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Does high onion plant density increase nitrogen demand?

Alta densidade de plantas de cebola pode aumentar a demanda por nitrogênio?

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ABSTRACT - An adequate N supply is essential for plant growth, and changing plant density increases nitrogen demand. The objective of this work was to evaluate the effect of top-dressing nitrogen fertilization on quality and yield of onions grown under three plant densities. The experiment was conducted from June to October, in Oratórios, state of Minas Gerais, Brazil, using the hybrid Superex. A randomized block experimental design was used, with a split-plot arrangement and four replications. N rates (0, 60, 120, and 240 kg ha^{-1}) were evaluated in the plots and plant densities (40 plants m^{-2} - one seedling per cell; 80 plants m^{-2} - two seedlings per cell; and 120 plants m^{-2} - three seedlings per cell) were evaluated in the subplots. The yield found for the treatment with 80 plants m^{-2} and 171 kg ha^{-1} of N was 51.28 Mg ha^{-1} of marketable bulbs, with approximately 75% class 3 and 17% class 4 bulbs. Bulb weight decreased with increasing plant density. Top-dressing nitrogen fertilization increases the quality and yield of onions, regardless of the plant density. The highest yield was found when using 80 plants m^{-2} and 240 kg ha^{-1} of N. A density of 80 plants m^{-2} (two seedlings per cell) and 171 kg ha^{-1} of N is recommended when intending to obtain class 3 and 4 bulbs.

Keywords: *Allium cepa*. Top-dressing fertilization. Plant arrangement. Yield.

RESUMO - O suprimento adequado de N é essencial ao crescimento das plantas e a alteração na densidade de plantio pode aumentar a demanda por nitrogênio. Objetivou-se nesse trabalho avaliar a influência de doses de nitrogênio na qualidade e na produtividade de cebola em três densidades de plantio a partir de uma, duas e três mudas por célula de bandeja. O experimento foi conduzido no período de junho a outubro de 2012 em Oratórios-MG, com o híbrido Superex. O delineamento experimental foi o de blocos casualizados em parcelas subdivididas, com quatro repetições. Nas parcelas avaliou-se doses de N (0, 60, 120 e 240 kg de N ha^{-1}) e nas subparcelas a densidade de plantio: 40 plantas m^{-2} (uma muda por célula), 80 plantas m^{-2} (duas mudas por célula) e 120 plantas m^{-2} (três mudas por célula). Com 80 plantas m^{-2} e 171 kg ha^{-1} de N, a produtividade foi 51,28 Mg ha^{-1} de bulbos comercializáveis com cerca de 75% de bulbos na classe 3 e 17% de bulbos na classe 4. A massa de bulbos reduziu com o aumento da densidade de plantio. A adubação com nitrogénio, em cobertura, aumenta a qualidade e o rendimento da cebola, independentemente da densidade das plantas. A maior produtividade foi observada com 80 plantas m^{-2} e 240 kg ha^{-1} de N. Recomenda-se a densidade de 80 plantas m^{-2} (duas mudas por célula) e 171 kg ha^{-1} de N para atender a preferência por bulbos das classes 3 e 4.

Palavras-chave: *Allium cepa*. Adubação em cobertura. Arranjo de plantas. Produtividade.

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INTRODUCTION

The productivity of plants is dependent on the interaction between genotype and nutrients, water, light, and temperature, whose availability and use are dependent on the plant population per area. Plant population density is directly related to intensity of competition between plants for space and growth factors, mainly light (HENRIQUES et al., 2014). The equilibrium point, with the highest plant population per unit area, results in high yields (SANTOS et al., 2018) and profitability (BRAVIN et al., 2021). Considering the competition between plants, increasing plant density may result in decreases in yield due to loss of space available to plants or greater severity of attacks of pests and diseases; in addition, losses in quality, such as changes in size and shape, have been found for vegetable species (ARRUDA JUNIOR et al., 2015; HACHMANN; DALASTRA; ECHER, 2017). Establishing an optimal onion plant population is a determining factor for commercial bulb production and is specific for each cultivar and cropping system (BAIER et al., 2009; YURI; RESENDE; COSTA, 2018).

The plant density for onion crops grown by transplanting of seedlings has been changed by changing the spacing between rows (0.10 to 0.40 m) and between plants in the planting rows (0.05 to 0.15 m) in different producing regions, as shown in several studies on onion crops. However, the production of seedlings in expanded polystyrene trays enables to change the number of seedlings per cell (1, 2, 3, or more) and the plant density in the field while maintaining the spacing between rows and between plants in the rows. Vargas, Braz ans May (2007) found no difference in onion yield between treatments with two and three seedlings per tray cell when transplanted with spacing of 0.08, 0.12, and 0.14 m between rows for the hybrids Princesa and Superex.

