0 to 20 cm: pH (CaCl₂) = 4.7; calcium (Ca), Mg, K, aluminum (Al) and cation exchange capacity (CEC) values of 1.7, 0.6, 0.10, 0.06 and 7.1 cmol_c dm⁻³, respectively; P_(mel), sulfur (S), zinc (Zn), boron (B), copper (Cu) and manganese (Mn) contents of 5.5, 11.3, 1.8, 0.12, 1.5 and 41.6 mg dm⁻³; base saturation (V%) = 33.8; organic matter (OM) = 2.0 g dm⁻³; and clay, silt and sand contents of 350, 50 and 600 g kg⁻¹, respectively. For depths of 20 to 40 cm, the soil analysis results presented the following characteristics: pH (CaCl₂) = 4.4; Ca, Mg, K, Al and CEC values of 0.9, 0.3, 0.07, 0.23 and 6.0 cmol_c dm⁻³, respectively; P_(mel), S, Zn, B, Cu and Mn contents of 1.9, 33.7, 0.4, 0.12, 1.9 and 21.9 mg dm⁻³; V% = 21.3; OM = 15.2 g dm⁻³; and clay, silt and sand contents of 375, 50 and 575 g kg⁻¹, respectively.

The experiment was arranged in a factorial design (4 × 3) with four levels of base saturation and three N doses. The levels of base saturation were as follows: 34 (natural soil), 40, 50 and 60%. Moreover, the following N doses were evaluated using urea as a source: Control (without application of N), 40 kg ha⁻¹ and 80 kg ha⁻¹. Four replications were used for each treatment totaling 48 plots. Natural base saturation of the soil was elevated with application of lime, and the need for correction (NC) was calculated using the following formula for increased base saturation. A lime filler (30.5% calcium oxide (CaO) and 18.7% magnesium oxide (MgO)) was applied to the soil. Application and incorporation into the soil in each plot occurred 15 days before planting. In all plots, a basic fertilization was performed consisting of 80 kg ha⁻¹ phosphorus pentoxide (P₂O₅) used as source of single super phosphate applied with the seeds at planting and 50 kg ha⁻¹ potassium oxide (K₂O) used as a source of potassium chloride (KCl) applied 22 days after emergence (DAE) in coverage. A row was dug approximately 3 to 4 cm deep at a distance of approximately 15 cm from the planting row where all N and K was deposited after which it was immediately covered by the removed soil.

The experimental plots were in the shape of a rectangle measuring 9 m² (2.25 × 4 m). Each plot consisted of five planted rows that were 4 m long, with 0.45 m spacing between rows. The

distance between the experimental plots was 1 m, and the distance between blocks was 2 m. Desiccation of the experimental area was performed one day after planting using glyphosate at a dose of 3 L ha⁻¹ in association with carfentrazone at a dose of 50 ml ha⁻¹.

Planting was conducted on March 8th, 2011 using a SHM 11/13 (planter brand Semeato) adapted for a spacing of 0.45 m using a cutting disc. The planting density was 12 kg ha⁻¹ of seeds at a depth of 2 cm. The crambe seeds used were from the FMS Brilliant cultivar acquired by the MS Foundation for Research and Dissemination of Agricultural Technologies (Fundação MS Para Pesquisa e Difusão de Tecnologias Agropecuárias - FUNDAÇÃO MS). Plants emerged on March 15th, 2011. The final average stand of plants was 1,220 plants per hectare. The plants reached physiological maturity on June 11th, 2011 at 88 DAE, and the harvest was performed on June 21st, 2011.

The following dependent variables were evaluated: (a) root and shoot dry mass in three different seasons (35 DAE when the plants were at the beginning of flowering; 45 DAE at which the plants were in the full flowering stage and beginning of the filling phase; and 55 DAE when the plants were in the filling phase); (b) grain yield; and (c) fixed oil content of the grain.

For evaluation of the dry root and shoot masses of crambe, three plants located along the boundary of each plot were harvested using a hoe, and all roots and shoots of the plant were removed as completely as possible at all collection times. Samples were collected at 35, 45 and 55 DAE. Roots were separated from the shoots in the field, and both were placed in paper bags and identified according to the plot. The material was taken to the laboratory where it was washed with distilled water, and the material was then placed in a forced air drying oven at 65°C for 72 h to be weighed.

To determine the grain yield (kg ha⁻¹), the lateral rows were discarded along with 0.5 m from each side of the plot. Three linear meters of the three central lines (totaling 4.05 m²) from the center of each plot were harvested. Harvest was performed manually, and the grains were placed in paper bags and transported to the laboratory, where they were cleaned and dried in a forced air circulation oven at 65°C for 72 h to standardize the moisture content before weighing.

For determining the oil content in crambe, the grains were crushed manually in a porcelain crucible. The sample (5 g) was

Table 1. Effect of increased soil base saturation (V%) and application of different N doses (kg ha⁻¹) on the crambe crop in field conditions (Table of mean squares).

