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Agronomic and economic efficiency of nitrogen fertilization in garlic culture

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This study was aimed at evaluating the influence of nitrogen fertilization on the productivity of garlic culture. The experiment was carried out at Goiás State University, Ipameri Unit. The randomized block design was adopted for the experiment, with six treatments and four replications. The treatment consisted of nitrogen doses in cover crop (0; 40; 80; 160; 320 and 640 kg ha^{-1}), applied at 15, 30 and 70 days after planting. The cultivar used was *Allium sativum* L. cv. Ito, from the Roxo Nobre group. Before each N application, the plants components, the presence of photosynthetic pigments and of N content in leaves were assessed. The bulbs were harvested at 100 days after planting and evaluated as to total, commercial productivity, and economic viability. Among the components produced, the average bulb weight and the average number of cloves per bulb were mostly determinant to production. Nitrogen-based fertilization that enabled the predominance of classes 5 and 6 bulbs. There was no significant incidence of pseudo-stem tillers. The doses with maximum agronomic and economic efficiency were 251.7 and 267.2 kg of N ha^{-1}, respectively, though with a considerable safety margin.
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Key words: *Allium sativum*, pseudo stem tillering, productivity.

INTRODUCTION

In Brazil, garlic (*Allium sativum* L.) is the fourth most economically important vegetable, cultivated mainly by small farmers (Marouelli et al., 2002a). In the past decade, the Brazilian total production of garlic increased, under Goiás leadership, representing 30.0% of domestic production (CONAB, 2014). This achievement was due to several factors such as mechanization, rationalized irrigation, planting intensification, favorable climate, use of noble garlic cultivars, vernalization, and use of virus-free garlic (Resende et al., 2004).

In spite of the increasing national garlic production, Brazil is still the world's greatest importer. The deficit in production is a reflection of the low competitiveness of domestic garlic against Argentina, as they present lower production costs, enjoy more favorable climate, and have subsidy policies. Moreover, improper irrigation and fertilization management also constitute limiting factors to the production of good quality garlic (Souza and Macedo 2009).

According to Marcussi et al. (2004), mineral nutrition is

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a primary factor in the production of *oleracea* species, accounting for increased productivity and better quality of harvested products. Resende and Cecílio Filho (2009) point out that properly provided nutrients, in both quantity and quality, are very important in the cultivation of garlic, since most Brazilians soils have low natural fertility.

Therefore, optimizing the provision of nutrients for maximum productivity and quality of the garlic culture is the solution, especially when considering that the globalization of economy interferes significantly in the quality of traded garlic (Souza and Macêdo, 2009).

In terms of plant development and production, Nitrogen (N) is the most responsive nutrient, contributing to increased productivity and quality of bulbs. Macêdo et al. (2009) observed that an N dose of up to 180 kg ha^{-1} enabled linear gains in the total productivity of cv. Roxo Pérola de Caçador. Fernandes et al. (2010) observed increasing linear behavior, and the dose of 320 kg ha^{-1} of N yield values of 9.1 t ha^{-1} of total productivity of cv. Caçador LV. However, excessive Nitrogen-based fertilization are responsible for the occurrence of pseudo-stem tillering. Such anomaly is one of the biggest problems in the garlic culture, particularly in the cultivars that produce the so-called “noble garlic” (Büll et al., 2002). This variability in results may be related to diversification in the garlic production system. Thus, this study was intended for verifying the influence of Nitrogen fertilization in agronomic characteristics in the total and commercial productivity of noble garlic culture.

MATERIALS AND METHODS

The study was carried out at Goiás State University, Ipameri Unit, in the municipality of Ipameri, GO, whose geographic coordinates are: 17°43’20”S and 48°09’44"W. The altitude is 800 m, and the climate, according to Köppen’s classification, is the Aw type, featuring high temperatures with summer rain and winter drought.