Obtaining high yields and maximum economic return from onion crops depends on fertilization with adequate amounts of nutrients, including nitrogen (N). N is the most required nutrient and has important functions in the plant. Among limiting nutrients, N and K are the nutrients most absorbed by onion crops; K is required in larger quantities (VIDIGAL; MOREIRA; PEREIRA, 2010; BACKES et al., 2018; MORAES et al., 2018) and is the most absorbed nutrient (MAY et al., 2008; KURTZ; FAYAD; VIEIRA NETO, 2020). The difference between N and K absorption depends on the cultivar/hybrid, growing season, soil type, climate, and cropping system.

Nitrogen fertilization increases onion yield; however, the maximum yield of marketable bulbs varies with the cultivar/hybrid, growing season, N application time, and soil type (CECÍLIO FILHO et al., 2010; KURTZ et al., 2012; VILLAS BÔAS et al., 2014; MENEZES JÚNIOR; KURTZ, 2016; VIDIGAL; MOREIRA, 2021). Moreover, plant density varies among onion producing regions in Brazil; it has direct effect on yield and commercial quality of bulbs, affecting the amount of N needed to achieve maximum yield due to competition for the nutrient. Therefore, an adequate N supply is essential for plant growth, and changes in plant density result in changes in the plant that affect their growth and development, as well as their demand for nutrients. Evaluations of interaction between plant population and nutrient rate are scarce in the literature, except for nitrogen.

The fertilizer rates recommended for onion crops is calculated by area and not by number of plants in the area; thus, it is expected that the demand for nitrogen and other nutrients will be higher for a higher density of onion plants. Therefore, the question raised is that whether changes in fertilizer rate is necessary when changing plant population.

Thus, the objective of the work was to evaluate the effect of top-dressing nitrogen fertilization on the quality and yield of onion crops grown under three plant densities.

MATERIALS AND METHODS

The experiment was conducted from June to October 2012 at the experimental farm of the Agricultural Research Company of Minas Gerais (EPAMIG), in Oratórios, state of Minas Gerais, Brazil (20°24'S, 42°49'W, and altitude of 480 m). The region's climate is classified as Aw, according to the Köppen and Geiger classification. The region presents mean maximum and minimum annual temperatures of 21.6 and 19.5 °C, respectively, and mean annual rainfall depth of 1162 mm.

A randomized block experimental design was used, with a split-plot arrangement and four replications. The plots consisted of four N rates (0, 60, 120, and 240 kg of N ha^{-1}), which were applied as top-dressing, divided into three applications: 10% at 56 days after sowing (DAS), 40% at 84 DAS, and 50% at 105 DAS, using urea (45% N) as the N source. The subplots consisted of three plant densities (40, 80, and 120 plants m^{-2}).

The plant densities were characterized by three planting arrangements: 1 plant per tray cell for 40 plants m^{-2} (PD1); 2 plants per tray cell for 80 plants m^{-2} (PD2), and 3 plants per tray cell for 120 plants m^{-2} (PD3), using a hole spacing of 0.10 m, i.e., the substrate block was transplanted with one, two, and three seedlings in each hole. Onion seeds of the hybrid Superex were sown in 200-cell expanded polystyrene trays, filled with a commercial substrate (Plantmax®). The seedlings were produced with one, two, and three seedlings per cell, for the treatments with 40, 80 and 120 plants m^{-2}, respectively. The seedlings were transplanted at 42 days after sowing (DAS) with spacing of 0.10 × 0.25 m. The experimental plot consisted of four rows with 20, 40, and 60 plants each and the useful area of the subplot consisted of 24, 48 and 72 plants, obtained from the two central rows.

The soil of the area (Red-Yellow Argisol) presented the following characteristics in the 0-20 cm depth layer: pH (water) = 5.5; Ca = 1.8 cmolc dm^{-3}; Mg = 0.7 cmolc dm^{-3}; Al = 0.0 cmolc dm^{-3}; H + Al = 2.97 cmolc dm^{-3}; P = 7.8 mg dm^{-3} (Mehlich 1); K = 151 mg dm^{-3}; organic matter = 12 g kg^{-1}; B = 0.3 mg dm^{-3}; Cu = 1.3 mg dm^{-3}; Fe = 89.5 mg dm^{-3}; Mn = 98.3 mg dm^{-3}; and Zn = 4.9 mg dm^{-3}.