Unfoldings	Root dry mass (g plant ⁻¹)			Shoot dry mass (g plant ⁻¹)			Yield	Oil content
	35 DAE	45 DAE	55 DAE	35 DAE	45 DAE	55 DAE	Kg ha ⁻¹	(%)
N	0.00264*	0.1568**	0.02030 ^{ns}	0.55648**	0.434 ^{ns}	5.1447 ^{ns}	48203.564**	0.42303 ^{ns}
Regression (V%)	Linear**	Linear**	Linear*	Linear**	Linear*	ns	Quadratic*	Linear**
Interaction (V% \times N)	0.00080 ^{ns}	0.00474**	0.01323 ^{ns}	0.01338 ^{ns}	0.945**	9.177**	8455.921**	0.33412 ^{ns}
CV (%)	29.56	19.08	35.46	35.57	25.56	30.33	9.65	1.83

DAE: Days after emergence; ns: non-significant; *: Significant ($P \leq 0.05$); **: Significant ($P \leq 0.01$).

Table 2. Root dry mass of crambe (g plant⁻¹) as a function of the addition of N doses and harvest at different times (Averages of 16 observations).

Nitrogen (kg ha ⁻¹)	Harvest time (DAE)		
	35	45	55
Control	0.083 ^b	0.156 ^b	0.257 ^a
40	0.090 ^{ab}	0.194 ^a	0.327 ^a
80	0.107 ^a	0.218 ^a	0.302 ^a
CV (%)	29.56	19.08	35.46

Averages followed by the same letter at the same harvest time do not differ according to Tukey's test ($p \leq 0.05$).

added to the cellulose thimble of the fat analyzer (model TE-044-8/50; TECNAL) for eight simultaneous tests, and hexane was used as the solvent (200 ml per sample). The temperature was controlled electronically at 120°C, and extraction took place for 4 h.

In the statistical analysis and for the levels of base saturation, a polynomial regression analysis was performed. For the three N doses, an analysis of variance was performed, and Tukey's test (5%) was performed when necessary. The statistical program used was Assist at 7.6 Beta.

RESULTS AND DISCUSSION

The effect of the treatments on root dry mass development of crambe depended on the assessment period. At the first time of plant collection (35 DAE), the statistical analysis showed a significant effect for both N and increased soil base saturation, but there was no significant interaction effect (V% \times N) (Table 1). At the second time of plant collection (45 DAE), a significant interaction effect (V% \times N) was observed. Moreover, at the third time of plant collection (55 DAE), a significant effect was only observed for the analysis of variance for regression of soil base saturation levels (Table 1).

At the two times (35 and 45 DAE) when a significant effect was observed, the highest N dose used (80 kg ha⁻¹) did not differ from the N dose of 40 kg ha⁻¹ although it differed from the control (Table 2), thereby indicating that crambe did not respond to higher N doses for this parameter evaluated and at the conditions of this study.

In evaluating the effect of increased base saturation for

the harvests at 35 and 55 DAE where the interaction (V% \times N) was not significant (Table 1), a linear effect was observed for root dry mass until a base saturation of 60% (Figure 3).

In the collection of plants performed at 45 (DAE), when the interaction (V% \times N) was significant (Table 1), unfolding was performed for the effect of increasing saturation in each N fertilization, and the observed behavior depended on the N dose applied. In the control (no N application), the behavior was polynomial (quadratic), and the maximum point of the regression equation for base saturation was 47.12%. In plots that received the 40 kg ha⁻¹ N dose, the behavior was linear, and in plots that received the 80 kg ha⁻¹ N dose, the behavior was not significant (Figure 4).

Comparison of the effect of N doses on development of the crambe root system with literature is difficult due to the low number of published papers. In a study of crambe in a nutrient solution, Brito (2009) did not report a significant result for N doses on the development of the crambe root system. Alves et al. (2010) studied greenhouse conditions and found a linear effect for N application of up to 160 kg ha⁻¹ using urea as a N source.

In evaluating the effect of increasing soil base saturation, the regression analysis showed a linear effect for the three root sampling times (35, 45 and 55 DAE) indicating that this evaluated variable for crambe was strongly influenced by soil base saturation (Table 1). These results were not in agreement with those obtained in literature where Carvalho et al. (2012) found a quadratic

