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Effects of Liming on the Growth and Nutritional Status of Crambe (*Crambe abyssinica* Hochst)

Willian Yuki Watanabe de Lima Mera
Dept. of Soil Sciences, Federal Rural University of Amazonia
Capanema, Pará, Brazil
E-mail: willian.watanabe.mera@gmail.com

Ismael de Jesus Matos Viégas
Dept. of Soil Sciences, Federal Rural University of Amazonia
Capanema, Pará, Brazil
E-mail: matosviegas@hotmail.com

Jessivaldo Rodrigues Galvão (Corresponding author)
Dept. of Soil Sciences, Federal Rural University of Amazonia
Belém, Pará, Brazil
E-mail: jessigalvao50@gmail.com

Tiago Kesajiro Moraes Yakuwa
Dept. of Soil Sciences, Federal Rural University of Amazonia
Belém, Pará, Brazil
E-mail: tiagokmyakuwa@gmail.com

Alasse Oliveira da Silva
Dept. of Soil Sciences, Federal Rural University of Amazonia
Capanema, Pará, Brazil
E-mail: alasse.oliveira77@gmail.com

Dioclea Almeida Seabra Silva

Dept. of Soil Sciences, Federal Rural University of Amazonia

Capanema, Pará, Brazil

E-mail: dioclea.seabra@ufra.edu.br

Ricardo Shigueru Okumura

Dept. of Soil Sciences, Federal Rural University of Amazonia

Parauapebas, Pará, Brazil

E-mail: ricardo_okumura@hotmail.com

Jorge Cardoso de Azevedo

Dept. of Animal Production Health, Federal Rural University of Amazonia

Belém, Pará, Brazil

E-mail: jorge.azevedo1@gmail.com

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Abstract

Crambe cultivation has expanded in Brazil. The species is a promising alternative for biodiesel production since its seed contain great amounts of oil. Nevertheless, only few studies have focused on the growth and nutritional requirements of crambe cultivated in acidic soils. Thus, this study aimed to evaluate the effects of liming on the growth and nutrient accumulation of crambe cultivated in a Yellow Latosol of medium texture. The experiment was carried out using a randomized complete block design. The treatments consisted of different soil base saturation levels (0%, 20%, 40%, 60% and 80%) with five replications. Plant height, leaf length, leaf width and the number of seeds were evaluated 90 days after planting. The plant material was separated into leaves, stem, seeds and roots, which were oven dried at 70 ºC until constant weight. Analysis of variance was performed, followed by data regression when significant at 5% probability level by the F test. Crambe responded positively to liming in the soil under study at a base saturation of 56.95% as a function of the biometric variables. The increase in the base saturation of the soil to up to 60% promoted a drastic reduction in plant growth and, therefore, in the final grain yield. The decreasing order of the leaf nutritional content at 56.95% base saturation was: N>Ca>K>Mg>S>P>Fe>B>Mn>Zn> Cu.

Keywords: acidic soil; base saturation, plant growth; nutrient accumulation

1. Introduction

Crambe (*Crambe abyssinica* Hochst), which belongs to the Brassicaceae family, is a species of great adaptability to different edaphoclimatic conditions, presenting rusticity, precocity, tolerance to water deficit, short production cycle, as well as resistance to pests (*Agrotis* spp., *Spodoptera* spp. e *B. brassicae*) and diseases (*Alternaria brassicicola* and TuMV) (Colodetti et al., 2012). Thus, the cultivation of crambe represents a great alternative for crop rotation, with a high potential for expansion for the growing period, which is different from other temporary crops, since the sowing season does not coincide with those of grain crops, such as soybeans and maize. Since the creation of the Brazilian National Program for the use and production of biodiesel (PNPB), in 2004, studies focusing on crambe have shown its potential for biodiesel production, since its seeds can present up to 36% of oil content (Donadon et al., 2015), producing high quality biodiesel (Rosa et al., 2014).

Crambe cultivation can be compromised in the presence of aluminum Al^{3+} (Bassegio et al., 2016; Rosmaninho et al., 2019) and low levels of calcium (Ca) and magnesium (Mg) in the soil. Successful crambe cultivation has been carried out at pH values higher than 5.8 in eutrophic soils (Pitol et al., 2010). According to Janegitz et al. (2010) and Silva et al. (2017), suitable base saturations for the development and production in medium and sandy textured soils are V% = 50-65% and V % = 70%, respectively. However, there is no specific recommendation for the crop, and only few scientific studies have focused on showing the amount of essential nutrients required by crambe (Alves et al., 2016).