The soil preparation consisted of plowing, harrowing, and raising of beds to a height of 0.15 meters. The amount of nutrients applied at planting was based on soil analysis and recommendations of Vidigal et al. (2022), which states that no N is applied at planting in onion production systems with transplanting of seedlings. A total of 1,500 kg ha^{-1} single superphosphate, 100 kg ha^{-1} potassium chloride, 70 kg ha^{-1} magnesium sulfate, 20 kg ha^{-1} borax, and 20 kg ha^{-1} zinc sulfate were applied at the time of transplanting of the seedlings. In addition, 200 kg ha^{-1} potassium chloride was applied in two plots, at 56 and 84 DAS, together with nitrogen fertilizer applications, as top-dressing. Cultural practices (pest control and irrigation) were applied according to the needs of the plants; irrigation was carried out using a sprinkler system with application of 2.5 mm of water every other day, following the recommendations for the crop (VIDIGAL; COSTA; CIOCIOLA JÚNIOR, 2019).

Nitrogen nutritional status was evaluated at 104 days after sowing by determining green intensity and total N contents in young fully developed leaves. Leaf green color intensity was determined using a portable chlorophyll meter (SPAD-502, Soil Plant Analysis Development 502) in the middle third of the leaves, between 8:00 and 11:00 hours. The leaves used for this determination were collected, packaged in paper bags, and later placed in a forced air-circulation oven at 70 °C until constant weight. After drying, the dried material was ground in a Wiley mill, equipped with a 20-mesh sieve, and subjected to sulfur digestion to determine total N contents by titration after distillation in a Kjeldahl micro distiller (SILVA et al., 2009).

The onions were manually harvested at 140 DAS, when more than 60% of the plants had ‘soft necks’. The plants were placed on the ground for five days for curing. The bulbs were then classified into five classes according to the largest transverse diameter: 1 = (< 35 mm); 2 = (35 to 50 mm); 3 = (50 to 70 mm); 4 = (70 to 90 mm) and 5 = (> 90 mm), according to BRASIL (1995). Marketable bulb yield was determined by the sum of weights of bulbs in classes 2, 3, 4, and 5, and non-marketable bulb yield was determined by the sum of weights of bulbs in class 1 (diameter < 35 mm) and bulbs disqualified due to occurrence of rotting, malformation, cracking, or damage caused by pest attack.

The data were subjected to analysis of variance by the F test for both evaluated factors, and their interaction was evaluated according to the experimental design; the means were compared by the Tukey's test at 5% probability. Additionally, the N rates was subjected to regression analysis. The significant equations of higher order and coefficients of determination were chosen. The software Genes was used to perform the analysis (CRUZ, 2013).

RESULTS AND DISCUSSION

The onion yield in the different bulb classes presented significant responses to the plant densities and N rates, and significant interaction between the factors was found for classes 4 and 3 (Table 1). These classes represented a higher proportion in yield of marketable bulbs, and responses to N rates were dependent on plant density (Figure 1).

Class 4 bulbs grown under 40 plants m^{-2} (PD1) presented highest yield (33.19 Mg ha^{-1}) with the rate of 143 kg ha^{-1} of N (Figure 1A). In the density of 80 plants m^{-2} (PD2), they presented the highest yield (18.44 Mg ha^{-1}) with the rate of 240 kg ha^{-1} of N. The N rates did not affect the yield of class 4 bulbs grown under the density of 120 plants m^{-2} (PD3), presenting a mean yield of 1.30 Mg ha^{-1} (Figure 1A). The yield of class 4 bulbs under PD1 was higher for all rates of N applied when compared to PD2 and PD3; the control without N presented higher yield than PD3. The yield of class 4 bulbs under PD2 was higher than that in PD3 only for the rate of 240 kg ha^{-1} of N. The yield of class 4 bulbs decreased as the plant density was increased (Figure 1B and Table 2). Similar results were found by Menezes Júnior and Kurtz (2016), who also found increases in bulb yield of large diameters up to the rates of 126 and 156 kg ha^{-1} of N, in a two -year study.

Table 1. Significant values of the F-test (p) for nitrogen (N) rates, plant density (PD), and interaction between N and PD for eight variables in Superex onion.