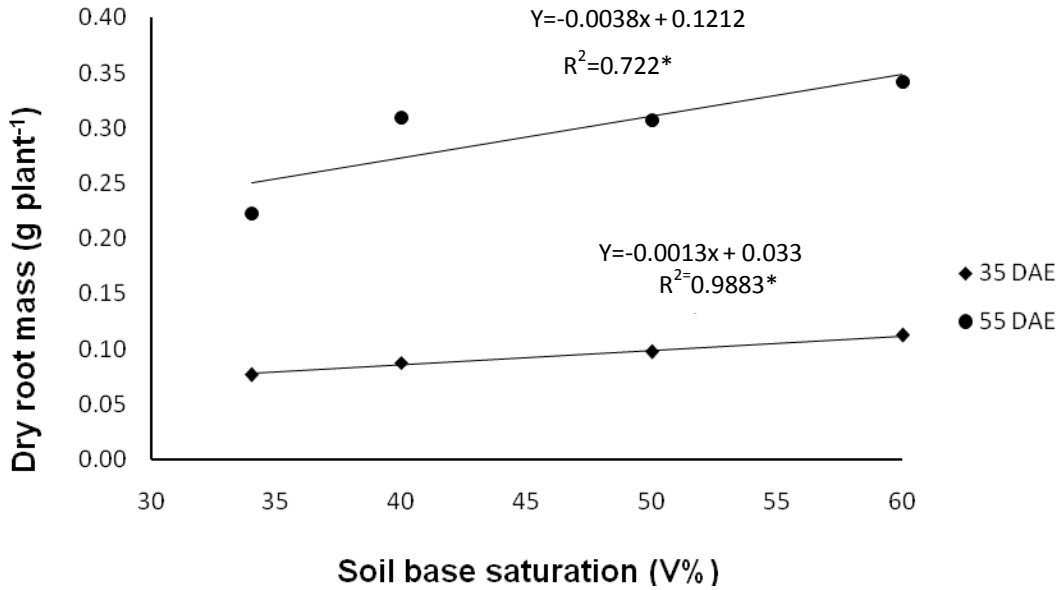


Figure 3. Root dry mass of crambe (g plant⁻¹) as a function of increasing soil base saturation (V%) harvested at 35 and 55 DAE. Averages of 12 observations.

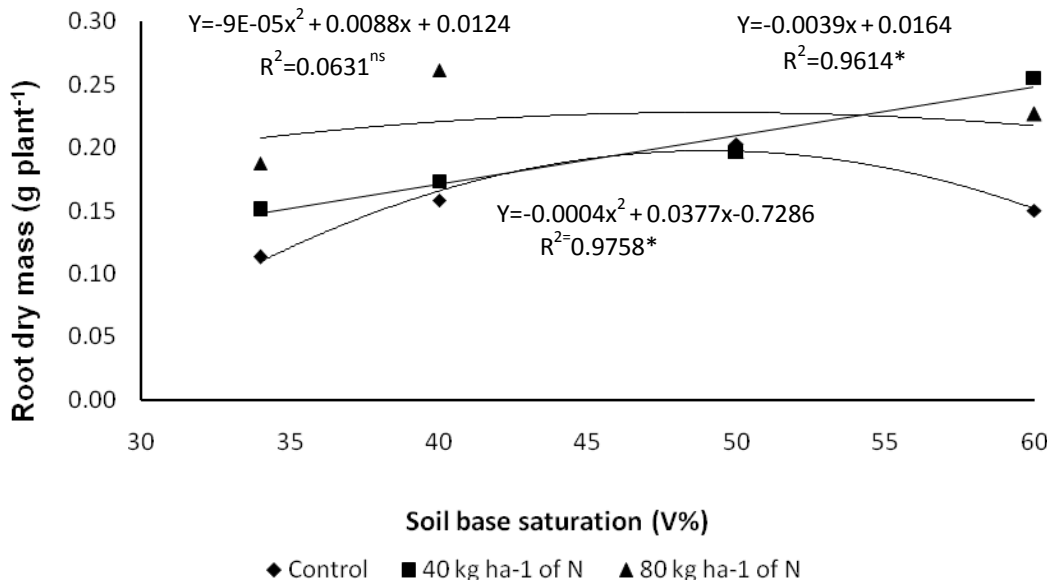


Figure 4. Root dry mass of crambe (g plant⁻¹) as a function of the increased soil base saturation (V%) harvested 45 days after emergence (DAE). Averages of 12 observations. ns = non-significant.

response as a function of the soil base saturation level for dry root weight in a pot experiment. These authors reported that the best base saturation level was 45% and that the dry root weight decreased at the 60 and 75% levels, which was different from that found in the present study. Janegitz et al. (2010) increased the soil base saturation up to 80% and obtained no effect on the development of the crambe root system. These

discordant results found in literature that were produced in soil were conducted in a similar Latosol to that used in this study. Therefore, further studies are needed to establish an efficient implementation of this culture to provide better conditions for root development and, consequently, the plant as a whole.

In the statistical analysis to evaluate the effect of the treatments on dry shoot mass development, a significant

Table 3. Dry shoot mass of crambe (g plant^{-1}) as a function of N doses and different harvest times (Averages of four observations).