The soil in the experiment area is classified as Red-Yellow Distrophic Oxisol (Embrapa, 2006). Physical-chemical analysis of the 0 to 0.2 m-deep layer found the following characteristics: clay content = 405 g kg^{-1}; silt content = 153 g kg^{-1}; sand content = 442 g kg^{-1}; pH = 5.8; P = 5.5 mg dm^{-3}; K = 130 mg dm^{-3}; Al = 0.2 cmolc dm^{-3}; Ca = 1.9 cmolc dm^{-3}; Mg = 0.5 cmolc dm^{-3}; H + Al = 2.0 cmolc dm^{-3}; Co = 0.06 mg dm^{-3}; Zn = 1.3 mg dm^{-3}; B = 0.2 mg dm^{-3}; Cu = 2.1 mg dm^{-3}; Fe = 86.1 mg dm^{-3}; Mn = 21.9 mg dm^{-3}; Mo = 0.08 mg dm^{-3}; CTC = 4.7 cmolc dm^{-3}; Base saturation = 58%; Organic matter = 30 g dm^{-3}. Liming was accomplished by applying 1,225 kg ha^{-1} of dolomitic limestone (PRNT 92%) aimed at increasing the saturation of bases to 80%, 60 days before sowing, incorporated with chisel plow into the 0 to 0.2 m layer. Subsequently, the soil was harrowed twice for leveling the ground.

The treatment was comprised of Nitrogen doses in crop cover (0; 40; 80; 160; 320 and 640 kg ha^{-1}) applied through fertilizing irrigation sourced from urea (45% of N). The randomized block design was applied, with four replications. The plots consisted of six simple 2.0-m-long rows on a bed with 1.4 m width and 0.15 m height. The rows were spaced at 0.2 m, with 0.10 m between cloves and 0.80 m between beds. The plot usable area was 1.28 m^2, including the four central lines and excluding two plants from the edges.

The cultivar used was Ito, from the Noble Purple Group. The seed bulbs were submitted to pre-planting vernalization, being stored in a cold chamber at the average temperature of 4°C, for a period of 50 days. The cloves were sieved for size, and those retained in sieve 2 (10 x 20 mm mesh) were used for planting. Transplanting was carried out on 18 April 2012, aiming to obtain an average population of 450 thousand plants ha^{-1}. The cloves were previously treated in a solution of 2.5% Iprodione for prevention against soil pathogens.

Soil fertilization was accomplished during de preparation of beds, by applying 150, 750 and 450 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. The source of micronutrients was a leaf fertilizer containing 18.5% S; 0.5% B; 1% Cu; 25% Mn; 4% Zn, at a dose of 9 kg ha^{-1}, divided into three equal applications at 5, 35 and 65 days after planting (DAP). In cover Nitrogen fertilization was carried out according to the doses established in the treatments, calculated as per the crop phenological stage, by applying 25% of the dose at the 4-leaf stage, 25% at the 6-leaf stage, and 50% at the clove growing stage.

Weekly sprayings were made, aiming to prevent and control diseases, alternating fungicides based on 80% Mancozeb, 20% Tebuconazole, 50% Thiophanate-methyl, 50% Boscalid and 84% Copper Oxychloride. In order to control plagues, insecticides 5% Beta-cyfluthrin, 24% Chlorfenapyr and 70% Imidacloprid were applied through alternated sprayings. Weed control was mechanic, through houging.

The experiment irrigation was done every two days, by applying a 12 mm water blade through conventional sprinkling, and was interrupted when there was equal or superior precipitation than the established blade. At 45 DAP, irrigation was suspended for a period of 15 days in order to reduce excessive sprouting (Macêdo et al., 2006). At 14, 29, 69 and 97 DAP samples were collected, each composed of two plants harvested in the external rows of the plot usable area, one from each row, to determine the contents of chlorophyll *a* and *b* and N in leaves; the number of photosynthetically active leaves, stem diameter and plant height.