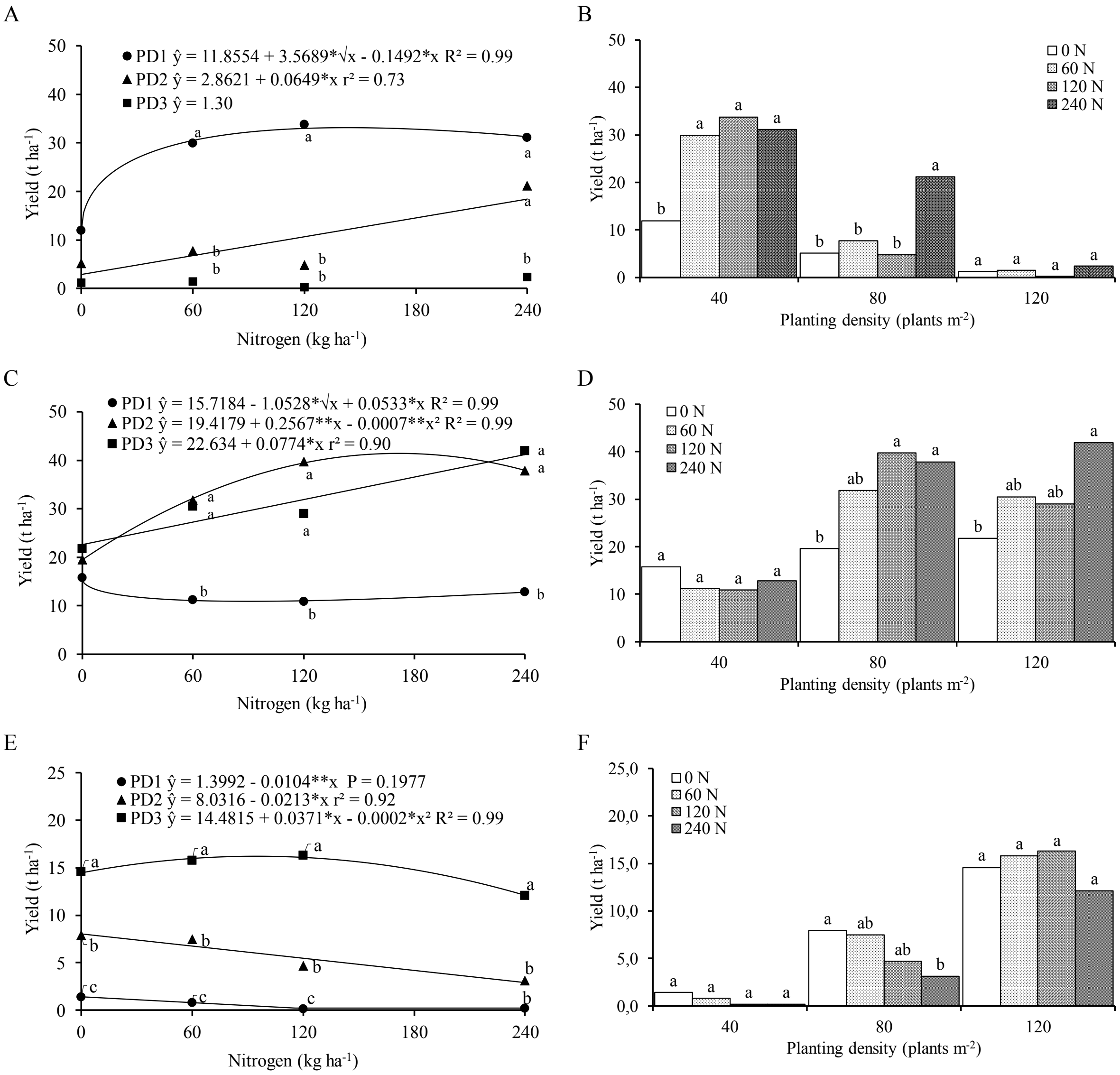
Variables	Nitrogen (N)	Plant Density (PD)	N × PD	CV (%)
Bulb Class 4	<0.001	<0.001	<0.001	34.0
Bulb Class 3	<0.013	<0.001	0.047	32.6
Bulb Class 2	<0.017	<0.001	0.266	32.8
Bulb Class 1	<0.001	<0.001	0.727	86.7
Mean fresh bulb weight	<0.001	<0.001	0.131	17.5
Total N content	0.011	0.701	0.294	9.2
SPAD index	<0.001	<0.001	0.062	4.3
Marketable bulb yield	<0.001	0.091	0.522	18.1

CV = coefficient of variation.

Table 2. Mean bulb yield of Superex onion as a function of plant densities of 40 plants m^{-2} (PD1), 80 plants m^{-2} (PD2), and 120 plants m^{-2} (PD3), and coefficient of variation.

Plant density	Class 4	Class 3	Class 2	Class 1	Marketable
	(t ha^{-1})				
40 plants m^{-2}	29.26a	12.64b	0.63c	0.17b	42.53a
80 plants m^{-2}	9.77b	32.22a	5.79b	0.41b	47.78a
120 plants m^{-2}	1.30c	30.76a	14.68a	1.12a	46.74a
CV (%)	40.77	32.23	31.23	86.48	17.58

Means followed by the same letter in the columns are not different by the Tukey's test at 5% probability. CV = coefficient of variation.



* and ** = significant at 5% and 1% probability by the t test, respectively.
Means with different letters are significantly different by the Tukey's test at 5% probability.