Base saturation (V%)	Harvest times (DAE)								
	35			45			55		
	Nitrogen doses (kg ha^{-1})								
	Cont	40	80	Cont	40	80	Cont	40	80
34	0.37 ^b	0.50 ^{ab}	0.82 ^a	1.22 ^a	1.53 ^a	1.81 ^a	4.57 ^a	1.85 ^b	4.38 ^a
40	0.43 ^b	0.60 ^{ab}	0.88 ^a	2.36 ^a	1.76 ^a	2.22 ^a	3.87 ^a	4.91 ^a	4.27 ^a
50	0.54 ^a	0.75 ^a	0.85 ^a	2.15 ^a	2.22 ^a	1.82 ^a	4.09 ^b	6.70 ^a	3.53 ^b
60	0.71 ^a	0.78 ^a	0.99 ^a	1.37 ^b	2.90 ^a	2.00 ^b	3.13 ^b	6.21 ^a	3.63 ^b
CV(%)		35.57			25.56			30.33	

Averages followed by the same letter on the line for the same harvest period do not differ according to Tukey's test ($P \leq 0.05$). Cont=control.

interaction ($N \times V\%$) was observed for the second and third sampling times (45 and 55 DAE) (Table 1). In the evaluation at 35 DAE and base saturation levels of 34 and 40 (V%), the addition of N differed from the control, and the highest N dose employed (80 kg ha^{-1}) did not differ from the 40 kg ha^{-1} N dose (Table 3). In the second evaluation period (45 DAE), the effect of N addition was only observed for the highest base saturation level used ($V\% = 60$) in which the 40 kg ha^{-1} N dose differed from both the control and the 80 kg ha^{-1} N dose (Table 3). In the third evaluation period (55 DAE), the effect of N doses also depended on the saturation level observed. For the first saturation level ($V\% = 34$), the 80 kg ha^{-1} N dose and the control differed from the 40 kg ha^{-1} N dose. At the highest base saturation levels ($V\% = 50$ and 60), the 40 kg ha^{-1} N dose differed from the control and the highest N dose (80 kg ha^{-1}).

Camargo et al. (2010) also obtained a significant response on the development of dry shoot mass of crambe 60 days after planting when mineral nutrients (NPK) were applied during planting and N was applied in coverage. In an experiment using a nutrient solution, Brito (2009) obtained a significant response to N (nitrate) for leaf dry mass and a non-significant response for the stem dry mass. It is expected that N has an effect on the development of crambe shoots. According to Oliveira et al. (1996), when N is deficient, plants are stunted, and the stem and branch are slender in addition to the leaves having a color between pale green and yellow. The same author reported that N fertilization well applied in coverage has the ability to meet all of the needs of the culture and, thus, increases its productivity. This significant effect of N on shoot growth of other plants is known. Wright et al. (1988) showed that N treatment of rapeseed prolongs the life of leaves, improves flowering and increases the general uptake of crops.

The highest mean grain yield obtained in this study was 582 kg ha^{-1} . This yield may be considered low compared to that found in literature because Pitol et al. (2010) reported an average yield of 1,000 to $1,500 \text{ kg ha}^{-1}$ for the FMS Brilliant cultivar. A literature review suggested that

several authors obtained grain yields for crambe higher than $1,500 \text{ kg ha}^{-1}$ in soil conditions similar to those used in the present study (Red Latosol) (Jasper et al., 2010b; Santos et al., 2012; Rogério et al., 2012, 2013). Figure 1 shows that precipitation is one of the factors that may have negatively influenced grain yield. In soils with good capacity to retain water, Roscoe et al. (2010) reported that crambe produces satisfactorily when it receives at least 50 mm of water distributed in two rainfalls after planting. These authors also reported that the ideal amount of water varies between 150 and 200 mm, particularly before full flowering, and they also suggested rainfall after full flowering is not necessary. According to data collected at the meteorological station of the University of Rio Verde (FESURV), more than 400 mm of precipitation was recorded during the study period, which is equivalent to twice the minimum required for this culture, as described by Roscoe et al. (2010). Nevertheless, distribution of rainfall was irregular and was concentrated in the vegetative growth phase (March) with small amounts in the later stages. Considering that the early process of crambe grain filling began at the end of April in this study, the amount of precipitation in the period of full flowering and grain filling stage may have impaired the productivity of this crop. Thus, the data reported here was in disagreement with that reported by Roscoe et al. (2010). To ensure higher yields, more information is needed regarding the behavior of this crop under different rainfall intensities to more clearly define the water requirements of the crop. In addition, no significant attack of pests and diseases that could have negatively influenced grain yield was observed, and plants apparently developed normally.

For grain yield, the statistical analysis showed a significant effect for the $V\% \times N$ interaction (Table 1). At the lowest base saturation level ($V\% = 34$), which was the natural soil base saturation, the addition of 40 kg ha^{-1} N increased productivity by 38.2%, thereby significantly differing from the control. However, use of 80 kg ha^{-1} N did not statistically differ from the lowest N dose, thereby indicating that high N doses should not be used in soils

Table 4. Grain yield for crambe (kg ha^{-1}) and yield relative to control (in parentheses) as a function of the increased soil base saturation (V%) and N doses (Averages of four observations, CV(%)=9.65).