The soils of the Amazon region are mostly constituted by Oxisols and Ultisols (Souza et al., 2018), which present high acidity, high exchangeable Al contents, low availability of basic cations, such as Ca and Mg, low availability of phosphorus (P) and micronutrients, such as boron (B) and cupper (Cu) (Veloso et al., 2001). Thus, since plant growth is limited on these soils, liming is considered one of the least expensive and effective practices to raise the soil pH, as well as its cation exchange capacity and nutrient availability (Li et al., 2019). Under soil acidity conditions, lime application promotes increases in soil pH, as well as Al^{3+} neutralization and Ca and Mg supply, since the lime dissolution products ($CaCO_3$) react with soil colloids, displacing Ca and Mg to solution; $CaCO_3$ and $MgCO_3$ react with H^+, releasing H_2O and CO_2 (Holland et al., 2018), while Al^{3+} is precipitated by reaction with OH^-, forming aluminum hydroxide (Melo et al., 2019).

This study evaluated the effects of liming on growth and nutrient accumulation of crambe in Yellow Latosol soil under greenhouse conditions at Igarapé-Açu, Federal Rural University of Amazonia, Brazil.

2. Material and Methods

2.1 Experimental Area

The experiment was carried out under greenhouse conditions at the experimental farm of Igarapé-Açu (FEIGA) from the Federal Rural University of Amazonia, Brazil. The soil is classified as Latosol of medium texture (Embrapa, 2018), and it was collected in the 0-20 cm deep layer. The chemical attributes of the soil prior to the experiment and after liming application were evaluated using the methodology described by Embrapa (1997) and are shown in Table 1.

Table 1. Soil chemical attributes prior to the experiment and after liming application.

Treatment	pH	C	OM	P	K	Na	Al	Ca	Ca+Mg	H+Al	CEC		Saturation	
											Tot.	Efet.	Base	Al
	H_2O	----g kg^{-1}----		--mg dm^{-3}--			----------$cmol_c$ dm^{-3}----------				$cmol_c/dm^3$		V%	M%
Prior to the experiment														
	5.2	---	15.43	2	15	7	0.4	0.6	1	4.13	6.27	---	17.05	27.23
After liming application														
0%	5.54	13.93	24.03	14	44	12	0.06	2.56	3.28	3.32	6.77	3.51	50.93	1.71
20%	5.04	15.25	26.31	16	46	13	0.07	2.87	4.12	3.25	7.54	4.36	56.95	1.60
40%	6.39	14.24	24.56	15	41	12	0.04	3.01	4.08	3.40	7.64	4.28	55.50	0.94
60%	5.94	12.58	21.70	13	39	13	0.02	2.99	4.19	1.36	5.70	4.36	76.17	0.46
80%	5.59	12.54	21.63	14	43	13	0.00	3.65	5.41	1.06	6.63	5.58	84.07	0.00

2.2 Experimental Design and Treatments

The experiment was carried out using a randomized complete block design, consisting of five treatments: 0%, 20%, 40%, 60% and 80% of base saturation, with five replications. The calculation to increase the base saturation (Equation 1) was carried out according to the methodology proposed by Raij (2011). The application was performed using dolomitic limestone, consisting of 32% CaO, 15% MgO, 95% NP and 91% of total relative neutralization power (TRNP), which was homogeneously mixed in the soil and incubated for a period of 30 days (Silva et al., 2017). The lime content in the treatments were determined using Eq 1.

$$LR = \frac{CEC\,(V2-V1)}{TRNP} \qquad (1)$$

LR = limestone requirement (in t ha^{-1}) with TRNP corrected to 100%;

CEC = soil cation exchange capacity at pH 7.0 (in $cmol_c$ dm^{-3}), which was calculated by: $[Ca^{2+} + Mg^{2+} + K^{+} + Na^{+} + (H^{+}+Al^{3+})]$;

V_2 = percentage of base saturation recommended for the crop (60%);

V_1 = percentage of the initial base saturation of the soil, calculated by: SB x 100/CEC;

SB = sum of exchangeable bases (Ca^{2+} + Mg^{2+} + K^+ + Na^+) (in $cmol_c$ dm^{-3});

TRNP = total relative neutralizing power (%).