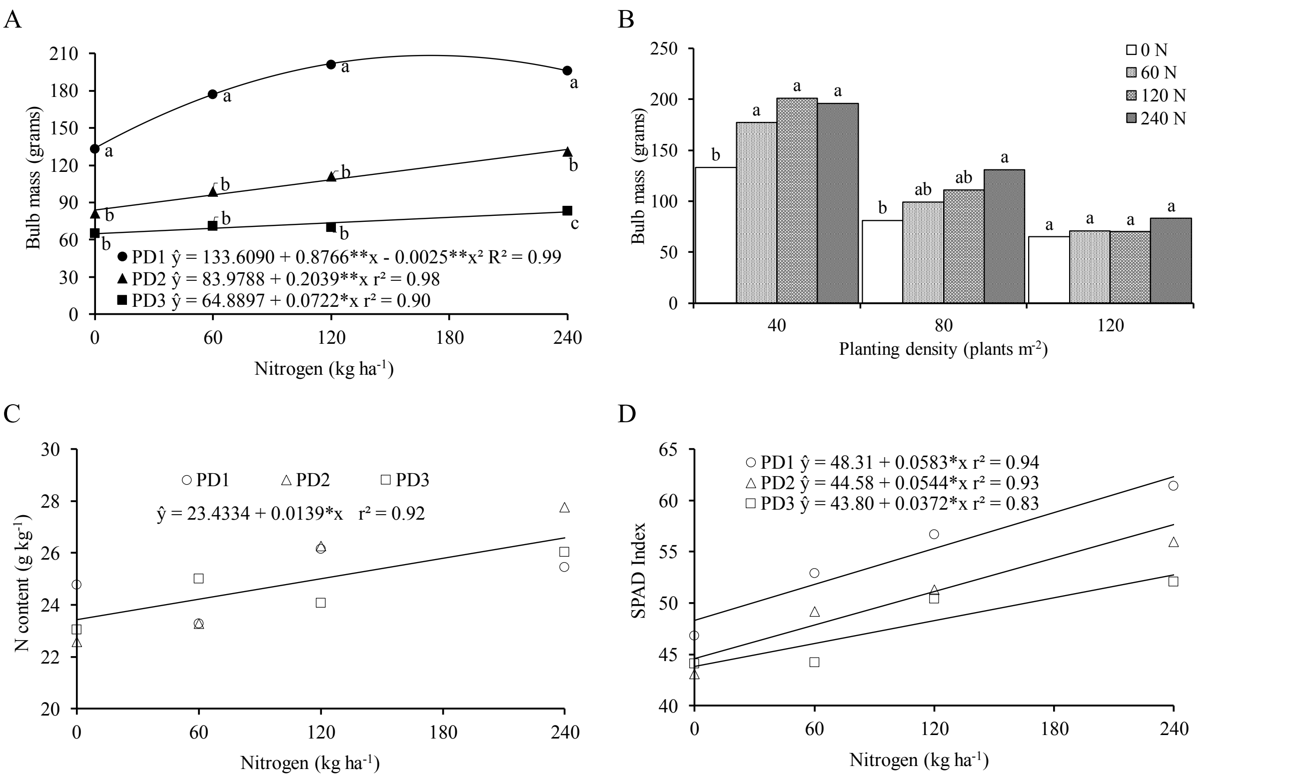
Figure 1. Bulb yield of Superex onion of class 4 (A and B), class 3 (C and D), and class 2 (E and F) as a function of nitrogen rates and plant densities of 40 plants m^{-2} (PD1), 80 plants m^{-2} (PD2), and 120 plants m^{-2} (PD3).

Class 3 bulbs showed a different response to N as a function of plant density (Figure 1C). The yield decreased as the N rates were increased, under the lowest plant density (PD1); the minimum estimated yield (10.89 Mg ha^{-1}) was found with the N rate of 91 kg ha^{-1}. The maximum estimated yield (41.43 Mg ha^{-1}) for PD2 was found with the N rate of 171 kg ha^{-1}. The highest estimated yield (41.20 Mg ha^{-1}) under the highest plant density (PD3) was found with the N rate of 240 kg ha^{-1} (Figure 1C). The highest yield of class 3 under PD2 and PD3 was similar, regardless of the N rate applied, but was higher than PD1 at N rates of 60 and 240 kg ha^{-1}. However, the amount of N required increased as the plant density was increased, as indicated by May et al. (2007). Furthermore, N application promoted higher yield for class 3 bulbs with increasing plant density (Figure 1D); similar results were found by Menezes Júnior and Kurtz (2016). Higher yields of class 3 bulbs were found as the plant density was increased (Table 2).

