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Photoassimilates partitioning in okra plants subjected to nitrogen doses

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ABSTRACT

Nitrogen (N) is the third nutrient more absorbed by okra. Therefore, an adequate supply of this element is essential for okra growth through the accumulation of dry matter in the leaves, stem, root and fruit. The objective was to evaluate the influence of N doses on growth, photoassimilates partition and yield of okra. The experiment was carried out in a Red-Yellow Argisol. A randomized complete block design with four replicates was used. The treatments consisted of N doses applied as topdressing (0, 60, 120, 240, 360 kg/ha). Samples of plants were held at 60, 75, 90, 105, 120, 135, 150 and 165 DAS for determination of the plant's dry weight. The plant showed slow growth until 70 days, and after that time, intensified its growth until the end of the cycle. Total dry mass and absolute plant growth rate increased with increasing N availability, reaching the maximum marketable fruit yield of 10,665 kg/ha with 346 kg/ha N. The growth and partition of photoassimilates among the organs of the okra plant 'Santa Cruz' are altered with increasing nitrogen availability applied in topdressing.

Keywords: *Abelmoschus esculentus*, growth curve, fertilization of okra, yield.

RESUMO

Partição de fotoassimilados em plantas de quiabo submetidas a doses de nitrogênio

O nitrogênio (N) é o terceiro nutriente mais absorvido pelo quiabo. Portanto, o suprimento adequado deste elemento é essencial para o crescimento do quiabeiro por meio do acúmulo de massa seca nas folhas, caule, raízes e frutos. O objetivo deste trabalho foi avaliar a influência do nitrogênio no crescimento, na partição de fotoassimilados e na produtividade do quiabeiro. O experimento foi realizado em Argissolo Vermelho-Amarelo. Utilizou-se o delineamento em blocos ao acaso com quatro repetições. Os tratamentos foram constituídos de doses de N aplicadas em cobertura (0, 60, 120, 240 e 360 kg/ha). As amostragens de plantas foram realizadas aos 60, 75, 90, 105, 120, 135, 150 e 165 dias para determinação da massa seca da planta. A planta apresentou um crescimento lento até 70 dias, e após esse tempo, intensificou o seu crescimento até o final do ciclo. A massa seca total e a taxa de crescimento absoluto das plantas aumentaram com o aumento da disponibilidade de N, alcançando a máxima produtividade de frutos comercializáveis de 10.665 kg/ha com a dose 346 kg/ha de N. O crescimento e a partição de fotoassimilados entre os órgãos da planta do quiabo 'Santa Cruz' são alterados com o aumento da disponibilidade de nitrogênio aplicado em cobertura.

Palavras-chave: *Abelmoschus esculentus*, curva de crescimento, adubação do quiabeiro, produtividade.

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Okra is an annual vegetable from the Malvaceae family, whose edible part is the fruit, considered of expressive economic and social importance in Minas Gerais. This crop presents some desirable characteristics such as low production cost, pest resistance and high food and nutritional value (Silva *et al*., 2019).

Vegetable growth studies, in general, are characterized and described by phases of development according to mathematical models of sigmoidal or exponential type. In the first phase, the plants have slow growth at the beginning, that is, from sowing or after transplanting seedlings; in the second phase, growth is fast and a third phase, followed or not by a fourth phase, in which there is a tendency to stabilize growth and in the fourth phase, a drop in growth is observed, depending on the cycle of the species until the final harvest of its commercial product (Galati *et al*., 2013; Kurtz *et al*., 2016; Cecílio Filho *et al*., 2017; Vidigal *et al*., 2021).

Nitrogen (N) promotes morphophysiological changes in the plant, being related to photosynthesis, root development and activity, nutrient ion uptake, cell growth and differentiation (Marschner, 2012). The greater accumulation of dry mass by the plants is related to the increase in photosynthetic rate and the production of photoassimilates and other structural compounds, such as amino acids, carbohydrates and fats (Lima *et al*., 2011; Tuncay *et al*., 2011), which results in greater fruit mass.

