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RESEARCH ARTICLE

GROWTH, PRODUCTION AND NUTRIENT USE EFFICIENCY OF SUNFLOWER CULTIVARS UNDER NITROGEN AND BORON FERTILIZATION

[1]Flávio da Silva Costa, *,[2]Lucia Helena Garófalo Chaves, [2]Antônio Suassuna de Lima, [3]Ivomberg Dourado Magalhães and [2]Ana Carolina Feitosa de Vasconcelos

[1]Field Education Department, Federal University of Amapá, Mazagão
[2] Technology Center and Natural Resources, Federal University of Campina Grande, Campina Grande
[3]Agricultural Science Center, Federal University of Alagoas, Rio Largo

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ABSTRACT

The objective of this study was to evaluate the vegetative growth, production of achenes and efficiency of use of nutrients in sunflower crop in function of N and B fertilization under semi-arid conditions of the Brazilian Northeast. The experiment was carried out in the experimental area of the State University of Paraíba, Campus II, Lagoa Seca, PB, Brazil. The experiment followed a randomized block design with three replications in a factorial outline 2 x 4 x 4; with two sunflower cultivars (Helio 250 and Helio 251), four doses of nitrogen (30; 60; 90 and 120 kg ha^{-1}) and four doses of boron (1; 2; 3 and 4 kg ha^{-1}).The following parameters were analyzed: plant height, stem diameter, area and leaf area index, the mass of achenes, the mass of 250 achenes and nutrient use efficiency. The cultivars differed significantly on the vegetative growth and mass achenes. The increments of nitrogen influenced, significantly, growth and yield characteristics of the sunflower. Boron application in soil up to 4 kg ha^{-1} did not cause significant effect on the variables analyzed in this study. Smaller doses of nitrogen and boron provided the greater efficiencies of use of these nutrients.

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INTRODUCTION

Sunflower (*Helianthus annuus* L.)has stood out among the crops of economic importance and food, mainly for easy adaptation to the most varied climatic conditions in different regions in the world (Freitas *et al.*, 2012). Sunflowercrop stands out among the world top five producing of vegetable oil. In Brazil, grain production reaches higher levels each year, reaching a total of 108,838 tons in 2013, which represented a 25.67% increase compared to 2010 production (FAO, 2015). The low productivity of sunflower usually is related to factors such as genetic variability, planting density, sowing date, growth stage of the crop, water availability and soil fertility (Tomich *et al.*, 2003). Among those mentioned factors, the availability of water and nutritional deficiency of a large amountof Brazilian soils are the most limiting production of this crop, since the sunflower is sensitive to water deficit and demanding to soil fertility (Biscaro *et al.*, 2008; Ivanoff *et al.*, 2010; Wolf *et al.*, 2012). Among the essential nutrients to the development of sunflower, nitrogen (N) is the most limiting for plant development, since its deficiency causes nutritional disorder in the plant, which negatively affected the growth of their organs (Prado and Leal, 2006) and its excess reduces the oil percentage (Biscaro *et al.*, 2008). According to Zobiole *et al.* (2010), the nitrogen is the element found in greater amount in the achenes in the grain harvest phase, followed by P = K> Mg = S> Ca. Thus, the importance of studies of adequate amounts of N to be applied for sunflower cultivation in different regions should be strengthened, since beyond what is exported by the grain, the loss of the element by leaching and volatilization is high (Lorensini *et al.*, 2012). Boron (B) is considered the most important micronutrient for sunflower cultivation by the fact that the achenes production is directly correlated with their content in leaves (Castro *et al.*, 2006) and its deficiency cause significant reduction in height and diameter of the shaft (Lima *et al.*, 2013), leaf area and dry biomass of shoot (Feitosa *et al.*, 2013). This element presents low mobility in soil and its absorption may be influenced by

Corresponding author: Lucia Helena Garófalo Chaves,
Technology Center and Natural Resources, Federal University of Campina Grande, Campina Grande

factors such as pH, soil texture, moisture, temperature, organic matter and light intensity (Hu and Brown, 1997). These authors also emphasize that one of the most important factors to maximize the absorption of B by the plant is its transpiration rate, which in turn is influenced by relative humidity, temperature and light intensity. Thus, it emphasizes the importance of studies on B for sunflower grown in specific conditions of climate and soil, because it is an element absorbed in small amounts and highly influenced by environmental factors. In order to obtain satisfactory yields in agricultural production is essential knowledge about appropriate fertility conditions of soil, regardless of the crop to be grown. Furthermore, it is necessary to know whether the nutrients that limit the growth and / or development of the plant are in shortage or excess in the soil. In this context, the aim of this study was to evaluate the vegetative growth, production of achenes and the use efficiency of nutrients by sunflower cultivars Helio 250 and Helio 251 according to the conventional fertilization with N and B under semiarid conditions of the Brazilian Northeast.

