Nitrogen doses and sources applied as top-dressing in onion crops grown under no-tillage and conventional tillage systems

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ABSTRACT

Nitrogen (N) fertilization effectiveness in onion depends on N source, as well as on soil type and management system. The aim of the study is to investigate the effect of N sources and doses applied as top-dressing on bulb yield, leaf N contents and on the postharvest conservation of onion bulbs grown under no-tillage (NTS) and conventional tillage (CTS) systems. Three experiments were carried out: two in Lebon Régis County-SC, under NTS; and one in Caçador County-SC, under CTS. The herein tested N sources comprised urea, ammonium nitrate, calcium nitrate and ammonium sulfate, in combination to N doses applied as top-dressing (70, 140, 210, 280 and 350 kg N ha^{-1}) in addition to the control, without N. The N sources did not affect yield parameters, leaf N content and post-harvest onion losses. The maximum technical efficiency in bulb yield was observed at N doses of 195.8 and 258.4 kg ha^{-1} in the no-tillage system (NTS) and at 270.7 kg N ha^{-1} in the CTS. The NTS enabled maximum yield at N dose 47% lower than the officially recommended one. Maximum relative commercial yield was associated with 31.1 g kg^{-1} of leaf N.

Keywords: *Allium cepa*; urea; calcium nitrate; ammonium nitrate ammonium sulfate.

INTRODUCTION

Nitrogen (N) is the nutrient mostly absorbed by onion plants (Kurtz *et al.*, 2016); however, it is the element mostly influencing crop yield, bulb quality (Kurtz *et al.*, 2013) and disease incidence (Pfeufer & Gugino, 2018). Crops producing 37.34 t ha^{-1} of bulbs extract 101.4 kg ha^{-1} of N from the soil; 58.3 kg ha^{-1} (57%) of this total is exported through bulb harvesting (Kurtz *et al.*, 2016). This value represents a significant amount of exported N, which must be replenished to help maintaining soil fertility (Moraes *et al.*, 2016).

Nitrogen fertilization can significantly increase bulb yield. According to Kurtz *et al.* (2012), maximum economic returns observed in three cycles under CTS were recorded at N doses ranging from 116 kg ha^{-1} to 142 kg ha^{-1} in medium-texture soil presenting medium organic matter (OM) content, as well as at 249 kg ha^{-1} of N in sandy soil presenting low OM content. Maximum economic return in NTS was observed at N doses ranging from 102 kg ha^{-1} to 131 kg ha^{-1} (Kurtz *et al.*, 2013). Resende & Costa (2014) observed the highest commercial yield at N dose of 161.4 kg ha^{-1}. On the other hand, excess N induces exuberant vegetative plant growth due to increased protein synthesis and water content, a fact that reduces plant resistance to diseases and bulb quality (Robles & García, 2013). According to Kurtz *et al.* (2016), maximum nutrient absorption rates were concentrated at bulbing stage, at 73 days after transplantation.

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Nowadays, there is large supply of N sources available in the market; these sources vary in concentration, chemical N form and association with other nutrients. Overall, many of these fertilizers present high cost per nutrient unit, a fact that increases production costs. In addition, there are losses associated with each of these sources; they result from leaching (Wang *et al.*, 2019), volatilization (Huang *et al.*, 2016) and denitrification (Alsina *et al.*, 2013) processes, as well as influence N availability in the soil and N-use efficiency by plants.

Systems based on seedling production in flower beds and on subsequent seedling transplantation prevail in Southern Brazil (Kurtz *et al.*, 2013). However, there has been fast expansion of no-tillage seeding in recent years; this system has been adopted in approximately 20% of production fields. It mainly happens due to scarcity of, and high cost with, manpower to perform seedling transplanting operations (Epagri, 2013).

Conventional tillage system (CTS) is the traditional soil preparation method adopted for onion crops; however, it leads to intense soil physical (Vizioli *et al.*, 2021), chemical (Thomaz & Antoneli, 2020) and biological (Bhaduri *et al.*, 2017) degradation. Thus, the onion no-tillage system (NTS) - which performs seeding without turning over the soil, crop rotation and cover crops - is a soil management alternative that should be implemented by technicians, researchers and producers due to broad benefits provided by this system to different ecosystems. Cover crops used in onion NTS in Santa Catarina State, Southern Brazil, were efficient in recovering and increasing total organic carbon contents, as well as in improving soil physical quality (Loss *et al.*, 2015).