However, there is a gap on how N availability influences growth phases and photoassimilate partitioning in okra plants. In this crop, N fertilization linearly increased the accumulation of aboveground dry matter mass up to 200 kg/ha N (Medeiros *et al*., 2018). Thus, N exerts an influence on plant growth and development with a direct effect on the source/drain relationships, by altering the distribution of assimilates between the vegetative and reproductive parts (Galati *et al*., 2013).

N is the third most absorbed nutrient by the 'Santa Cruz' okra plant and the plant accumulated 146.5 kg/ha N (Galati *et al*., 2013). The recommended dose is 120 kg/ha N for Minas Gerais (Silva *et al*., 2007; 2019) and for São Paulo (Teodoro *et al*., 2018), for an expected yield between 15,000 and 22,000 kg/ha, which may vary with plant population and harvest period (Silva *et al*., 2007, 2019). Oliveira *et al*. (2003) obtained maximum yield of 16,701 kg/ha with 141 kg/ha N and a harvest period of 22 weeks. Sediyama *et al*. (2009) obtained 31,230 kg/ha (35,714 plants/ha) and 21,900 kg/ha (23,809 plants/ha) with the use of swine biofertilizer, as a source of N, and a harvest period of 14 weeks. Galati *et al*. (2013) obtained 12,000 kg/ha (50,000 plants/ha) with 160 kg/ha N and harvest period of 8 weeks. While Coutinho-Miranda *et al*. (2020) obtained 17,746 kg/ha (autumn/winter) and 13,812 kg/ha (spring/summer) with 250 kg/ha N. On the other hand, Yoldas *et al*. (2021) found yields of 12,888.9 kg/ha with only 40 kg/ha N.

Considering the above, the objective was to evaluate the influence of nitrogen on the growth, photoassimilate partitioning and productivity of okra.

MATERIAL AND METHODS

The experiment was conducted at the experimental farm of EPAMIG (20º30'S, 43º00'W; 480 m altitude), Oratórios_MG, from February to June 2013. The region's climate varies from Cwa, humid tropical to Aw, semi-humid with hot summers, according to Köppen and Geiger (Cunha *et al*., 2000). The maximum and minimum average annual temperatures are respectively 21.6°C and 19.5°C; the average precipitation is 1,162 mm. During the experimental period, the average maximum, minimum and average temperatures were 25.6°C; 15.5°C and 20.6°C, respectively, and the accumulated rainfall was 400 mm.

The treatments consisted of five N doses (0, 60, 120, 240 and 360 kg/ha), defined according to the recommended dose of 120 kg/ha for Minas Gerais (Silva *et al*., 2007, 2019). These doses were applied in topdressing, in three plots, 20%, 40% and 40% of the applied dose, at 52, 72 and 92 days after sowing (DAS). The N source used was urea (45% N). The treatments were arranged in a randomized complete block design, with four replicates. Each experimental unit consisted of five rows, with 20 plants each.

The soil of the area was classified as Red-Yellow Argisol (Santos *et al*., 2018) and presented, in the 0-20 cm depth layer, the characteristics pH (water) = 4.5; Ca = 1.0 $cmol_c/dm^3$; Mg = 0.3 $cmol_c/dm^3$; Al = 1.0 $cmol_c/dm^3$; H+Al = 3.96 $cmol_c/dm^3$, P = 21.8 mg/dm^3 (Mehlich 1); K = 43.0 mg/dm^3; organic matter = 11.0 g/kg.

Soil preparation consisted of plowing and harrowing. Except for N, planting fertilization, based on soil analysis and recommendations for okra (Silva *et al*., 2007, 2019), consisted of 500 kg/ha single superphosphate, 100 kg/ha potassium chloride, 20 kg/ha borax, and 15 kg/ha zinc sulfate. In addition, 120 kg/ha potassium chloride was used, applied in three plots, together with the nitrogen fertilizer applications, in topdressing.

The cultivar Santa Cruz 47 was used, and seeds were sown in 200-cell expanded polystyrene trays, filled with commercial substrate Plantmax®. Seedlings were transplanted at 35 DAS, in 0.80 x 0.40 m spacing (31,250 plants/ha). Plants were irrigated by micro-sprinkler with a flow rate of 52 L/h and arranged at 3.0 m x 3.0 m spacing. The other cultural practices were performed according to the needs and recommendations for the crop (Silva *et al*., 2007, 2019).