Base saturation (V%)	Nitrogen doses (kg ha^{-1})		
	Control	40	80
34	372(100) ^b	514(138) ^a	494(133) ^a
40	410(110) ^b	445(120) ^{ab}	509(137) ^a
50	473(127) ^b	582(156) ^a	503(135) ^b
60	385(103) ^b	534(143) ^a	398(107) ^b

Averages followed by the same letter on the line do not differ according to Tukey's test ($P \leq 0.05$).

that are not corrected because the crambe plant is not able to respond to the treatment (Table 4).

When the soil base saturation was increased to 40%, the average of the control yield (410 kg ha^{-1}) did not differ from the first N dose (40 kg ha^{-1}) in which a yield of 445 kg ha^{-1} was observed, thereby indicating that this increased base saturation was equivalent to the application of N (Table 4). In the higher levels of soil base saturation (50 and 60%), the yield observed for 40 kg ha^{-1} N was significantly higher than that of the control, but it was also significantly lower than that with 80 kg ha^{-1} N (Table 4), thereby indicating that higher doses of N did not increase crambe productivity but may even reduce it. The highest average grain yield obtained in this study was 582 kg ha^{-1} , and it was obtained when plants were subjected to a soil base saturation of 50% and a N dose of 40 kg ha^{-1} . This productivity was 56.4% higher than in the control (Table 4).

Broch and Roscoe (2010) also found a response to N fertilization in the crambe culture in soils with low OM. However, the results found by these authors showed a beneficial effect with quadratic behavior for N addition and decreased productivity for N dosages greater than 35 kg ha^{-1} . The data obtained in the present study confirmed the results obtained by Broch and Roscoe (2010) regarding N doses. In this study, the use of 80 kg ha^{-1} N resulted in lower average grain yields compared to 40 kg ha^{-1} N for all base saturations evaluated (Table 4).

Different from that obtained in this study, Freitas (2010) obtained no significant response of crambe grain yield when 60 and 120 kg ha^{-1} N were used in an experiment performed during two consecutive years. However, this author used urea as a N source and reported that the fertilizer was spread manually in the plant rows, which was a small amount when considering the amount of rainfall that occurred during the experiment. In addition, soil moisture content may have been low, which may have increased N losses by volatilization. Lara Cabezas et al. (1997) reported that when selecting urea as the N fertilizer and applying it via spreading without incorporation into the soil, N losses by the ammonia volatilization process in this system can reach 78% of the fertilizer applied. Lunelli (2012) found no significant effect in the FMS Brilhante crambe cultivar cultivated in a Red

Latosol when 90 kg ha^{-1} N in the form of urea was applied to the soil, and this lack of significant effect may have occurred because the soil was rich in nutrient content and OM, in contrast to the conditions under which the present study was conducted. Another possibility is that the N dosage used by these authors (90 kg ha^{-1}) is a high dose for this crop because the results obtained in the present work and those obtained by Broch and Roscoe (2010) indicated that doses greater than 40 kg ha^{-1} N can decrease grain production of this crop. In a study using a nutrient solution, Brito (2009) also obtained no significant effect of N doses (NO_3^-) on grain yield.

In evaluating the effect of base saturation for each N dose on crambe productivity, the analysis of variance for regression showed a significant effect only for the linear model of 40 and 80 kg ha^{-1} N, but the coefficient of determination (R^2) was low, thereby indicating that although significant, the model did not satisfactorily explain the results obtained in this work. Working in greenhouse conditions, Janegitz et al. (2010) also obtained no significant response for increased base saturation to 80% for the crambe crop. This non-significant result on yield was not expected because Broch and Roscoe (2010) reported that crambe is a plant sensitive to soil acidity and that its productivity is severely impaired when in the presence of exchangeable Al and low levels of Ca and Mg. In the present study, the sum of Ca and Mg levels in the soil was equal to $2.3 \text{ cmol}_c \text{ dm}^{-3}$. Therefore, the presence of Ca, presence of Mg, low yields and the absence of toxic Al may have contributed to the base saturation levels not having a significant effect.

In evaluating the effect of the treatments on oil content of crambe, the statistical analysis showed no significant effect for N and for the interaction (V% x N) (Table 1), but the analysis of variance for regression was highly significant for the linear model of soil saturation (Figure 5). These results were in agreement with those obtained in the literature for other oil crops. Smiderle and Costa (2010) worked with soil base saturations ranging from 30 to 75%, and they obtained a linear increase in the oil content of sunflower.