Class 2 under PD3 presented maximum estimated yield (16.24 Mg ha^{-1}) with the N rate of 95 kg ha^{-1}; under PD2, the yield decreased as the N rate was increased, from 8.03 to 2.92 Mg ha^{-1}; under PD1, the yield decreased up to the N rate of 116 kg ha^{-1}, presenting a mean yield of 0.20 kg ha^{-1} from this rate onwards (Figure 1E). Decreases in yield of class 2 bulbs as the with increasing N rates were also found by Menezes Júnior and Kurtz (2016). This is important for marketing, as bulbs of smaller diameters have lower prices; studies have shown that their price reaches 50% of that for class 3 and 4 bulbs (MENEZES JÚNIOR; VIEIRA NETO, 2012). The increases in plant density increased the yield of class 2 bulbs (Table 2) and the plants required a lower amount of N (Figure 1F), as also found by Menezes Júnior and Kurtz (2016). Higher yields of class 1 bulbs were found as the plant density was increased (Table 1). Higher yields of smaller diameter bulbs at higher plant densities have been found for onion crops (BAIER et al., 2009; HENRIQUES et al., 2014).

Class 4 presented the highest proportion of marketable bulbs (60.82%) under PD1; it was 18.90% under PD2, and 2.71% under PD3. The larger space between plants contributed to a higher growth and development of bulbs, whereas the larger populations presented smaller bulb diameters due to the competition between plants (Figure 1 and Table 2). The increases in the plant density resulted in different responses to N rates, denoting the need for larger amounts of N to increase yield, mainly for class 3 bulbs, which presented higher proportion of marketable bulbs in larger populations (PD1 = 29.72%, PD2 = 67.43%, and PD3 = 65.81%) (Figure 1 and Table 2). Furthermore, the number of smaller bulbs (class 2) decreased with application of N associated with the lower plant densities (PD1 = 1.48%, PD2 = 12.12%, and PD3 = 31.41%) (Figure 1 and Table 2). Plant density and nitrogen fertilization present an inverse correlation for bulb growth and development. Increases in yield of bulbs of larger-diameter classes by increasing N rates and decreases in yield of smaller diameter bulbs have been found in several studies (CECÍLIO FILHO et al., 2010; KURTZ et al., 2012; RESENDE; COSTA, 2014a,b; RODRIGUES et al., 2015; MENEZES JÚNIOR; KURTZ, 2016; GONÇALVES et al., 2019).

Mean fresh bulb weight was affected by plant density and N rate, with no significant interaction between the factors (Table 1). The maximum estimated bulb weight (208 g) was found with the N rate of 171 kg ha^{-1} for PD1, which was higher than those found for the other populations, regardless of the N rates. The highest estimated bulb weights under PD2 (133 g) and PD3 (82 g) were found with the N rate of 240 kg ha^{-1}, (Figure 2A). This suggests that a higher amount of N may be required for increase bulb weight in larger plant populations, as indicated by May et al. (2007), who found the highest estimated bulb weights in plants of the hybrids Optima (150.36 g) and Superex (168.78 g) at a plant density of 60 plants m^{-2} and with a N rate of 150 kg ha^{-1}.



* and ** = significant at 5% and 1% probability by the t test, respectively.
Means with different letters are significantly different by the Tukey's test at 5% probability.

Figure 2. Mean fresh bulb weight (A and B), total N content (C), and SPAD index (D) in young fully developed leaf of Superex onion as a function of nitrogen rates and plant densities (PD) of 40 plants m^{-2} (PD1), 80 plants m^{-2} (PD2), and 120 plants m^{-2} (PD3).

The increases in N availability resulted in higher bulb weights for PD1; under PD2, the N rate of 240 kg ha^{-1} N resulted in higher yield than the control without N application; and under PD3, there was no difference between the treatments (Figure 2B). The bulb weight decreased as the plant density was increased; PD1 (40 plants m^{-2}) presented bulb weights 67.4% and 144.7% higher than PD2 (80 plants m^{-2}) and PD3 (120 plants m^{-2}), respectively (Figure 2B). Higher bulb weights at lower plant densities have been found for onion crops (BAIER et al., 2009; HENRIQUES et al., 2014). However, nitrogen has a much stronger effect on bulb size and weight than plant density (GEISSELER; ORTIZ; DIAZ, 2022).