Nitrogen management in CTS, mainly in onion no-tillage sowing in NTS, is an important research demand to help defining the N doses and sources to be applied, mainly due to increase in the adoption of these techniques in Santa Catarina State, which is the largest onion producer among Brazilian states (IBGE, 2023). The aim of the current study was to assess the effect of N sources and doses, applied as top-dressing, on onions planted based on no-tillage seeding, under conventional tillage and no-tillage management systems.

MATERIALS AND METHODS

Two experiments - called experiments 1 and 2 - were carried out in the 2016/2017 planting season; one experiment - called experiment 3 - was carried out in the 2017/2018 planting season. Experiments 1 and 2 (at coordinates: -26.911225 S and -50.766628 W; and -26. 846680 S and -51.077776 W, respectively) were implemented in Lebon Régis County/SC. Experiment 3 (at coordinates: -26.904108 S and -50.751973 W) was implemented in Caçador County/SC. All experiments were carried out in typical Dystrophic Bruno Nitosol (Embrapa, 2013). Based on Köeppen's classification, the climate in the experimental region is of the Cfb type – i.e., temperate, humid mesothermal, with mild summer (Alvares *et al.,* 2013). Climatic data were collected in meteorological stations located 100 m away from the experiments (Figure 1).

Soil samples were collected from the 0-20 cm soil layer at experiments' implementation time (Table 1). Soil acidity was corrected based on limestone application (PRNT 80%); fertilizations with phosphorus and potassium were performed based on the CQFS-RS/SC (2016) to achieve crop yield of 70 t ha^{-1}.

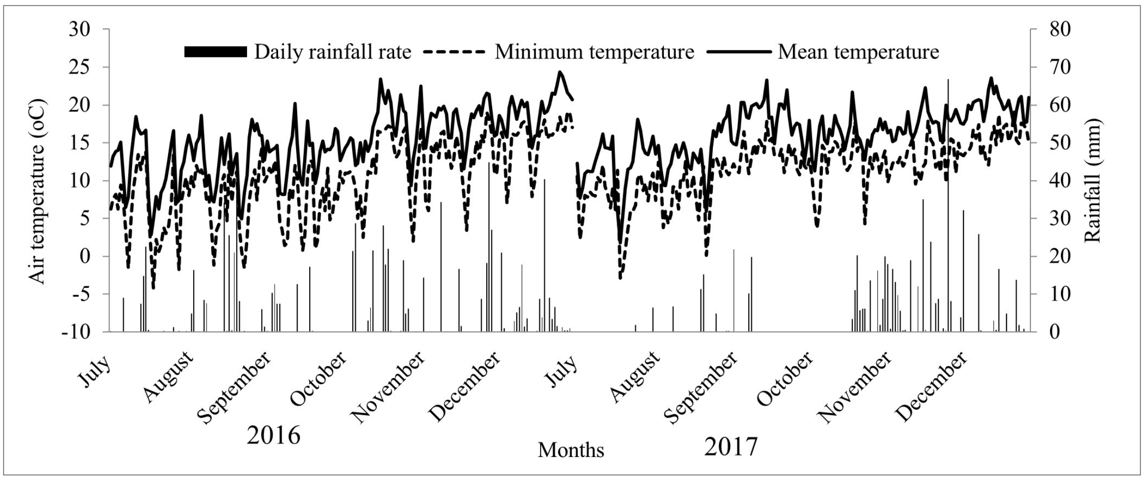

Figure 1: Daily rainfall rate, minimum and mean temperatures recorded throughout the months in two years of experiments.