During the growing period, random samples consisting of three whole plants were collected at seven different times. Harvesting started at 60 DAS and continued until 165 DAS considering a regular interval of 15 days. The plants were separated into leaf + stem (aerial part), flower + fruit (fruits) and roots collected in soil block (0.3 x 0.3 x 0.3 m) and after, washed under running water in a 2 mm sieve. The dry mass of all parts of each plant was determined using a precision balance after drying to a constant weight in a forced-air oven at 65°C. These data were used to determine the dry matter mass accumulation curve for okra.

Harvest of fruits, larger than 12 cm in length, straight and without deformities, was performed weekly (Silva *et al*., 2007, 2019). Commercial yield was obtained by summing the masses of fruits from each harvest after 12 weeks.

The obtained data were submitted to analysis of variance and polynomial regression. The regression models for the production variables were chosen based on the biological significance, the significance of the regression coefficients, by the t test, and the highest coefficient of determination. The N doses that provided the maximum yield of commercial fruits was obtained by equating to zero the first derivative of the equation of response of commercial fruit yield to the doses of N.

Data of the dry mass were subjected to regression analysis, in which the plant age, expressed in days after sowing, was the independent variable. Plant growth was characterized by dry matter mass of total plant (Wt), leaves + stem (aerial part - Wpa), flower + fruit (fruit - Wfr) and root (Wr). The primary data of accumulated dry mass (W) were adjusted using the equations $W = \exp(A - Bx - C/x^2)$ or $W = \exp(A - B/x^2)$ and the absolute growth rate of the plant (Cwt), fruit (Cwfr) and root (Cwr) by the first derivative of the W-adjusted equation with respect to time. The software Genes was used to perform the analysis (Cruz, 2013).

RESULTS AND DISCUSSION

The okra plants had their growth positively influenced with the increase of N availability by the doses applied in topdressing.

Four growth phases were observed for all treatments: the first with slow growth; the second with rapid growth; the third with deceleration of growth until reaching the maximum accumulation of dry mass of the plants and the fourth phase with reduction in growth until the final harvest. However, applying 120 kg/ha N, the first three phases were observed, and the plants continued to accumulate dry mass until the final harvest. The phases were defined as a function of the accumulated amount of total plant dry mass (Wt) and absolute growth rates (Cwt), and the duration of these phases varied with the N doses (Figures 1 and 2).

In Phase I, the plants accumulated about 10% of the final Wt and showed slow growth in the period from 60 to 70 DAS. The dose 120 kg/ha N provided the highest Wt of 29.27 g/plant and 360 kg/ha N provided the highest Cwt of 3.17 g/plant/day, at the end of the phase (Figure 1 and 2A).

Nitrogen promoted greater plant growth by the difference in the values of Wt and Cwt in relation to the control without N, since, in this period, 20% of the N had already been applied, at 52 DAS. Slow growth in the initial phase is observed in several plant species because the plants present a smaller root volume, low absorption of water and nutrients, smaller leaf area, besides reduced net assimilation rate and respiration rate (Aumonde *et al*., 2011). Therefore, in this phase, the leaves behave as both source and drain, because they store the compounds resulting from their own production of photoassimilates (Lopes *et al*., 2011). In the following phases, the beginning of flowering and fruiting causes the photoassimilates to be directed from the leaves to the fruits in a more accelerated way, because they are preferential drains (Lopes *et al*., 2011), and the other parts of the plant (leaves, stems and root) are users of the compounds from the photosynthetic process in a smaller quantity for the structural maintenance of the plant.

In Phase II the highest growth speed occurred, as the plants reached the maximum Cwt at about 50% of the final Wt. The duration of this phase varied between 18 and 37 days, in the periods from 66 to 107 DAS, according to the dose of N applied, being the shortest period for 60 and 240 kg/ha N and the longest for 120 kg/ha. The dose of 120 kg/ha also provided the highest Wt of 138.64 g/plant and 240 kg/ha the highest maximum Cwt of 5.58 g/plant/day, at the end of phase II (Figure 1 and 2A). In this phase, when 60% of the N had already been applied, N provided an increase in plant growth, by the large difference between Wt and Cwt in the control without N and the other doses. Also, the negative effect of N in the highest dose applied is observed, by the lower values of Wt (130.60 g/plant) and Cwt (5.35 g/plant/day), when compared to 120 kg/ha N (Figure 1 and 2A).