Other authors have also reported finding no effect of N on the oil content of oilseeds. When working with an

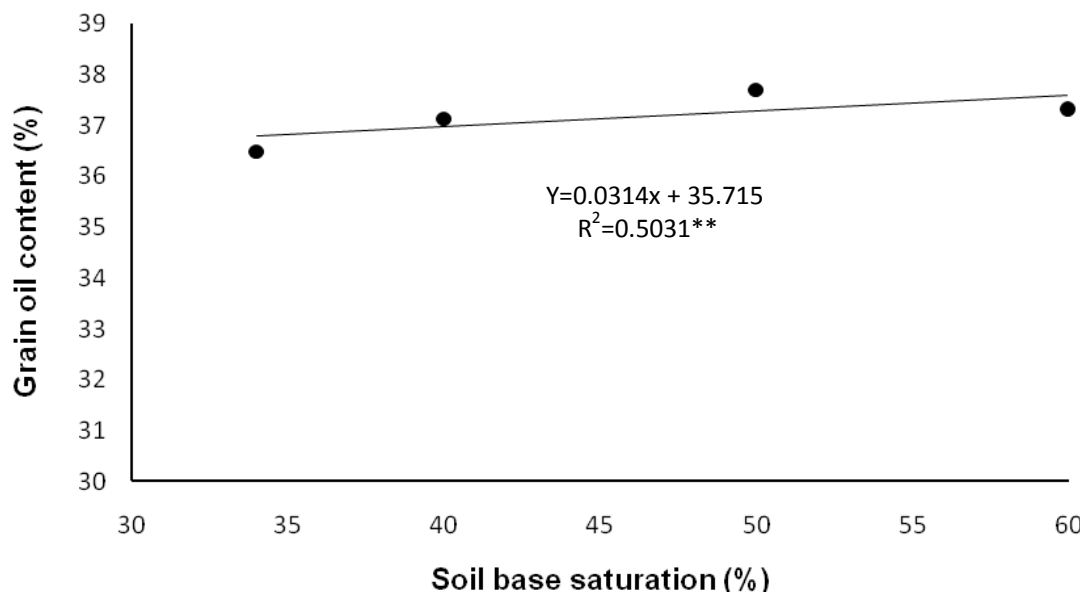


Figure 5. Oil content of crambe grains (%) as a function of the increased soil base saturation (V%). Averages of 12 repetitions. CV(%) = 1.83.

oilseed crop from the same family as crambe, namely rapeseed (*Brassica napus*), Dreccer et al. (2000) reported that no significant effect of N on oil content is observed. A review by Rathke et al. (2006) reported that most results show that N application often results in an increase in productivity and protein content as well as a decrease in oil content for the rapeseed culture. These authors report in their work an inverse correlation for the rapeseed culture, particularly between protein and oil content, and Brito (2009) confirmed these results in the crambe culture. In one experiment using a nutrient solution, this author observed that the addition of higher doses of nitrate reduces oil content in relation to that observed in the control. Thus, when an oilseed crop is fertilized with high N concentrations, contents of this nutrient are increased in the tissues, reducing the synthesis of oils and favoring the metabolic pathway of protein accumulation in the achenes (Castro et al., 1999).

Conclusions

1. The addition of N doses influenced root development, shoot development and productivity of crambe. The optimal dosage was 40 kg ha⁻¹ N;
2. Base saturation influenced root development, shoot development, productivity and oil content of crambe, and the optimal base saturation level was 50%.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors thank the Foundation for Research Support of Goiás State (Fundação de Amparo a Pesquisa do Estado de Goiás - FAPEG) and the IFGoiano for their assistance in development and publication of this study.

REFERENCES

- Alves JM, Vieira LF, Leandro WM, Machado PAL, Oliveira Júnior JP, Fernandes EP (2010). Doses de nitrogênio no desenvolvimento vegetativo e produtividade do crambe [Nitrogen doses on plant development and yield of crambe]. In: Congresso Brasileiro De Ciência Do Solo Brazilian Congress On Soil Science 36. Uberlândia. Anais... Uberlândia: SBCS, CD-ROM.
- Brito DMC (2009). Aspectos do metabolismo de plantas de crambe (*Crambe abyssinica*) submetidas a diferentes doses de nitrogênio visando a produção de óleo para biodiesel [Aspects of the crambe (*Crambe abyssinica*) plant metabolism submitted to different nitrogen doses for production of oil for biodiesel]. 2009. 64 f. Dissertation (Master's in Chemistry) – Universidade Federal Rural do Rio de Janeiro, Seropédica.
- Broch DL, Roscoe R (2010). Fertilidade do solo, adubação e nutrição do crambe [Soil fertility, fertilization and nutrition of crambe]. In: Pitol, C.; Broch, D. L.; Roscoe, R. (Ed.). Tecnologias e produção: crambe [Technologies and production: crambe] 2010. 1. Ed. Maracaju: FUNDAÇÃO MS 1(4):22-36.
- Camargo FP, Lazarini E, Vazquez GH, Picole PRF, Marcandalli LH, Hayashi FK (2010). Massa seca, acúmulo de nutrientes e produtividade de crambe em função da adubação de sementeira [Dry mass, accumulation of nutrients and productivity of crambe in function of fertilization at planting]. In: FertBio, Guarapari – ES. Anais... Guarapari: 2010. 1 CD-ROM.
- Carlsson AS, Clayton D, Salentijn E, Toonen M (2007). Oil Crop Platforms for Industrial Uses. New York. Cpl press. P. 158.
- Carvalho KS, Silva BEM, Cabral CEA, Leite N, Koetz M (2012). Crambe cultivado em latossolo do cerrado submetido à calagem [Crambe cultivated in latosol of the Brazilian cerrado submitted to liming].