After incubation, two seedlings of crambe from the cultivar *FMS Brilhante* were planted in pots with a capacity of 5 kg of air-dried soil. The plants were irrigated to maintain the humidity close to 70% of the field capacity, which was carried out by weighting the pots. Soil fertilization was carried out by applying 150 mg of N per kg of soil (urea), 50 mg of P per kg of soil (Na_2HPO_4), 100 mg K per kg of soil (KCl), 20 mg of S per kg of soil (sodium sulfate), 0.5 mg of B per kg of soil (boric acid), 0.5 mg of Cu per kg of soil (copper sulfate), 0.7 mg of Mn per kg of soil (manganese sulfate) and 0.6 mg of Zn per kg of soil (magnesium sulfate).

After 90 days, plant height and leaf length and width were measured using a metric ruler and the number of leaves was counted (Vasconcelos et al., 2015). The collected material was separated into leaves, stem, seeds and roots, packed in paper bags and dried in a forced air circulation oven at 70 ºC until constant weight, followed by analysis of the contents of the macro and micronutrients (Miyazawa et al., 1992).

The crop productivity, foliar macro and micronutrient contents, and leaf cation contents (LCC) were calculated using Equations 2, 3, 4 and 5, respectively, according to Souza et al. (2014), Silva et al. (2018) and Malavolta (2006).

The calculation to obtain crop productivity were determined using Eq 2.

$$Productivity\ \left(\frac{kg}{ha}\right) = number\ of\ plants\ \left(\frac{pl}{ha}\right) \times number\ of\ grains\ \left(\frac{gr}{pl}\right) \times grain\ weight\ (Kg) \quad (2)$$

The calculation to obtain macro (A) and micronutrient (B) leaf accumulation were determined using Eq 3.

$$A\ (g) = \frac{foliar\ content\ (g/kg) \times leaf\ dry\ mass\ (g)}{1000} \quad (3)$$

$$B\ (mg) = \frac{foliar\ content\ (mg/kg) \times leaf\ dry\ mass\ (g)}{1000} \quad (4)$$

The calculation of the leaf cation contents (LCC), in cmol kg^{-1} of dry matter were determined using Eq 4.

$$LLC = \left(\frac{leaf\ contents\ of\ K}{39.1} + \frac{leaf\ contents\ of\ Mg}{12.15} + \frac{leaf\ contents\ of\ Ca}{20.05}\right) \times 1000 \quad (5)$$

2.3 Statistical Analysis

The experimental data were initially submitted to the Shapiro-Wilks and Levene tests ($p<0.01$) to verify residual normality and homoscedasticity, respectively. After meeting the basic assumptions, the polynomial regression analysis was performed, observing the significance by the F test ($p <0.05$) of the analysis of variance, using SPSS 17.0 (SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0 Chicago: SPSS Inc.) and Minitab 18 (Minitab 18 Statistical Software).

3. Results and Discussion

The highest plant height was observed for the base saturation percentage of 28%, with a maximum value of 74.83 cm. There were drastic reductions for V% values higher than 60% (Figure 1A). As for the number of leaves, the highest value (8.8) was obtained for V% = 44%, with a significant reduction in extreme levels of V% (0 and 80%) (Figure 1B). Low (or high) pH values have been reported to interfere with the availability of assimilable forms of some nutrients. Janegitz et al. (2010) and Carvalho et al. (2012) observed smaller numbers of leaves at saturations levels below 20% and close to 80%.

Regarding leaf width (Figure 1B) and length (Figure 1D), base saturations of 29.50 and 36% caused leaves to be wider (Y maximum 3.34 cm) and longer leaves (with maximum Y of 4.61 cm), respectively. The increase in the base saturation to higher values resulted in smaller leaf area. Janegitz et al. (2010) observed similar behavior, in which the plants responded negatively to the saturation increase to values higher than 65%. According to van Kleunen & Fischer (2005), higher leaf area is important for the better use of light and the capture of atmospheric CO_2, which, in addition to other environmental factors, ensure the growth and development of plants.