The first flowers and fruits were produced after 65 DAS, at the end of Phase II, verifying the beginning of the reproductive phase as observed by Galati *et al*. (2013). In this phase, photoassimilates translocation were observed for flowers and fruits, which accumulated dry mass (Wfr) differently as a function of applied N, as values equal to 1.93, 2.39, 4.05, 1.61 and 3.83 g/plant were estimated for 0, 60, 120, 240 and 360 kg/ha N, respectively (Figure 2). At the reproductive stage, the drain strength of the plant is altered by increased translocation of photoassimilates from leaves to fruits (Marschner, 2012). N increased the strength of the main drains, flowers and fruit, by the increment in the acceleration of Cwfr, mainly, at 360 kg/ha N, in this Phase II (Figure 2B).

The deceleration in plant growth and the reaching of 100% of Wt, associated with fruit maturation, characterize Phase III. The duration of this phase varied between 33 and 65 days, in the period from 84 to 165 DAS, according to the dose of N applied, with the shortest period for 240 kg/ha and the longest for the control without N. In this phase, the plants continued to accumulate dry

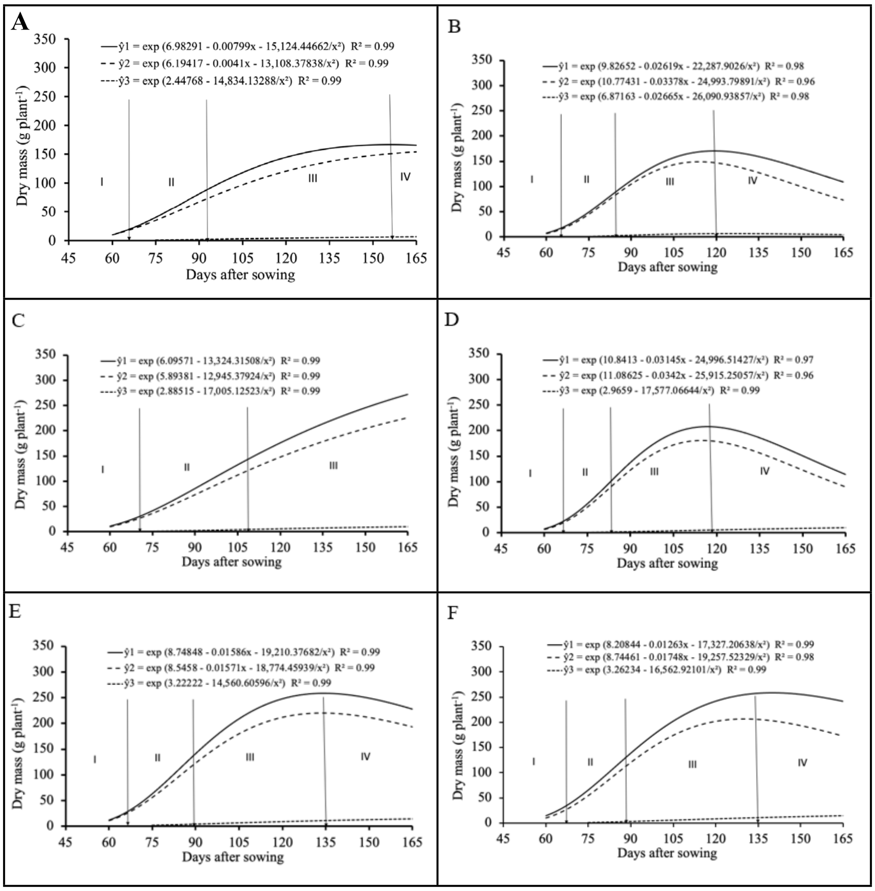

Figure 1. Total dry mass of plant (ŷ1), aboveground (ŷ2) and fruit (ŷ3) of okra 'Santa Cruz 47' for nitrogen doses: 0 (A), 60 (B), 120 (C), 240 (D), 360 (E) and 346 kg/ha (F), in Red-Yellow Argisol, as a function of plant age, in the growth phases I, II, III e IV. Oratórios, EPAMIG, 2013.

mass, but with each day lower Cwt until reaching 100% of plant Wt. With 240 kg/ha N, okra plants reached earlier (117 DAS) a maximum plant Wt of 207.60 g/plant, while plants with 120 kg/ha were later, accumulating dry mass until the final harvest (165 DAS) with a maximum Wt of 272.13 g/plant (Figures 1 and 2).