Table 1: Chemical attributes of, and clay content in, soils used in all three experiments conducted in the 2016 and 2017 crop seasons

Crop seasons	Soil management system	Experiments	Clay	OM	pH (H_2O)	P	K	S	Ca	Mg	CEC pH 7,0
			%			mg dm^{-3}			cmol$_c$ dm^{-3}		
2016	NTS	1	50	5,4	4,2	3,9	160	20,2	1,5	0,8	15,8
2017	NTS	2	67	5,7	5,4	7,8	412	29,8	6,1	3,2	17,1
2017	CTS	3	55	5,8	5,7	8,2	321	24,5	7,2	3,6	16,9

NTS: no-tillage soil management system; CTS: conventional tillage system; Clay: pipette method; OM: organic matter determined according to the Walkley-Black method; pH(H_2O) at a soil:solution ratio of 1:1; P and K were extracted with Mehlich^{-1}; Ca^{2+} and Mg^{2+} were extracted by KCl 1 mol L^{-1}; S was extracted with calcium phosphate; CEC: cation exchange capacity at pH 7.0.

Experiments were carried out based on a randomized block design, with 4 repetitions. Experiment 1 has followed factorial arrangement 3x4+1; it combined 3 N sources (urea, ammonium nitrate and calcium nitrate) and 4 N doses applied as top-dressing (70, 140, 210 and 280 kg ha^{-1}), in addition to the control treatment (without N application) – this experiment comprised 13 treatments, in total. Experiments 2 and 3 have followed factorial arrangement 4x5+1; it comprised 4 N sources (ammonium sulfate was added to the N sources of experiment 1) and 5 N doses applied as top-dressing (N dose of 350 kg ha^{-1} was added to N doses adopted in experiment 1), in addition to the control treatment (without N application as top-dressing) – these experiments comprised 21 treatments, in total. Nitrogen sources presented the following compositions: urea (UR, 45% of N), calcium nitrate (CN, 15.5% of N and 19% of Ca), ammonium nitrate (AN, 32% of N) and ammonium sulfate (AS, 21% of N and 22% of S). All experiments were 3.0-m wide and 5.0-m long, spacing between rows was 0.30 m and usable area was 1.2 m^2.

Experiments 1 and 2 were conducted in no-tillage (NTS) soil management system; they comprised previous soybean crop in Summer, which was followed by black oat crop used as cover crop in Fall. Black oat was sown in April in both crop seasons and managed through desiccation before stem elongation (phenological stage V6), at 30 days before onion sowing. Experiment 3 was implemented in area subjected to conventional tillage system (CTS), after subsoiling and double harrowing procedures. Onion sowing density was set at 26 seeds / meter; thinning was carried out at 60 days after sowing (DAS) and left a final population comprising 550 thousand plants ha^{-1}. In total, 20 kg N ha^{-1}, 370 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O were applied in the sowing furrow via formulated fertilizer, at sowing time. Top-dressing comprised the application of 120 kg ha^{-1} of K_2O divided into two equal doses at 45 and 80 DAS. Top-dressing N doses were split into 5 doses applied at 45 (25% of N), 80 (25% of N), 110 (30% of N) and 140 (20% of N) DAS (CQFS-RS/SC, 2016).

Experiments 1 and 2 have used onion cv. Mulata, whereas experiment 3 used onion cv. Salto Grande. Onion seeds were treated with fungicides pyraclostrobin and thiophanate methyl, as well as with insecticide fipronil. Invasive plants, pests and diseases were controlled based on spraying with chemical products registered for onion crops in the Ministry of Agriculture.

The last fully expanded leaf was collected from 10 plants at bulbing stage (at approximately 90 DAS) for leaf N content determination purposes. Leaves were dried in forced air circulation oven, at 65 ± 5 °C, until they reached constant mass; then, they were ground in Wiley mill. Samples were digested with sulfuric acid, and the N content in them was determined in micro-kjeldahl still (Tecnal, TE-0363, Brazil), based on Tedesco *et al.* (1995).

Bulbs were harvested at 170 DAS, when approximately 80% of plants showed shoot popping. Plants' shoot was cut; bulbs were placed in plastic boxes and stored in shed at room temperature for approximately 10 days, for pre-curing purposes. Subsequently, bulbs were separated into commercial and non-commercial classes, based on Maara (1995). All commercial bulbs were placed in plastic boxes, stored in shed at room temperature and evaluated again after 150 days in order to determine post-harvest losses (%).