MATERIALS AND METHODS

The experiment was carried out from July to October 2012 under field conditions at Center for Agricultural and Environmental Sciences of the State University of Paraíba, Paraiba State, Brazil, situated at 07° 10' 15" S and 35° 51' 14"W, 620 m of altitude. According to the Köppen methodology the climate is As' (tropical hot and semi humid), with an average temperature, relative air humidity and rainfall of 22˚C, 65% and 940 mm, respectively. The soil of the area is classified as Entisol with the following chemical attributes: pH (1:2.5; soil:H_2O ratio) = 5.95; Ca^{2+} = 2.63 $cmol_c dm^{-3}$; Mg^{2+} = 2.30 $cmol_c dm^{-3}$; Na = 0.12 $cmol_c dm^{-3}$; K^+ = 0.42 $cmol_c dm^{-3}$; $H^+ + Al^{3+}$ = 1.23 $cmol_c dm^{-3}$; organic matter = 18.9 g dm^{-3}; available P = 14.55 mg dm^{-3}, B = 1.7 mg dm^{-3}. A week before planting the soil was prepared with plowing and harrowing and fertilized with phosphorus and potassium based on chemical analysis of soil and on the recommendation by Leite *et al.* (2007) for sunflower cultivation. The superphosphate (18% P_2O_5) and potassium chloride (60% K_2O) were used as sources of nutrients. Nitrogen fertilization (urea, 45% N) was splitted: 1/3 N was applied to foundation and the remaining 2/3 applied in coverage at 30 days after sowing. The boron was applied by using boric acid (17% B) as source of nutrient and it was fully applied at sowing. After fertilization in foundation, sowing was done in groove with a depth of 0.05 m. The experimental design was a randomized block factorial (2 x 4 x 4) with two sunflower cultivars (Helio 250 and Helio 251), four nitrogen doses (30; 60; 90 and 120 kg ha^{-1}), four boron doses (1; 2; 3 and 4 kg ha^{-1}) and three replicates. The experimental plot consisted of 40 plants spaced in 0.7 m between rows and 0.3 m between plants with 3 meters long with a total plot area of 8.4 m².The plants located in the border were despised and considered for the 16 central plants analysis, with total useful floor area per plot of 3.36 m². Irrigation was performed in the dry season, between August and October 2012, starting 25 days after plant emergence, since the sowing period coincided with the rainy season in the region. The drip system used was the drip tape with a diameter of 16 mm and spacing between drippers 0.2 m flow rate of 1.02 L h^{-1} by issuer. The drip tapes followed lines planting and were placed 0.05 m away from the plants. The determination of the water depth was based on agro-meteorological data collected daily automatic station located near the experimental area. Then it was determined the reference evapotranspiration (ETo) by Penman-Monteith standard model by Allen *et al*. (1998). ETc was determined using the culture coefficients (kc) 0.54; 0.78; 1.01 and 0.82 for early development stages, vegetative growth, flowering and physiological wilt respectively (Cavalcante Junior *et al*. (2013).The irrigation interval was two days, i.e. the water depth to be applied was calculated based on the sum of ETc two days prior to the time of irrigation.

At the end of sunflower crop cycle, plant height (m), stem diameter (mm), number of leaves per plant and total leaf area per plant (m²) (LA) were measured. For LA, it was measured all the leaves that were fully opened and with more than 50% green area, following the methodology proposed by Maldaner *et al*. (2009) (Equation 1), becoming then square centimeter to square meter.

$$\mathrm{LA} = 1.7582 * \mathrm{L}^{1.7067}\ (\mathrm{cm}^2) \qquad \text{Equation (1)}$$

Where:

L - length of leaf blade (cm).

The relationship between leaf area and the area occupied by the plant has used for determining the leaf area index (LAI) sunflower as Equation 2.

$$\mathrm{LAI} = \frac{\mathrm{LA}}{\mathrm{AP}}\ (\mathrm{m}^2\mathrm{m}^{-2}) \qquad \text{Equation (2)}$$

Where:

LA - leaf area (m²);
AP - area occupied by the plant (m²).