During Phase III, in the period from 84 to 165 DAS, the maximum accumulation of aerial part dry mass (Wpa) occurred at all doses. At 120 kg/ha N, the highest Wpa of 225.50 g/plant was estimated (Figure 2). Moreover, the fruits reached the maximum Cwfr at this phase for all doses of N. At 99 DAS, 360 kg/ha N provided the highest maximum Cwfr, 0.17 g/plant/day, a value twice as high as the maximum Cwfr for the control without N (Figure 2B). In this phase, the decrease in growth is due to the continued change in the source/drain relationship initiated at the end of Phase II, because the N acts directly on the source/drain relationships, by altering the distribution of photoassimilates between the vegetative and reproductive parts (Queiroga *et al*., 2007).

The maximum accumulation of root dry mass (Wr) was observed in Phase III in the period between 118 and 165 DAS. With 360 kg/ha N, the highest Wr (56.37 g/plant) was estimated and the lowest (24.19 g/plant) in the control without N. However, the roots reached the maximum Cwr between 86 and 102 DAS, with the lowest Cwr estimated with 240 kg/ha N, equal to 0.51 g/plant/day, respectively (Figure 3).

Phase IV was characterized by reduced Wt and negative Cwt values in all doses, except for 120 kg/ha N. This was probably due to the loss of dry mass of the aerial part (senescent branches and leaves) until the final harvest, which occurred at 165 DAS, ending the okra cycle in all treatments. The duration of this phase was shorter, seven days, in the control without N. Phase IV lasted 46, 48 and 31 days for 60, 240 and 360 kg/ha N, respectively. The excess of N can promote supranormal vegetative growth, disfavoring the beginning of the reproductive stage, besides less number and size of the commercial product of the vegetables (Vidigal *et al*., 2019).

Although the maximum Wt of the plants marked the end of Phase III, it was in Phase IV that the fruits reached the maximum dry mass accumulation, estimated at 165 DAS, with the dry mass of 6.70, 9.59, 10.18 and 14.69 g/plant for 0, 120, 240 and 360 kg/ha N, respectively, while for 60 kg/ha N, the maximum fruit dry mass of 6.49 g/plant occurred at 125 DAS (Figure 2). Therefore, N had a direct positive influence on the growth and development of okra plants. Lower N availability may limit the time for plants to reach maximum dry mass accumulation, while higher N availability may allow plants more time to reach this maximum dry mass accumulation. In a study by Coutinho-Miranda *et al*. (2020), N influenced all the development characteristics of okra plants, showing the importance of nitrogen fertilization for the crop.

The positive influence of N on the partition of photoassimilates was observed by the maximum amount of dry mass in the different parts of the plant, varying with the doses throughout the cycle (Figure 4). The accumulation of dry mass in the root and in the aerial part remained balanced in all doses of N, in the period between 60 and 75 DAS, when the aerial part accumulated about 89% of the dry mass of the plant. This may be due to the lower availability of N (only 20% of the doses had been applied) that promoted the slow growth of the plants, observed in Phase I (Figure 1). From 75 DAS on, in Phase II, there was an increase in the accumulation of dry mass in the roots and fruits with the N and less accumulation in the aerial part until the end of the cycle (Figures 1 and 4). In Phases III and IV, N promotes greater accumulation of dry mass in the fruits due to the change in the source/drain relationship of okra plants, because according to Lopes *et al*. (2011), in the reproductive phase, the flowers and fruits of the plants become the preferential drains.