Data were subjected to analysis of variance and to regression analysis for quantitative data; bifactorial comparisons between N doses and sources were performed. All analyses were carried out in R software (R Development Core Team, 2020). Regressions were applied to adjust the polynomial degree in order to establish the maximum technical efficiency (MTE) and economic efficiency (MEE) of the variables of interest, based on equation 1:

$$y = a \pm b_1 x \pm b_2 x^2 \qquad (1)$$

Equation 2 was used to estimate the MTE:

$$MTE = -b_1 : 2b_2 \qquad (2)$$

Equation 3 was used for the estimation of the MEE:

$$MEE = \frac{\left[\left(\frac{t}{w}\right) - b1\right]}{2b2} \qquad (3)$$

Where: *t* is the value of the input (nitrogen source) and *w is* the marketable value of the product (onion).

The average price of UR, CN, AN and AS in the year 2016 was US\$0.77, 6.18, 1.34 and 1.91 kg^{-1} of N, respectively, and US\$0.86, 6.76, 1.47 and 2.09 kg^{-1} of N, in the year 2017 (Conab, 2021a). The average price of a kilogram of marketable onion in the years 2016 and 2017 was US\$0.19 kg^{-1} (Conab, 2021b).

Critical leaf N level was estimated through the regression equation obtained by associating MTE with leaf N contents.

RESULTS AND DISCUSSION

Climate differed between the two crop seasons (Figure 1), since there were considerably higher and better distributed rainfall events in 2016 (780 mm) than in 2017 (564 mm).

Nitrogen sources tested in experiment 1 – i.e., urea, ammonium nitrate and calcium nitrate, which were added with ammonium sulfate in experiments 2 and 3 - did not show difference in commercial bulb yield (Figure 2), post-harvest losses (Figure 3), distribution in commercial classes (Figure 4) and leaf N levels (Figure 5). Lack of N sources' effect on onions was also reported in other studies (Sullivan *et al.*, 2001; Boyhan *et al.*, 2007). According to the aforementioned authors, splitting top-dressing N applications into smaller doses, based on the N demand curve, is more important than the used N source.

The tested N sources provide different N concentrations in their amide (e.g., urea), ammoniacal (e.g., ammonium sulfate) and nitric (e.g., calcium nitrate) forms. Some studies have evidenced positive effect of N source combinations on species belonging to genus *Allium*. Gamiely *et al.* (1991) have shown that nitrate and ammonium supply at ratio 1:3 has favored the production of onion leaves, roots and bulbs. NH_4-NO_3- applications to *Allium tuberosum*, at ratios 50:50

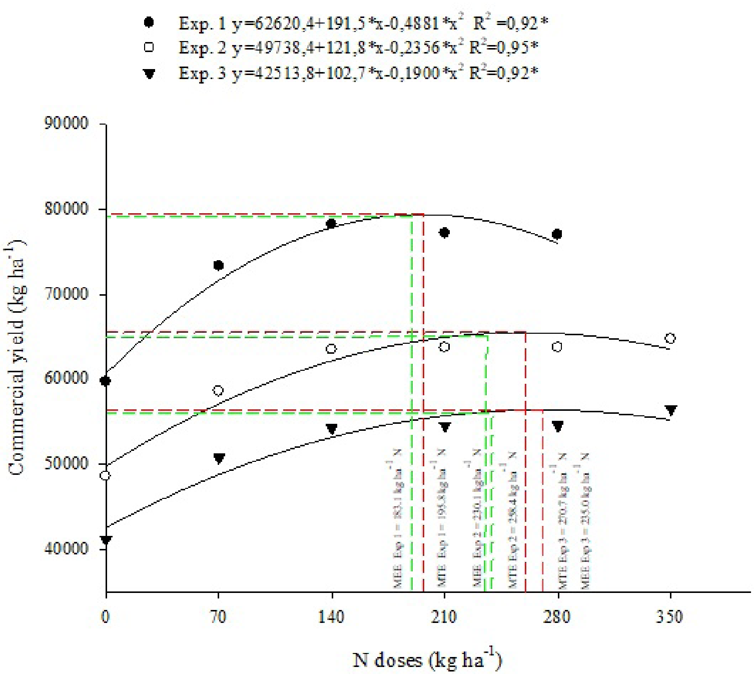

Figure 2: Doses of maximum technical efficiency (MTE) and maximum economic efficiency (MEE) for commercial onion yield in the three experiments, at different N doses (70, 140, 210, 280 and 350 kg ha^{-1}) applied as top-dressing and treatment without N application. *: Significant at 5% probability level.

and 75:25, were the most suitable for the species quality and growth (Sun *et al.*, 2014). The application of calcium nitrate and ammonium nitrate in two crops investigated in the state of Georgia (USA) has increased the total weight of onions when N concentrations increased from 84 kg ha^{-1} to 168 kg ha^{-1}, in comparison to results recorded for sodium nitrate, potassium sodium nitrate and potassium nitrate (Batal *et al.*, 1994). In addition, the aforementioned authors have shown that ammonium nitrate was capable of increasing the production of onions belonging to larger diameter classes.