Regarding productivity (Figure 1E), there was a higher base saturation yield of 29% (with maximum Y of 2004.76 kg ha^{-1} of dry seeds and 2548.9 kg ha^{-1} of fresh seeds). The grain yield obtained was similar to that described by Oplinger et al. (1991) for crambe and by Janegitz et al. (2010) for the cultivar *FMS brilhante*. As for Pitol et al. (2010), the authors obtained lower grain yield averages between 1000 and 1500 kg ha^{-1}.

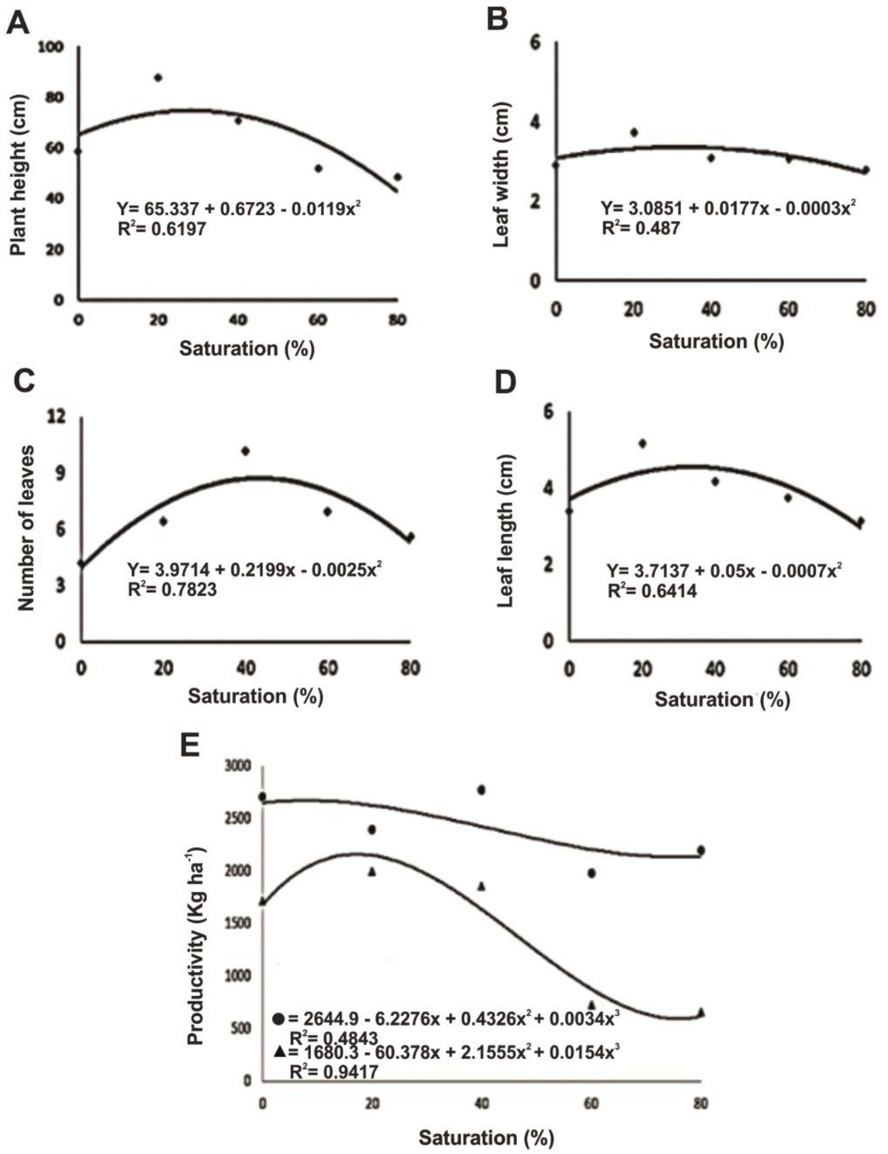

Figure 1. Plant height (A), number of leaves (C), leaf width (B), leaf length (D), fresh (●) and dried (▲) grain productivity (E) per hectare as a function of base saturation in a Latool of medium texture

As for the contents of the leaf macronutrients (Table 2 and Figure 2), there were increases in the contents of P, Ca, Mg and S with increasing levels of base saturation. However, the maximum total dry mass production (TDM) was obtained at V% = 20%. Thus, considering that the V% of maximum TDM is adequate for crambe development, it was verified that the recommended leaf contents, in g kg^{-1}, were 2.8 (P), 25.5 (Ca), 4.8 (Mg) and 4.11 (S). Malavolta (2006) explained that with the increase in pH, some nutrients become more available to plants. Thus, pH presents a direct influence on nutrient absorption, in which the greater availability of a nutrient in the soil solution promotes greater absorption by the plant root system.