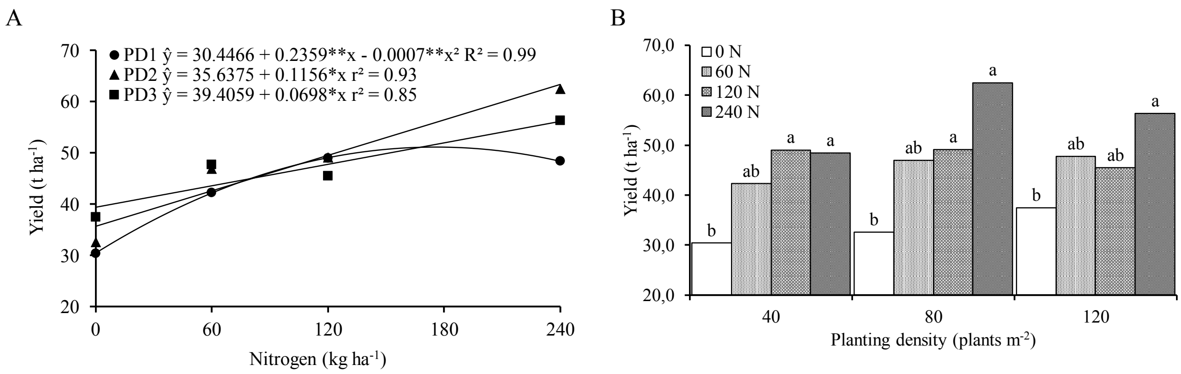
The interaction between plant density and N rate was not significant for total N contents in young fully developed leaves, with no difference between plant densities. Total N contents in young fully developed leaves increased as the N rate was increased, regardless of the plant population density: the highest N content (26.58 g kg^{-1}) was found for the rate of 240 kg ha^{-1} (Figure 2C). The N contents found were below the adequate range (30 to 40 g kg^{-1}) described by Trani et al. (2018). However, considering the positive correlations with marketable yield (r = 0.888, p=0.055), fresh bulb weight (r = 0.922, p=0.038), and dry bulb weight (r = 0.913, p=0.043), the N contents can be considered adequate for the conditions of the present study. Menezes Júnior and Kurtz (2016) also found no interaction between plant density and N rate, reporting leaf N contents ranging from 23.0 to 34.0 g kg^{-1}, also considered adequate in view of the yield results obtained.

The green color intensity (SPAD index) increased as the N rate was increased, and decreased as the plant density was increased. The highest estimated SPAD indexes were found for the N rate of 240 kg ha^{-1}: 62.30 (PD1), 57.64 (PD2), and 52.73 (PD3) (Figure 2D). Increase in SPAD index denotes increase in plant green color intensity and, indirectly, measures chlorophyll content and indicates the plant N status (FONTES, 2016). The positive correlation between leaf nitrogen content and plant green color intensity (SPAD), or estimates of leaf chlorophyll contents, can be used as an indirect criterion to evaluate the N status of onion plants in the field (VIDIGAL; MOREIRA, 2009). Vidigal and Moreira (2009) found critical SPAD indexes (69.24 and 68.12) at 80 and 121 DAS in a clay soil. The SPAD index may vary with the time of the year, cultivar, date of determination, and environment, among other factors (GODOY; SOUZA; VILLAS BÔAS, 2010). There was a significant correlation between SPAD index (r = 0.9746, p=0.0127) and total leaf N content.

There was a positive linear correlation between SPAD index, total N content in young fully developed leaves, and marketable bulb yield. SPAD indexes showed a correlation coefficient with bulb yield of r = 0.968 (p=0.015) and total N content of r = 0.888 (p=0.055). Several researches have shown that chlorophyll contents measured with SPAD-502 correlate with plant N concentration and yield of several species (GODOY; SOUZA; VILLAS BÔAS, 2010; MOREIRA; VIDIGAL, 2011; VIDIGAL et al., 2018).

Increases in SPAD index caused by nitrogen fertilization denote the relationship between N and plant green color intensity, and increases in chlorophyll synthesis (TAIZ et al., 2017). In addition, the SPAD chlorophyll meter can detect the onset of N deficiency before it is visible to the human eye and early enough to correct this deficiency with no decreases in yield (SAMBORSKI; TREMBLAY; FALLONE, 2009), provided that there is no undesired interruption in the cycle and that other factors do not become limiting.

The interaction between N rate and plant density was not significant for marketable bulb yield; however, there was significant difference for N rates (p<0.001) and plant densities (p=0.091) (Table 1). The maximum estimated yield under 40 plants m^{-2} (PD1) (51.17 Mg ha^{-1}) was found for the N rate of 176 kg ha^{-1} (Figure 3A). The highest yields under 80 plants m^{-2} (PD2) (63.38 Mg ha^{-1}) and under 120 plants m^{-2} (PD3) (56.17 Mg ha^{-1}) were found for the N rate of 240 kg ha^{-1} (Figure 3A). Herison, Masabni and Zandstra (1993) found no significant effect on onion yield with one, two, or three seedlings per cell, as well as Vargas, Baz and May (2007) for one or two seedlings per tray cell. In addition, Menezes Júnior and Kurtz (2016) also found no interaction between plant density and N rate, and estimated yields of 58.30 and 55.10 Mg ha^{-1} for the N rates of 161 and 129 kg ha^{-1}, respectively.



* and ** = significant at 5% and 1% probability by the t test, respectively.
Means with different letters are significantly different by the Tukey's test at 5% probability.

Figure 3. Marketable bulb yield of Superex onion as a function of nitrogen rates and plant densities of 40 plants m^{-2} (PD1), 80 plants m^{-2} (PD2), and 120 plants m^{-2} (PD3).