Nitrate is the main N form absorbed by onions (Geisseler *et al.*, 2022). Moreover, soil and climate features in sub-tropical regions favor amide and ammoniacal N transformation into NO_3- (Silvia & Bohannan, 2016). Therefore, the tested N sources may have supplied different NH_4-NO_3- rates to onion plants, and they did not affect onion plants' growth and yield.

Urea N losses due to NH_3 volatilization may have been minimized by irrigation after fertilizer application (Viero *et al.*, 2015). Soil acidification promoted by ammonia sources (Bindraban *et al.*, 2015) has also shown insignificant negative effects on results in the present study. The addition of Ca and S deriving from calcium nitrate and ammonium sulfate sources, respectively, did not have impact on the current results. Soil Ca and S contents (Table 1) were higher than the critical values recommended by CQFS-RS/SC (2016) for onion - 4.0 $cmol_c$ cm^{-3} and 15 mg dm^{-3}, respectively.

Maximum technical efficiency (MTE) in experiment 1 was achieved at N dose of 195.8 kg ha^{-1}; it recorded commercial onion production of 79,410.7 kg ha^{-1} (Figure 1). On the other hand, MTE in experiments 2 and 3 was achieved at higher N doses - 258.4 kg ha^{-1} and 270.7 kg ha^{-1} –; these experiments recorded commercial onion yield of 65,491.2 kg ha^{-1} and 56,391.2 kg ha^{-1}, respectively. On the other hand, maximum economic efficiency (MEE) in experiment 1, 2 and 3 was achieved at N dose of 183.1, 230.1 and 235.0 kg ha^{-1}, respectively. The difference between the doses of MTE and MEE, were 12.7, 28.3, and 35.7 kg N ha^{-1}. This reduction in fertilizer application causes the decrease of only 1,885.0, 200.7 and 235.7 kg ha^{-1} of marketable onion, respectively in experiment 1, 2 and 3.

CQFS-RS/SC (2016) recommends using 288 kg ha^{-1} of N for expected onion yield of 70.000 kg ha^{-1}. MTE doses obtained in experiments 2 and 3 in the present study were close to the official recommendation, mainly if one takes into consideration that CQFS-RS/SC (2016) has suggested