- Enciclopédia Biosfera. 8(15):552-558. <http://www.conhecer.org.br/enciclop/2012b/ciencias%20agrarias/crambe.pdf>
- Castro C, Balla A, Castiglioni VBR, Sfredo G (1999). Levels and methods of nitrogen supply for sunflower. *Scientia Agricola*, Piracicaba, 56(4):827-833. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-90161999000400009
- Dreccer MF, Schapendonk AHCM, Slafer GA, Rabbinge R (2000). Comparative response of wheat and oilseed rape to nitrogen supply: absorption and utilization efficiency of radiation and nitrogen during the reproductive stages determining yield. *Plant Soil* 220(1-2):189-205. <http://link.springer.com/article/10.1023%2FA%3A1004757124939>
- Empresa Brasileira de Pesquisa Agropecuária - Centro Nacional de Pesquisa de Solos (2006). [National Center for Soil Research]. Sistema brasileiro de classificação de solos [Brazilian system of soil classification]. 2.ed. Rio de Janeiro, P. 306.
- Falasca SL, Flores N, Lamas MC, Carballo SM, Anschau A (2010). *Crambe abyssinica*: An almost unknown crop with a promissory future to produce biodiesel in Argentina. *Int. J. Hydrogen Energy* 35(11):5808-5812. <http://www.sciencedirect.com/science/article/pii/S0360319910003952>
- Freitas ME (2010). Comportamento agrônomico da cultura do crambe (*Crambe abyssinica* Hochst) em função do manejo empregado [Agronomic behavior of the crambe culture (*Crambe abyssinica* Hochst) in function of the employed management]. 2010. 42 f. Dissertation (Master's in Agronomy) – Universidade Federal da Grande Dourados, Dourados.
- Heinz R, Garbiate MV, Neto ALV, Mota LHS, Correia AMP, Vitorino ACT (2011). Decomposição e liberação de nutrientes de resíduos culturais de crambe e nabo forrageiro [Decomposition and liberation of nutrients from crambe residues and nabo litter]. *Ciência Rural*. 41(9):1549-1555. <http://www.scielo.br/pdf/cr/v41n9/a11611cr5315.pdf>
- Janegitz MC, Souza-Schlick, Tropaldi L, Cardoso SM (2010). Influência da saturação por bases no crescimento e produção de crambe [Influence of base saturation on growth and production of crambe]. *Cultivando o Saber*. 3(4):175-182. <http://www.fag.edu.br/graduacao/agronomia/csvolume34/20.pdf>
- Jasper SP, Biaggioni MAM, Silva PRA (2010a). Comparação do custo de produção do crambe (*Crambe abyssinica* Hochst) com outras culturas oleaginosas em sistema de plantio direto [Comparison of production costs of crambe (*Crambe abyssinica* Hochst) with other oil crops in no-tillage systems]. *Revista Energia na Agricultura*. 25(4):141-153. <http://energia.fca.unesp.br/index.php/energia/article/viewFile/96/64>
- Jasper SP, Biaggioni MAM, Silva PRA, Seki AS, Bueno OC (2010b). Análise energética da cultura do crambe (*Crambe abyssinica* Hochst) produzida em plantio direto [Energetic analysis of crambe (*Crambe abyssinica* Hochst) produced in no-tillage]. *Engenharia Agrícola*. 30(3):395-403. <http://www.scielo.br/pdf/eagri/v30n3/04.pdf>
- Lara Cabezas WAR, Korndorfer GH, Motta AS (1997). Volatilização de N-NH₃ na cultura de milho: II. Avaliação de fontes sólidas e líquidas em sistema de plantio direto e convencional [Volatilization of N-NH₃ in maize production: Evaluation of solid and liquid sources on no-till and conventional planting systems]. *Revista Brasileira de Ciência do Solo*. 21(3):489-496. <http://sbcs.solos.ufv.br/solos/revistas/v21n3a19.pdf>
- Lazzeri L, Lapenta E, Santangelo E, Malaguti L, Ventrella D, Pinheiro M (1995). *Crambe abyssinica* Hochst ex R.E. Fries: agronomic performance and oil quality in three locations in Italy. *Agricultura Mediterranea*. 125(3):251-266. <http://eurekamag.com/research/002/587/002587353.php>
- Lunelli IE (2012). Efeitos de arranjos nutricionais de NPK na produtividade de grãos e rendimento de óleo da cultura do crambe [Effects of NPK fertilizer blends on productivity of grains and oil yields of the crambe culture]. 2012. 40 f. Dissertation (Masters in Energy in Agriculture) - Universidade Estadual do Oeste do Paraná.