In order to determine the chlorophyll content, two 6 mm foliar disks were extracted from fully expanded leaves and placed in glass jars containing dimethylsulfoxide (DMSO). Subsequently, extraction was made in water bath at 65°C for one hour. Aliquots were then extracted for spectrophotometric reading at 480, 649 and 665 nm. Thus, the contents of chlorophyll *a* and *b* were determined through the equation proposed by Wellburn (1994).

In order to determine the total content of N in the leaves, the samples were dried out in a forced ventilation oven at 65°C for 72 h, and then the dry matter was weighed, ground and submitted to nitric and ammoniacal nitrogen analysis, according to the methodology described by Cataldo et al. (1974, 1975).

The number of photosynthetically active leaves was determined by mere counting of leaves per plant. The stem diameter was measured at the base of the pseudo stem, and the plant height was measured through the vertical distance between the pseudo stem base and the end of the junction of all the leaves. At 103 DAP the harvest was accomplished, when all the plants from the plot usable area were collected and submitted to the drying process (shadow drying of leaves) for 20 days. Then the bulbs were processed and cleaned. After the drying period, evaluations were made to the production components for total and commercial productivity, maximum economically efficient dose and economic viability. In order to do so, all the plants harvested by plot were analyzed.

The evaluated production components were the following: average mass of bulbs, average mass of cloves, average number of cloves per bulb, percentage of pseudo stem tillered bulbs, bulb transversal diameter, which were ranked in classes according to Ordinance no. 242, of 17 September 1992 of MAPA: class 3 (longer than 32 up to 37 mm), class 4 (longer than 37 up to 42 mm), class 5 (longer than 42 up to 47 mm), class 6 (longer than 47 up to 56 mm) class 7 (>56 mm).

The total production analysis took into consideration the bulbs free of plagues, diseases and abnormalities, and the commercial

Table 1. Basic minimum price of garlic class according to the bulb transversal diameter, stated in Reais per kilogram.

Class	Harvest					
	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	Average
	Basic minimum price (R$ kg^{-1})					
Class 7	3.17	3.17	3.17	3.53	3.77	3.36
Class 6	2.64	2.64	2.64	2.94	3.14	2.80
Class 5	2.20	2.20	2.20	2.45	2.62	2.33
Class 4	1.83	1.83	1.83	2.04	2.18	1.94
Class 3	1.47	1.47	1.47	1.63	1.75	1.56

Source: Adaptation of CONAB releases - Title 42, Specific Rules of Garlic - 2008 to 2012 Crops.