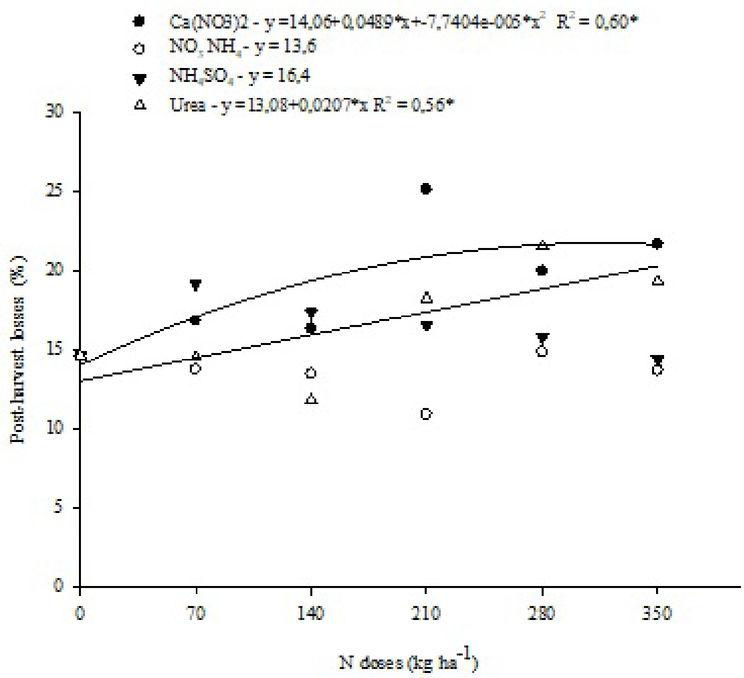

Figure 3: Post-harvest losses based on N doses (70, 140, 210, 280 and 350 kg ha^{-1}) and sources (calcium nitrate ($Ca(NO_3\text{-})_2$), ammonium nitrate (NO_3NH_4), ammonium sulfate ((NH_4NO_3)) and urea applied as top-dressing, and on treatment without N application in onion crop grown under NTS in experiment 2.

*: Significant at 5% probability level.

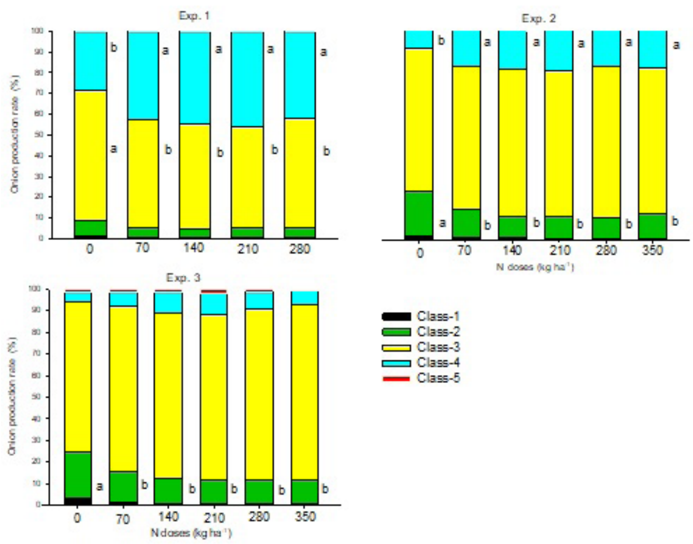

Figure 4: Onion production rate in five commercial classes based on nitrogen rates (70, 140, 210, 280 and 350 kg ha^{-1}) applied as top-dressing and treatment without N application, in all three experiments. Different letters indicate differences between treatments (Tukey, 0.05).

reducing the N dose by up to 25% in consolidated no-till system, as observed in experiment 2. However, MTE in experiment 1 was achieved at N dose 47% lower than the recommended one. Experiment 1 was conducted under CTS, whose management is well-known for increasing the efficiency of N applied in these production systems (Silva *et al.*, 2020; Yang *et al.*, 2020), mainly by increasing OM and N availability and by improving soil quality (Tiritan *et al.*, 2016; Daigh *et al.*, 2018).

Assumingly, the higher performance of plants subjected to lower N doses in NTS is explained by N produced by soybean and black oat straw decomposition – these crops were precursors to onion sowing. This N likely replaced most of the applied mineral N. According to Kurtz *et al.* (2016), the estimated N uptake by onions reached 409 mg plant^{-1}, which corresponded to N extraction of 101.4 kg ha^{-1}. The aforementioned authors have pointed out that the amount of absorbed N was 35.2% higher than that added by mineral fertilization; this finding highlights the important contribution of soil organic matter in N supply.

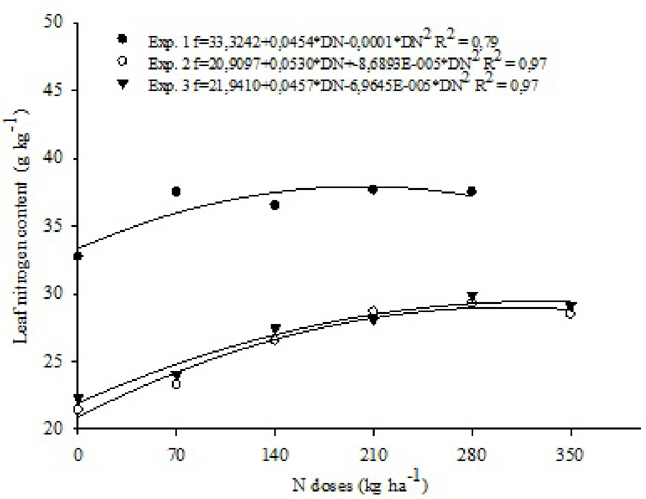

Figure 5: Leaf nitrogen contents based on N doses (70, 140, 210, 280 and 350 kg ha^{-1}) applied as top-dressing and treatment without N application, in onion crop grown in all three experiments - experiment 1 does not present treatment with N dose of 350 kg (Statistical significance level at 5%).