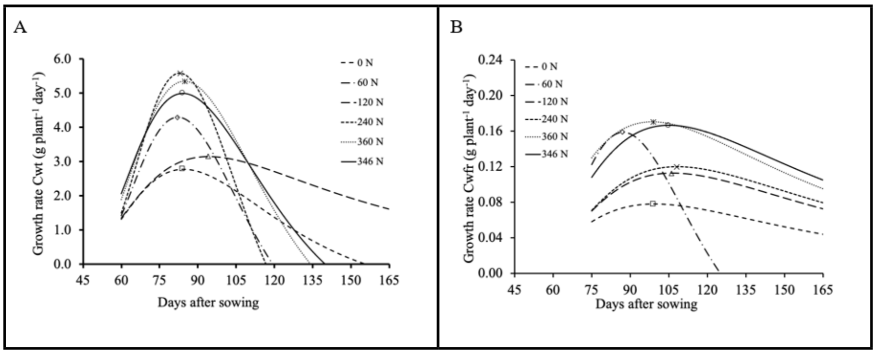

Figure 2. Absolute plant growth rate [Cwt (A)] and absolute fruit growth rate [Cwfr (B)] of okra plants 'Santa Cruz 47' as a function of nitrogen doses: 0, 60, 120, 240, 360 and 346 kg/ha, in Red-Yellow Argisol, as a function of plant age. Oratórios, EPAMIG, 2013.

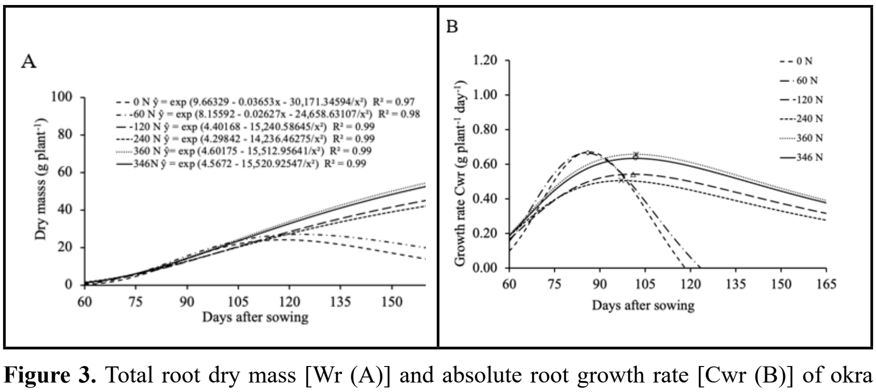

Figure 3. Total root dry mass [Wr (A)] and absolute root growth rate [Cwr (B)] of okra 'Santa Cruz' plants as a function of nitrogen doses: 0, 60, 120, 240, 360 and 346 kg/ha, in Red-Yellow Argisol, as a function of plant age. Oratórios, EPAMIG, 2013.