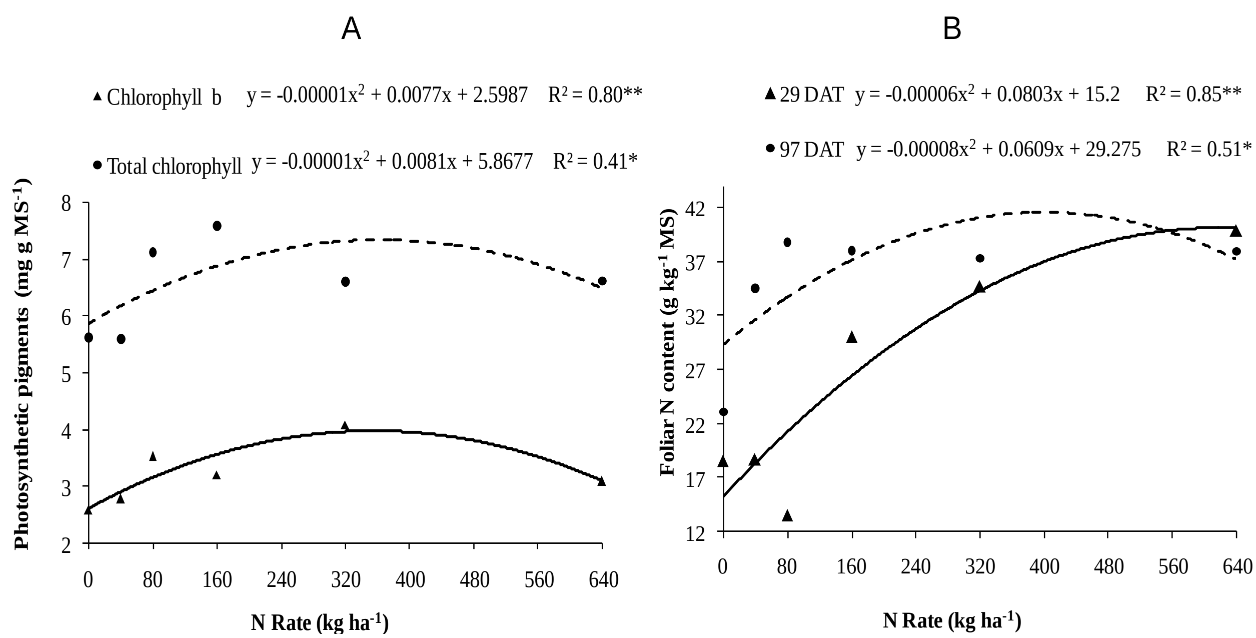

Figure 1. Effect of in-cover Nitrogen fertilization of garlic crop on (A) chlorophyll *b* content and total chlorophyll content; and (B) N content in leaves at 29 and 97 days after planting.

production analysis considered bulbs without pseudo-stem tillering and with transversal diameter longer than 32 mm.

In order to obtain the maximum economically efficient dose and the net revenue, apart from the in-cover Nitrogen-based fertilizer cost, all other fixed costs of the garlic crop production were taken into consideration.

Calculations of economic viability were based on the average price recorded along five years (2007 to 2012), considering the value charged by kilogram (R$ kg^{-1}) of each bulb class of the noble purple group (Table 1). As to the cost of the Nitrogen source applied in the in-cover fertilization, urea (45% of N), the average price per N ton (R$ ton^{-1}) was R$ 3,321.09 (IEA, 2012). The results referring to the ranking of bulbs by class were converted into arcsin functions before analysis and, together with the other results, submitted to variance and regression analyses.

RESULTS AND DISCUSSION

The content of chlorophyll *b* and total chlorophyll presented significant square adjustments only at 97 DAP, when doses of 385 and 405 kg de N ha^{-1} yielded values of 4.08 and 7.50 mg per g of MS^{-1} photosynthetic pigments, respectively (Figure 1A). In previous evaluations, the Nitrogen-based fertilization applied in the treatments is likely to have yielded enough chlorophyll contents for the plant development. Similar results were observed by Lima (2005), where chlorophyll contents in garlic crop were significant at 100 DAP with the application of a 360 kg of N ha^{-1} dose.

A square adjustment to the foliar N content was observed with in-cover Doses of N. The highest foliar concentration of N resulted from the estimated doses of 669.1 and 380.6 kg of N ha^{-1} at 29 and 97 DAP, respectively (Figure 1B). These results are higher than those found by Fernandes (2008), who observed maximum N content (30.8 g kg^{-1} of MS) with a dose of 320 kg ha^{-1}. Nonetheless, they are consistent with those obtained by Lima (2005), who observed a foliar N content