There were decreases in the contents of K as a function of saturation increases, which were likely due to the inhibitory action of calcium. Marschner (2012) and Malavolta (2006) reported that K^+ ions present reduced absorption in the presence of high Ca^{2+} levels because they compete for the same path to cross the plasma membrane. Although there were no visual symptoms of K deficiency, plants with the lowest nutrient content, especially at 60% of base saturation (when there were higher Ca levels in the soil), showed lower growth and productivity when compared with the other treatments.

Another important aspect is the interaction between N and K, in which, although high levels of N were obtained in the leaves (up to 53.97 g kg^{-1}), plant productivity was not negatively affected. Potassium uptake by crambe also provided better plant development, and, consequently, an increase in the contents of dry mass, in which the maximum total dry mass obtained at the base saturation of 20% coincided with high levels of N and K and low levels of Al. Ledur et al. (2016) found similar behavior.

Other nutritional interactions observed in the present study and reported in the literature (Shelp et al., 1995) are related to the antagonist interaction between N and B. The absorption of B did not follow the same patterns of the plant growth rate and high nitrogen concentration promoted reduction in B contents. Kojoi et al. (2009) stated that K and S leaf contents in cauliflower were reduced with increasing boron doses, and the results of the present experiment behaved similarly, so that the V% with maximum TDM presented the leaf content of 139.39 mg kg^{-1} of B.

Tito et al. (2014) observed a reduction in grain productivity promoted by the low Cu contents, although no detrimental effect on the growth of crambe plants was identified. However, this fact was not observed in the present study (Figure 2 C), probably because the micronutrient demand for the crop is low (Soratto et al., 2013), or also due to the excess of N, reported in the literature, as a consequence of the N-Cu interaction, in which the highest growth promotes higher micronutrient demand, depending on the soil nutrient availability (Mattos Júnior et al., 2010).

Table 2. Leaf contents of macro and micronutrients and aluminum in normal and deficient crambe plants reported in the literature and values observed in the present study

Treatment	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Al
Values reported in the literature (macro: g kg^{-1} | micro: mg kg^{-1})												
Normal	33.1[b]	2.2[b]	19.4[c]	28.4[b]	5.3[b]	4.4[a]	234.4[c]	10.3[b]	1377[b]	83.3[b]	71[c]	*143.18[d]
Deficient	<20.6[a]	<2.1[c]	<11.1[c]	<16.2[a]	<1.8[c]	<1.2[c]	<69.2[c]	<4.8[b]	<1.04[b]	<30.4[b]	<51.8[e]	---
Values observed in the experiment (macro: g kg^{-1} | micro: mg kg^{-1})												
0	62.36	2.89	14.53	26.75	4.88	3.51	214.22	0.5	920	83.55	54.19	470
20	53.97	2.8	21.33	25.5	4.8	4.11	139.39	0.5	615	68.5	56.33	207
40	55.41	2.77	12.53	29.25	7.33	4.41	181.57	0.5	805	59.7	52.95	730
60	38.65	3.34	12.43	31.75	6.18	4.01	97.73	1.7	3770	51.2	55.97	1020
80	53.06	4.15	12.08	33.25	8.6	4.91	153.59	2.8	2385	40.65	56.17	3475

Source: [a]Mauad et al. (2013); [b]Soratto et al. (2013); [c]Brito (2018); [d]Rosmaninho et al. (2019); [e]Tito et al. (2016). * Tolerable value

According to Malavolta (2006), the availability of Fe in the soil increases at more acidic pH. Nevertheless, in the present study, a high leaf Fe content (615 mg kg^{-1}) was observed (Figure 2). Crambe demands large amounts of Fe when compared with other grain crops, such as soybean

(*Glycini max*) and beans (*Phaseolus vulgaris*) (Malavolta, 2006; Soratto et al., 2013).