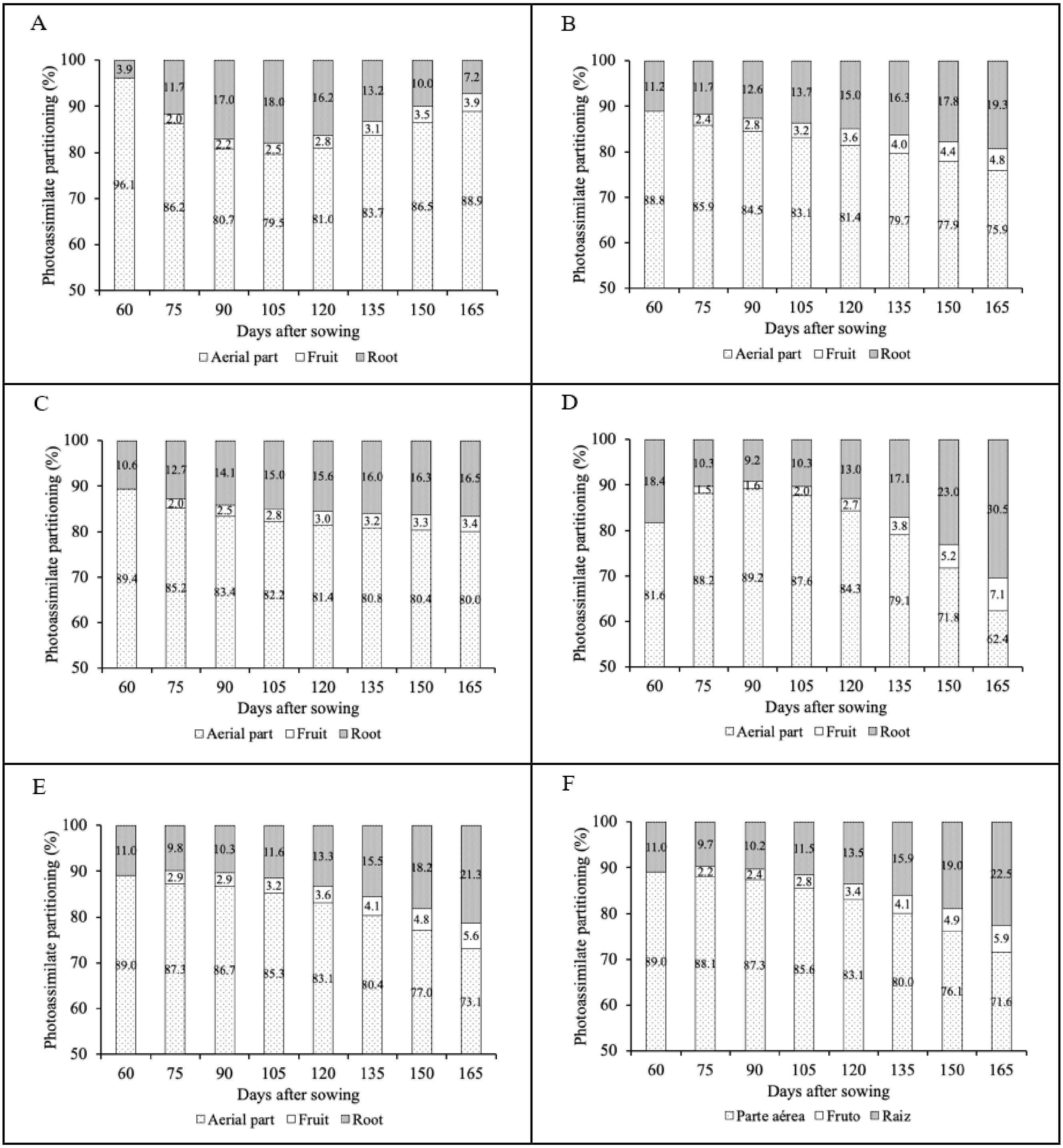

Figure 4. Partition of photoassimilates in okra plant 'Santa Cruz 47' for the nitrogen doses: 0 (A), 60 (B), 120 (C), 240 (D), 360 (E) and 346 kg/ha (F), in Red-Yellow Argisol, as a function of plant age. Oratórios, EPAMIG, 2013.

After the application of 100% N, with the increase in the availability of N to the plants, there was a reduction in the accumulation of dry mass in the aerial part (branches and leaves) and an increase in the roots and, principally, in the fruits (Figures 1 and 4). Due to the senescence of the leaves, there is a translocation of photoassimilates and nutrients to the fruits, preferential drains (Lopes *et al*., 2011). Therefore, in the initial period, N has a positive influence on the growth of the stem and leaves and consequent increase in the photosynthetic apparatus, promoting an increase in the production of photoassimilates (Engels *et al*., 2012). So, there is an increase in fruit growth and consequent increase in the yield of marketable fruits with the increase in N availability (Figure 5B).

Greater availability of nutrients, at the time of greatest absorption, is one of the factors that promote plant growth and allow them to express their growth and yield potential. N is the third most absorbed nutrient by okra 'Santa Cruz' (Galati *et al*., 2013), standing out for the amount required and the functions it exerts in the plant. As part of the chlorophyll molecule, N favors the photosynthetic apparatus and promotes the optimization of photoassimilates production (Engels *et al*., 2012). Therefore, the management of N fertilization deserves attention to ensure the yield and quality of okra fruits, as well as other vegetables.