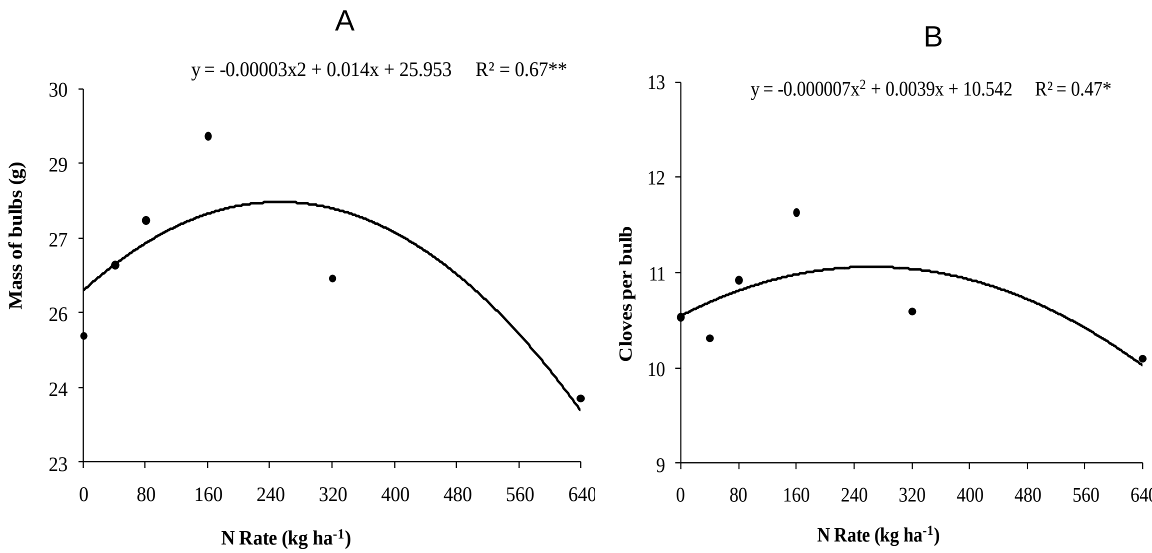

Figure 2. Effect of in-cover Nitrogen fertilization of garlic crop on A) average mass of garlic bulbs; and B) average number of cloves per garlic bulb.

of 32.4 g kg^{-1} of MS at 100 DAP when applying a dose of 360 kg ha^{-1} of N. The production components were affected by the in-cover Nitrogen-based fertilization, except for the clover average mass and the incidence of pseudo-stem tillered bulbs.

The tested N doses did not cause significant pseudo-stem tillering, reaching an average rate of 7.5% of the value considered acceptable according to production patterns. This can be explained by the certainty of the hidric stress, which probably prevented the occurrence of such anomaly. A similar result was recorded by Macêdo et al. (2009), who, in studies of Nitrogen and Molybdenum doses applied to a vernalized garlic crop in Lavras municipality, in southern Minas Gerais state, did not observe any effect of the treatment on that physiological anomaly, with an average rate of 8.7%. However, Lima et al. (2008) observed a linear effect in the occurrence of such anomaly proportional to the application of Nitrogen, as each 100 kg ha^{-1} of N applied caused pseudo-stem tillered bulbs to increase by 3.5%.

Another relevant aspect of the incidence of super sprouting is the level of response of each cultivar to the N supply, particularly in cover. Büll et al. (2002) pointed out that even though pseudo-stem tillering is related to excessive supply of Nitrogen, noble cultivars may react differently to yearly climatic influence, as they are forcefully adapted by vernalization to cultivation in the Cerrado climate conditions.

The average mass of bulbs presented square adjustment to Nitrogen doses, and the estimated dose of 233.3 kg ha^{-1} of N enabled a maximum mass of 27.56 g (Figure 2A). In spite of the difference, a decrease or increase of up to 100 kg ha^{-1} of N related to the estimated maximum dose indicates a variation of only 1.08% in the average mass of bulbs. Backes et al. (2008), working with a Roxo Pérola de Caçador cultivar, observed a square effect of the N doses, which reached a maximum 36 g bulb average with the established dose of 268 kg ha^{-1}. A study accomplished by Resende and Souza (2001a) recorded linear gains in bulb average mass with the application of N doses of up to 120 kg ha^{-1}. However, such result differs from those found by Lima et al. (2008) and Macêdo et al. (2009), which did not find significant differences for that component with doses up to 360 and 180 kg ha^{-1} of N, respectively.