- Malavolta E, Vitti GC, Oliveira AS (1997). Avaliação do estado nutricional de plantas: Princípios e aplicações [Evaluation of the nutritional state of plants: Principles and applications]. Piracicaba, Potafos, 308 pages.
- Oliveira IP, Araújo RS, Dutra LG (1996). Nutrição mineral e fixação biológica de nitrogênio [Mineral fertilization and biological fixation of nitrogen]. In: ARAÚJO, R. S.; RAVA, C. A.; STONE, L. F.; ZIMMERMANN, M. J. O. *Cultura do feijoeiro comum no Brasil* [Production of the common bean in Brazil]. Piracicaba: Potafos, pp.169-216.
- Panno G, Prior M (2009). Avaliação de substratos para a germinação de crambe (*Crambe abyssinica*) [Evaluation of substrates for germination of crambe (*Crambe abyssinica*)]. *Cultivando o Saber*. 2(1):151-157. <http://www.fag.edu.br/graduacao/agronomia/csvolume22/18.pdf>
- Pitol C, Broch DL, Roscoe R (2010). Época, espaçamento e densidade de plantio [Season, spacing and density of planting]. In: PITOL C, BROCH DL, ROSCOE R (2010). (Ed.). *Tecnologias e produção: crambe* [Technologies and production: crambe] Ed. Maracaju: FUNDAÇÃO MS, 1(3):10-21.
- Rathke GW, Behrens T, Diependbrock W (2006). Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): A review. *Agric. Ecosys. Environ.* 117(2):80-108. <http://www.sciencedirect.com/science/article/pii/S0167880906001472>
- Rogério F, Santos JI, Silva TRB, Migliavacca RA, Gouveia B, Barbosa MC (2012). Efeito de doses de fósforo no desenvolvimento da cultura do crambe [Effect of phosphorus doses on crambe culture development]. *Biosci. J.* 28(1):251-255. <http://www.seer.ufu.br/index.php/biosciencejournal/article/view/13212>
- Rogério F, Silva TRB, Santos JIS, Poletine JP (2013). Phosphorus fertilization influences grain yield and oil content in crambe. *Ind. Crops Products* 41(2):266-268. <http://www.sciencedirect.com/science/article/pii/S0926669012002063>
- Roscoe R, Pitol C, Broch DL (2010). Necessidades climáticas e ciclo da cultura [Climate needs and culture cycle]. In: PITOL C, BROCH DL, ROSCOE R (2010). (Ed.). *Tecnologias e produção: crambe* [Technologies and production: crambe] 2010. 1. Ed. Maracaju: FUNDAÇÃO MS, 1(2):07-21.
- Santos JI, Rogério F, Migliavacca RA, Gouveia B, Barbosa MC (2012). Efeito da adubação potássica na cultura do crambe [Effect of potassium fertilization on the crambe culture]. *Biosci. J.* 28(3):346-350. <http://www.seer.ufu.br/index.php/biosciencejournal/article/view/13232>
- Silva TRB, Lavagnoli RR, Nolla A (2011). Zinc and phosphorus fertilization of crambe (*Crambe abyssinica* Hochst). *J. Food Agric. Environ.* 9(1):132-135. <http://world-food.net/zinc-and-phosphorus-fertilization-of-crambe-crambe-abyssinica-hoechst/>
- Soratto RP, Souza-Schlick GD, Fernandes AM, Souza EFC (2013). Effect of fertilization at sowing on nutrition and yield of crambe in second season. *Revista Brasileira de Ciência do Solo*. 37(3):658-666. http://www.scielo.br/scielo.php?pid=S0100-06832013000300012&script=sci_arttext
- Souza AV, Favaro SP, Itavo LCV, Roscoe R (2009). Caracterização química de sementes e tortas de pinhão-manso, nabo-forrageiro e crambe [Chemical characterization of seeds and cake of *Jatropha curcas*, nabo litter and crambe]. *Pesquisa Agropecuária Brasileira*. 44(10):1328-1335. <http://www.scielo.br/pdf/pab/v44n10/v44n10a17.pdf>
- Smiderle OJ, Costa LAMA (2010). Produtividade e teor de óleo de girassol em plantio direto sob quatro doses de calcário [Productivity and oil content of sunflower in no-tillage submitted to four lime concentrations]. *EMBRAPA*, P.19 (Boletim de Pesquisa e Desenvolvimento / Embrapa Roraima, 30). <http://core.kmi.open.ac.uk/display/15444241>
- Wright PA, Randall DJ, Wood CM (1988). The distribution of ammonia and H⁺ between tissue compartments in lemon sole (*Parophrys retulus*) at rest, during hypercapnia and following exercise. *J. Exp. Biol.* 136(1):149-175. <http://jeb.biologists.org/content/136/1/149.full.pdf>