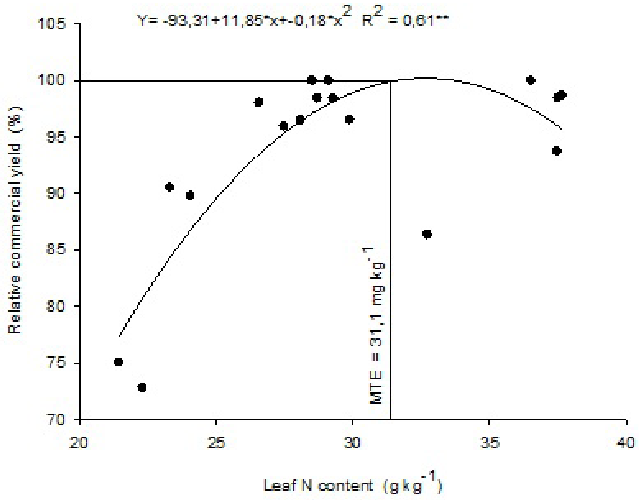

Figure 6: Association between leaf N contents and relative commercial yield in 3 experiments conducted with different N sources and doses.

Experiments 1 and 3 did not show difference in onion losses after storage for approximately 150 days. However, storage losses presented quadratic increase associated with calcium nitrate source and linear increase associated with urea in experiment 02 (Figure 3). Post-harvest losses reached approximately 20% at the highest N doses.

Class-2 bulbs, which have low commercial value, recorded increased participation in commercial yield due to lack of N in experiments 2 and 3 (Figure 4). Class-4 bulbs, which have high commercial value, recorded increased participation in commercial yield due to N application in experiments 1 and 2. However, N application in experiment 1 reduced the participation of class-3 onions in commercial yield. According to Rodrigues *et al.* (2015), class-3 and -4 onions are commercially desirable, since these classes are preferred by the consumer market and enable producers to get higher marketing price. These very same authors recorded yield by 86% in these two onion classes, and considered 168 kg ha^{-1} of N as the efficient dose to be applied to this crop type.

Leaf N levels recorded quadratic increase due to the application of increasing N doses as top-dressing, in all three experiments (Figure 5). Maximum estimated values reached 37.9 g kg^{-1}, after the application of 185.9 kg N ha^{-1} in experiment 1; 28.9 g kg^{-1}, after the application of 288.6 kg N ha^{-1} in experiment 2; and 28.9 g kg^{-1}, after the application of 329.5 kg N ha^{-1} in experiment 3. Differences between cultivars and different climates between crop seasons can explain these variations. Nitrogen application has also increased N content in onions in studies carried out by Kurtz *et al.* (2012), who observed maximum N levels of 40, 35 and 32 g kg^{-1} after the application of 237, 136 and 150 kg N ha^{-1}, respectively, in three consecutive onion crops. Rodrigues *et al.* (2018) recorded maximum estimated value for leaf N content equal to 32.7 g kg^{-1} at N dose of 168 kg ha^{-1}, and 41.2 g kg^{-1} at N dose of 67 kg ha^{-1}, in two different experiments. Relative commercial yield recorded quadratic increase due to leaf N content (Figure 6) - maximum commercial yield was obtained at leaf N content of 31.1 g kg^{-1}.

CONCLUSIONS

Nitrogen, ammonium nitrate and sulfate, calcium nitrate and urea sources did not affect onion yield parameters, leaf N content and postharvest losses;

The maximum technical efficiency recorded for bulb yield was observed at N doses of 195.8 kg ha^{-1} and 258.4 kg ha^{-1} in the no-tillage system (NTS) and at N dose of 270.7 kg ha^{-1} in the conventional tillage system (CTS).

Onion postharvest losses took place as N doses deriving from calcium nitrate and urea sources increased in NTS.

Maximum relative commercial yield was associated with 31.1 g kg^{-1} of leaf N.

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