The maximum number of cloves by bulb was 11.08 obtained with the estimated dose of 278.5 kg ha^{-1} of N (Figure 2B). Despite the statistical significance, the effect observed between the minimum and maximum applications of N was only 3.5%, a value corresponding to 0.4 cloves per bulb. This low relation is likely due to the fact that such component is genetic in nature, hence inherent in the cultivar. Resende and Souza (2001a) found a linear increase in the number of cloves per bulb arising from an increase in Nitrogen doses up to 120 kg ha^{-1}. Yet, studies carried out by Resende and Souza (2001b) and Macêdo et al. (2009) did not report on effects of the treatments on the average number of cloves per bulb with the application of N doses up to 160 and 180 kg ha^{-1}, respectively.

Nitrogen fertilization was responsive in bulb classes with respect to the transversal diameter, presenting square adjustments in all of the classes (Figure 3). A directly proportional effect of N is observed through the increased percentage of bulbs ranked in classes 5 and 6, whereas an inversely proportional effect is seen in bulbs from classes 3 and 4. The formation of bulbs with transversal diameter higher than 56 mm is not recorded in class 7 bulbs.

These results are similar to those presented by Macêdo

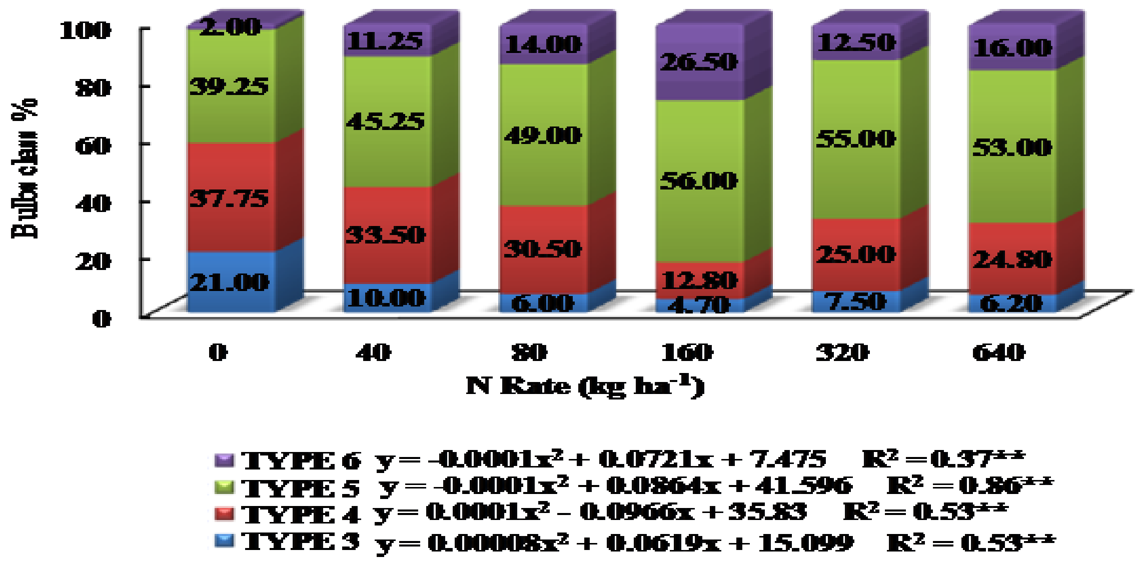

Figure 3. Percentage of garlic bulbs in classes 3 to 6 resulting from in-cover Nitrogen fertilization.