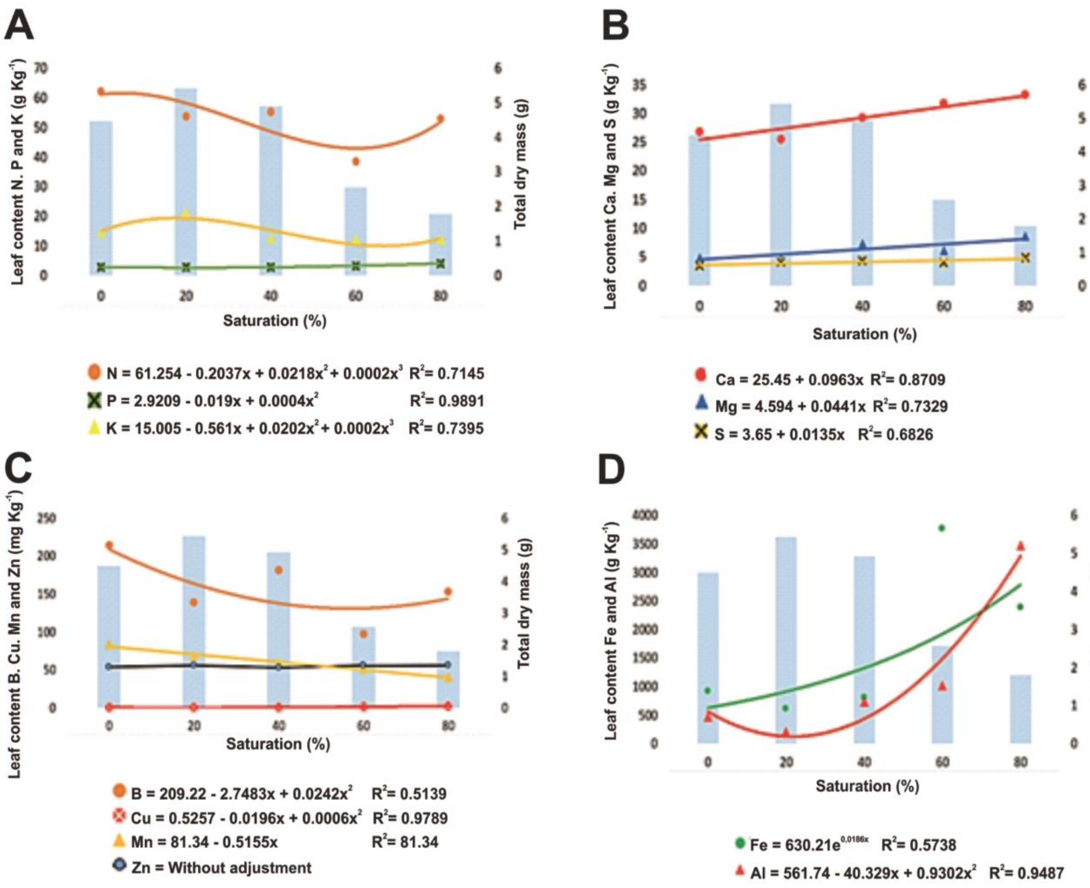

Figure 2. Contents of macronutrients (A and B), micronutrients (C) and aluminum (D) and total dry mass production as a function of base saturation in a Latosol of medium texture

There was an increase in the contents of Al with the increase of the soil base saturation, with the highest values obtained for V% = 60% and 80%. There was also a reduction of total dry mass, due to a probable nutritional imbalance with the high Al content in the soil. Despite the application of lime in the soil, the insufficient time of reaction of the lime in the soil did not allow the increase of the soil pH due to the precipitation of Al^{3+} in the form of $Al(OH)_3$, which presents low solubility (Li & Johnson, 2016). Malavolta (2006) and Marschner (2012) highlighted the beneficial action of Al at low concentrations, conferring an increase in plant growth rate. Nevertheless, the same authors pointed out the toxic effect of this element. On the other hand, Rosmaninho et al. (2019) evaluated the tolerance of crambe to aluminum and observed a reduction in root growth, TDM and grain productivity. Colodetti et al. (2015) observed a reduction in the hypocotyl and root length of crambe seedlings, compromising the initial growth of the plant. Costa et al. (2014) observed strong interference in the absorption of N and K. All of these aspects were also observed in the present study, in which the maximum grain productivity and TDM peaks were obtained at the lowest Al content in the leaves (207 mg kg^{-1}). The high demands of N, Ca, K and Fe by crambe were also observed in other grain species, such as soybeans, rapeseed and beans (Malavolta, 2006; Soratto et al., 2013).