The definition of okra yield is in Phase II, which is the most important growth phase for fertilization, a period when plants need the greatest availability of N, as observed by Galati *et al*. (2013), in which okra plants absorb most of the N in the period from 30 to 90 DAS. N increased the yield of marketable fruits up to 346 kg/ha, reaching the maximum marketable fruit yield of 10,665 kg/ha for a population of 31,250 plants/ha (Figure 5A).

Oliveira *et al*. (2003) and Singh *et al*. (2020) observed that okra fruit yield was also influenced by N, estimating the maximum value of 16,701 kg/ha (20,000 plants/ha) with 141 kg/ha N and 16,590 kg/ha with 150 kg/ha N. On the other hand, Galati *et al*. (2013) obtained 12,000 kg/ha (50,000 plants/ha) with 160 kg/ha N, while Coutinho-Miranda *et al*. (2020) observed linear response for N and obtained 17,746 kg/ha (autumn/winter) and 13,812 kg/ha (spring/summer) with 250 kg/ha N, all higher than 120 kg/ha, the recommended dose for okra (Silva *et al*., 2007, 2019). This suggests that the yield potential of okra can be expanded by using higher doses of N.

However, the average temperatures suitable for okra cultivation are 21.1 to 29.4°C, with the average maximum at 35°C and the average minimum at 18.3°C (Sediyama *et al*., 2009). Thus, the growing season (February to June) was not favorable for the crop, because the average temperature ranged from 14.7 to 26.1°C with an average of 20.6°C; the maximum daily temperature ranged from 19.1 to 32.7°C, with an average of 25.6°C and the minimum daily temperature was 8.2 to 20.1°C with an average of 15.5°C, all temperatures below those considered appropriate. Thus, climatic conditions may have influenced the yield of marketable fruits, since the observed values (Figure 5A) were lower than the yield of 15,000 to 20,000 kg/ha, which varies with plant population and growing conditions (Silva *et al*., 2007, 2019). However, the effect of N on okra growth and development through dry mass accumulation was demonstrated (Figures 1, 2 and 3).

The number of fruits per plant was increasing until 360 kg/ha N, reaching the highest value of 29.2 units. At the control without N, it was estimated at 19.3 units (Figure 5B). The number of fruits per plant showed a high correlation (r = 0.9976; p = 0.000) with the yield of marketable fruits. N interfered positively in the processes of plant growth and development (Figure 1). Thus, these results demonstrate the effect of N fertilization on okra yield by increasing the fresh mass and the number of fruits per plant.

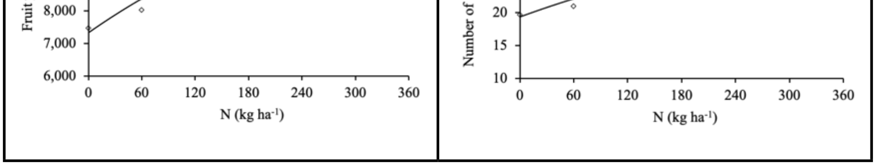

Figure 5. Fruit yield (A) and number of marketable fruits per plant (B) of okra as a function of nitrogen (N) doses in Red-Yellow Argisol. Oratórios, EPAMIG, 2013.

Under the conditions of this work, the optimum dose for okra fruit yield was 346 kg/ha N, however the maximum estimated values of Wt (258.84 g/plant), Wpa (207.00 g/plant); Wfr (14.21 g/plant) and Wr (54.44 g/plant) did not correspond to the highest estimated values (Figure 1), as observed for hybrid pumpkin by Vidigal *et al*. (2021). Queiroga *et al*. (2007) affirm that plants with greater mass and leaf area have greater production of photoassimilates and fruits, so the greater growth and development of okra plants estimated with the optimum dose was expected. Since, the greater accumulation of dry mass by plants is related to the increase in photosynthetic rate and the production of photoassimilates and other structural compounds, such as amino acids, carbohydrates, and fats (Lima *et al*., 2011; Tuncay *et al*., 2011), resulting in greater mass of reproductive organs, such as flowers and fruits.

The growth and partition of photoassimilates among the organs of the okra plant 'Santa Cruz' are altered with the increase in the availability of N applied in topdressing. The yield of marketable fruits increased until 346 kg/ha N.

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