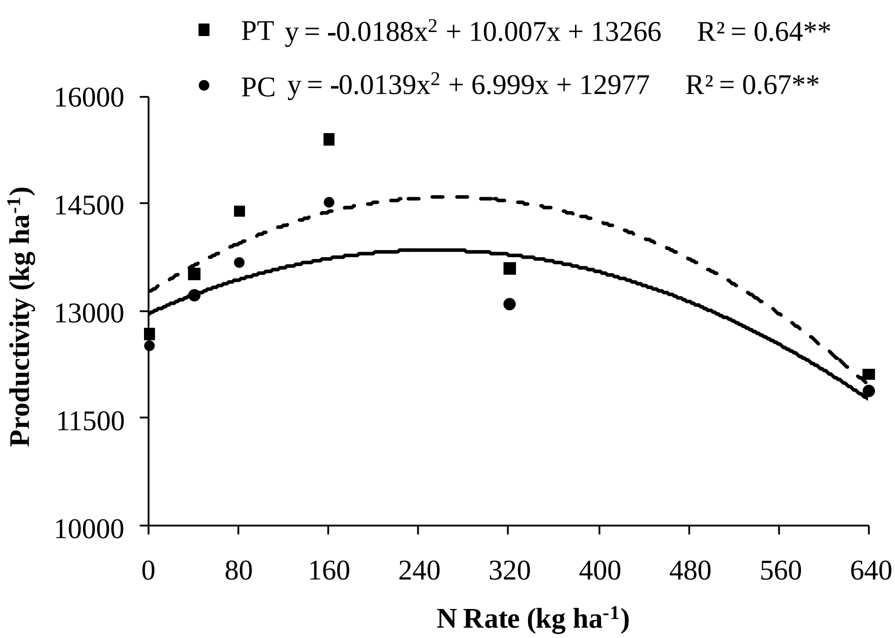

Figure 4. Total and commercial productivity of garlic crop as a result of Nitrogen fertilization.

et al. (2009), where an increase in Nitrogen in cover up to 180 kg ha^{-1} enabled an increase in the percentage of class 6 bulbs, pointing to linear gains in total and commercial productivity. In turn, Backes et al. (2008), observed in similar studies higher concentration of bulbs in classes 5 and 6 with the application of doses up to 160 kg ha^{-1} of N. However, when the dose was increased to 320 kg ha^{-1}, there was a predominance of bulbs from classes 3 and 4, which have lower economic value. The total productivity of bulbs was responsive to the Doses of N applied in cover, expressing square adjustment (Figure 4); the dose of 266.1 kg of N ha^{-1} enabled a maximum estimated productivity of 14,597.6 kg ha^{-1}. Accordingly, the commercial productivity also presented square adjustment, enabling a maximum productivity of 13,858.0 kg ha^{-1} with an estimated dose of 251.7 kg of N ha^{-1}.