Considering the marketable bulb yield, the plant responses to plant density within N rates (Figure 3) showed that increases in N availability increase marketable bulb yield for all plant densities evaluated, unlike fresh bulb weight which decreases as the plant density was increased within N rates (Figure 2B). Thus, a larger number of plants per area increases yield and decreases fresh bulb weight, confirming that N has a much stronger effect on bulb size and weight than the plant density in the field (GEISSELER; ORTIZ; DIAZ, 2022). The highest yield gain found for the N rates of 120 and 240 kg ha^{-1} were, respectively, 60.93% and 59.17% under PD1, and 49.19% and 91.92% under PD2. The yield gain found for the N rate of 240 kg ha^{-1} under PD3 was 50.21% higher than that found for the treatment without N (Figure 3B).

The highest bulb yields under PD2 (63.38 Mg ha^{-1}) and PD3 (56.17 Mg ha^{-1}) were higher than the mean yield of the state of Minas Gerais (55.56 Mg ha^{-1}); these results, including that under PD1 (51.17 Mg ha^{-1}), were well above the Brazilian national mean of 29.01 Mg ha^{-1} (IBGE, 2017). Positive responses to nitrogen have been found in researches conducted in onion producing regions in Brazil with different cultivars/hybrids and plant densities, however, with variation in estimated N rates for maximum yield. Kurtz et al. (2012) found a maximum yield of 38.00 Mg ha^{-1} when using 200 kg ha^{-1} of N for 'Bola Precoce' (25 plants m^{-2}), in Santa Catarina; May et al. (2008) found 64.80 Mg ha^{-1} when using 105 kg ha^{-1} of N for the hybrid Optima (60 plants m^{-2}) and 78.91 Mg ha^{-1} when using 125 kg ha^{-1} of N for the hybrid Superex (60 plants m^{-2}), in a clay soil in São Paulo; Cecílio Filho et al. (2010) found 89.50 Mg ha^{-1} when using 150 kg ha^{-1} of N combined with 150 kg ha^{-1} of K_2O for Superex (76 plants m^{-2}); Resende and Costa (2014a) found 65.70 Mg ha^{-1} when using 173 kg ha^{-1} of N for the variety IPA -11 (65 plants m^{-2}); Resende and Costa (2014b) found 69.20 and 65.00 Mg ha^{-1} when using 161 and 215 kg ha^{-1} of N, respectively, for the cultivars Alfa Tropical and Alfa São Francisco (65 plants m^{-2}), in Pernambuco; Villas Bôas et al. (2014) found 80.00 Mg ha^{-1} when using 180 kg ha^{-1} of N for the cultivar Bella Vista (33 plants m^{-2}) in São Paulo; and Baptestini et al. (2018) found 45.60 Mg ha^{-1} when using 230 kg ha^{-1} of N for the hybrid Aquarius (80 plants m^{-2}), in the Zona da Mata region in Minas Gerais, Brazil. The variation in these results can be attributed to the different soil types, growing season (YURI; RESENDE; COSTA, 2018), and hybrid or open-pollinated cultivar used, since hybrid cultivars tolerate higher plant densities, thus increasing the crop yield (MADEIRA; OLIVEIRA, 2014).

The different yield responses in each bulb size class (diameter) resulted in a balance in marketable bulbs, as commercial yield is the sum of yields of the classes 2, 3, and 4 (Figures 1 and 3). In addition, the mean bulb weight (Figure 2A) may have compensated the higher bulb weight found at the lower plant density, as found by May et al. (2007) for plant densities of 60 to 108 plants m^{-2} when using N rates from 0 to 150 kg ha^{-1}. Menezes Júnior and Kurtz (2016) also found no interaction between N rates (0 to 200 kg ha^{-1} N) and plant densities (30, 40, 50, and 60 plants m^{-2}) and no direct effect of plant density on marketable bulb yield.

The Brazilian market prefers medium-sized bulbs (between 80 and 150 grams), i.e., class 3 and 4 bulbs. The isolated factors affected the mean bulb weight, which increased as the N rate was increased, differently for each plant density, and increased as the plant density was decreased. Thus, a balance between plant density and N rate is suggested to produce medium-sized bulbs under similar conditions to the present study, using a plant density of two seedlings per cell (80 plants m^{-2}) and application of 171 kg ha^{-1} of N, which may reach a yield of 51.28 Mg ha^{-1}, with approximately 75% class 3 bulbs and 17% class 4.

CONCLUSIONS

Top-dressing nitrogen fertilization increases onion quality and yield, regardless of the plant density.

The highest yield was found when using a plant density of 80 plants m^{-2} and a nitrogen rate of 240 kg ha^{-1};

A density of 80 plants m^{-2} (two seedlings per cell) and application of 171 kg ha^{-1} of N are recommended when intending to produce class 3 and 4 bulbs.

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