Malavolta (2006) described that nutrients such as Ca, Mg and K participate in several mechanisms and structures that are essential to plant development. However, high levels of Ca and Mg generate competitive inhibition with K. Although the presence of K or Mg at levels less than 25% of the LCC (Leaf Cation Content) represents a deficiency of these nutrients, it should be adjusted for the specificities of each culture. For crambe, the greater participation of Ca, and, consequently, lower participation of K and Mg, has been reported by Mauad et al. (2013) and Soratto et al. (2013), via analyzes of the leaf contents. Figures 3 and 4 present fertigrams[1] with adequate nutrient contents as a function of plant productivity When comparing the percentages of individual participation of these cations in the different treatments, there was a greater presence of Ca in the leaves, accounting for nearly 60% of the LCC (Figure 3). On the other hand, in Figure 4, it was verified high presence of N in the treatments 0% to 40% and the exorbitant percentage of Fe in the treatment 60%. The treatment with 20% of base saturation was the closest one to the ideal conditions for the good development of the plant.

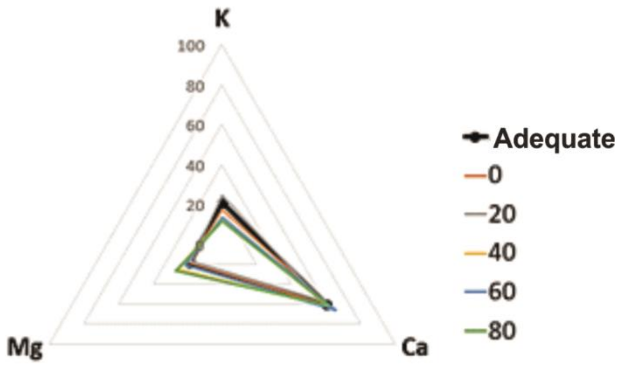

Figure 3. Fertigram of leaf cation contents (LCC) in the different treatments

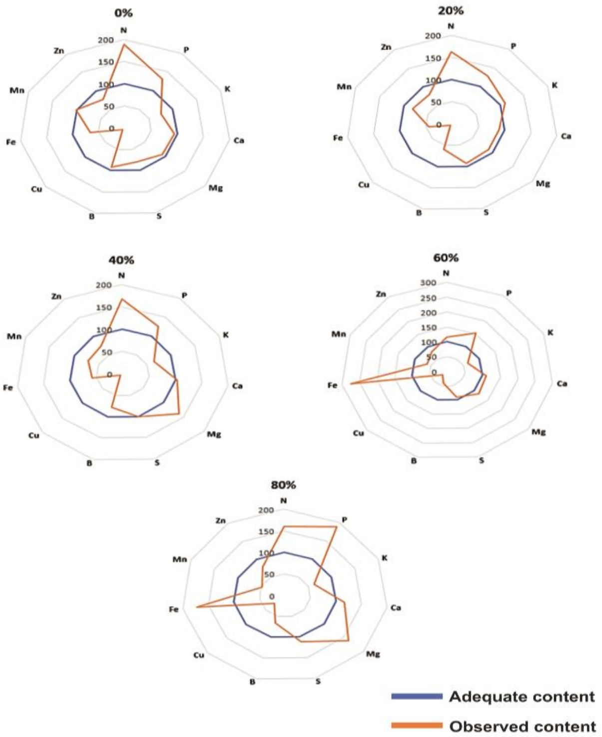

Figure 4. Fertigrams of leaf nutrient contents in the different treatments

[1]Radar graphs with radial divisions plotted for each element, showing the optimal values for the crop and the values obtained in the leaf analysis of the treatments. Points beyond the optimal value polygon indicate excess and points below it (within the polygon) indicate lack (Martinez et al., 1999.

4. Conclusion

Crambe plants responded satisfactorily to liming at base saturation levels ranging from 20% to 56.95% as a function of the biometric variables evaluated in the Yellow Latosol of medium texture of the present study.

Base saturation levels higher than 60% promoted drastic reductions in plant growth and grain productivity.

At the base saturation levels of 57%, the following decreasing order of macro and micronutrient contents in the leaf tissues was: N>Ca>K>Mg>S>P>Fe>B>Mn>Zn>Cu.

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