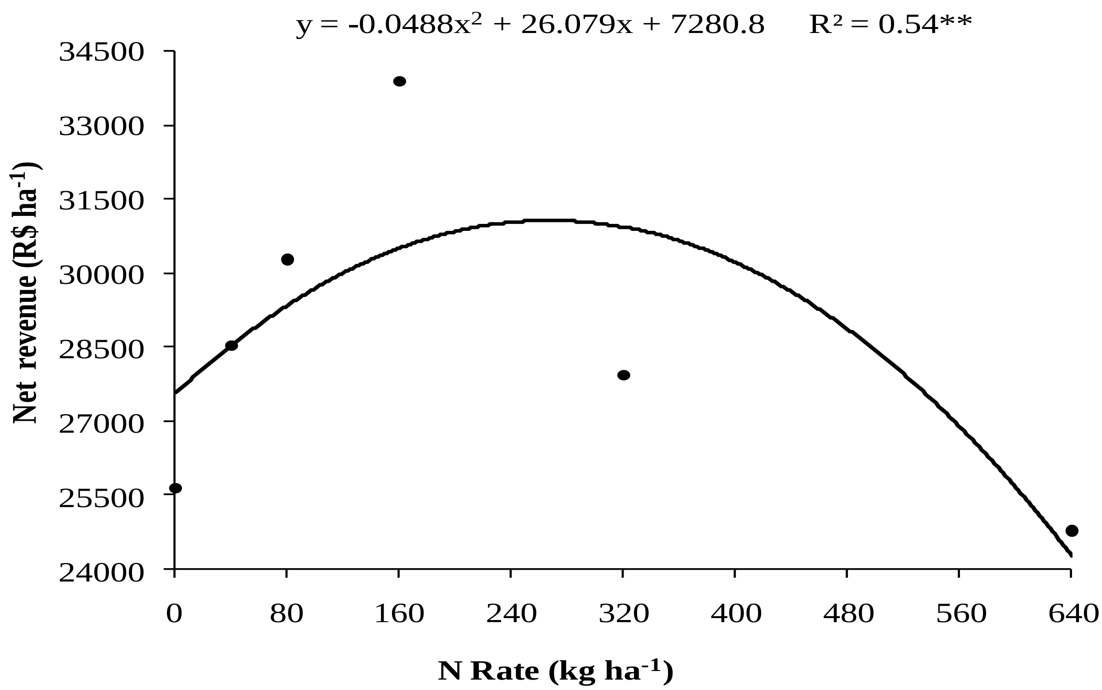

Figure 5. Effect of in-cover N doses on the revenue, free of expenditures on Nitrogen, from the garlic crop.

The results obtained with this study show that the variance, whether an increase or a decrease, by up to 100 kg ha^{-1} of N to the estimated dose, brought about reductions of 1.2 and 2.8%, respectively, in commercial and total productivity. Such results indicate the safety margin for the choice of the Nitrogen dose for in-cover fertilization in view of the excessive sprouting problem. The values observed in this study are higher than those found by Marouelli et al. (2002b), who obtained increases in total productivity up to the 64 kg/ha^{-1} of N dose. In turn, in studies carried out by Backes et al. (2008), total production of bulbs was obtained with the estimated dose of 268 kg ha^{-1} of N, yielding a maximum productivity of 14,250.0 kg ha^{-1}. However, such results differ from those found by Lima et al. (2008), as studies with application of doses up to 360 kg ha^{-1} of N did not obtain responses in the productivity of bulbs from the Roxo Pérola de Caçador cultivar. Now, the cost effectiveness of the garlic crop was indeed affected by Nitrogen-based fertilization. Maximum cost effectiveness was obtained with the estimated dose of 267.2 kg ha^{-1} of N, which provided a net revenue of R$ 31,045.73 (Figure 5). It can be seen that this result comes close to the maximum commercial productivity (251.7 kg ha^{-1} of N), since that difference implies a reduction of only 0.3% to the net revenue (R$31,033.96).

The results found in this analysis, like those about productivity, allow for variance of up to 100 kg ha^{-1} of N in the maximum estimated dose (267.2 kg ha^{-1}) with reduction of only 1.5% in cost effectiveness (R$ 30,557.73). This safety margin of the maximum estimated dose regarding cost effectiveness is likely due to lower concentration of bulbs from classes 3 and 4 in it, since the values paid for smaller bulbs are up to 50% of those of classes 5 and 6 bulbs. The results found differ from those by Lima (2005), who did not observe any interaction of bulb classes with N doses up to 360 kg ha^{-1}, but it did observe higher concentration of classes 6 and 7 bulbs. In turn, Backes et al. (2008), in a work conducted in the municipality of Santa Juliana, Minas Gerais state, a traditional region in the production of noble purple garlic, obtained higher cost effectiveness (R$ 45,623.98) with the application of 237 kg ha^{-1} of N. The authors infer such result by the higher concentration of classes 5 and 6 bulbs, when they apply doses greater than 160 kg ha^{-1} of N.

Conclusions

(1) The agronomic characteristics of the garlic crop were affected by Nitrogen fertilization, in that the average weight of bulbs and the average number of cloves per bulb were components responsible for the increases in productivity, there being a predominance of classes 5 and 6 bulbs.

(2) Maximum agronomic efficiency and cost effectiveness were obtained with the doses of 251.7 and 267.2 kg ha^{-1} of N, respectively, though with a considerable safety margin.

Conflict of Interest

The authors have not declared any conflict of interest.

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