After harvest were quantified mass of 250 achenes (g) and total mass of achenes per plant (TMA, g). The nutrient use efficiency (NUE) was determined by the ratio between TMA and the amount of fertilizer used (g) according Fageria (1998) (Equation 3).

$$\mathrm{NUE} = \frac{\mathrm{TMA}}{\mathrm{F}}\quad (\mathrm{g\,g}^{-1}) \qquad \text{Equation (3)}$$

Where:

F - Amount of nutrient applied (g).

The results were analyzed statistically through the analyses of variance (ANOVA) (Ferreira, 2011).

RESULTS AND DISCUSSION

Among sunflower cultivars Helio 250 (H250) and Helio 251 (H251) there was no statistical difference (p> 0.05) for leaf area (LA) and leaf area index (LAI); unlike plant height (PLH)

Table 1. Analysis of variance for plant height (PLH), stem diameter (SD), leaf number (LN), leaf area (LA) and leaf area index (LAI) under nitrogen and boron fertilizers of two sunflower varieties in semiarid conditions of Paraiba State

Source	DF	Mean Squares				
		PLH (m)	SD (mm)	LN	LA (m^2)	LAI ($m^2\ m^{-2}$)
Blocks	2	0.00806^{ns}	0.2076^{ns}	0.0729^{ns}	0.00171^{ns}	0.03885^{ns}
Cultivar (C)	1	0.80850^{**}	35.1626^{**}	102.0937^{**}	0.00647^{ns}	0.14260^{ns}
Nitrogen (N)	3	0.02762^{**}	19.6516^{**}	2.2604^{ns}	0.02977^{**}	0.66094^{**}
Linear	1	0.02567^{*}	58.4505^{**}	0.9187^{ns}	0.08278^{**}	1.83769^{**}
Quadratic	1	0.04550^{**}	0.4788^{ns}	5.5104^{ns}	0.00599^{ns}	0.12760^{ns}
Boron (B)	3	0.00573^{ns}	0.5786^{ns}	4.2882^{ns}	0.00089^{ns}	0.01649^{ns}
Linear	1	0.00018^{ns}	1.0849^{ns}	0.0020^{ns}	0.00043^{ns}	0.00919^{ns}
Quadratic	1	0.01680^{ns}	0.6501^{ns}	11.3437^{ns}	0.00074^{ns}	0.01760^{ns}
C x N	3	0.00912^{ns}	0.1960^{ns}	3.5104^{ns}	0.00157^{ns}	0.03344^{ns}
C x B	3	0.00206^{ns}	0.3586^{ns}	2.4826^{ns}	0.00049^{ns}	0.01121^{ns}
N x B	9	0.00206^{ns}	0.5526^{ns}	1.3715^{ns}	0.00125^{ns}	0.02473^{ns}
C x N x B	9	0.00666^{ns}	0.3706^{ns}	2.9734^{ns}	0.00111^{ns}	0.03094^{ns}
Error	62	0.00393	0.3846	4.6858	0.00211	0.04971
CV (%)		5.16	3.90	11.87	17.75	18.09
				Mean test		
H250		1.12 b	15.29 b	19.27 a	0.267 a	1.27 a
H251		1.31 a	16.50 a	17.21 b	0.264 a	1.19 a

ns (Nonsignificant), * and ** (Significant at 5% and 1% probability, respectively). Means followed by the same letters do not differ statistically by the F test at 5% probability.

and stem diameter (SD), where cultivars differed significantly ($p<0.01$) and the cultivar H251 presented best indices compared to cultivar H250 in both parameters (Table 1). Regarding the leaf number (LN), the cultivar H250 exceeded by 1.94 cultivar H251, reaching 19.27 leaves per plant at the beginning of achenes filling (R7). Regarding fertilizers, the variation from 1 to 4 kg B ha^{-1} did not affect ($p> 0.05$) plant growth, unlike the N, which significantly influenced all growth variables, except for the LN. There was no significant effect on the interactions between the quantitative factors (N x B) or those with qualitative factor (cultivars). It is noteworthy that the soil of the experimental area had a considerable amount of B (1.70 mg dm^{-3}) at the time of sowing and it may have supplied the nutritional needs required by the plant for growth. The variation of the PLH in relation to treatments with nitrogen was adjusted to a quadratic model with estimated maximum height of 1.23 m using a dose of 63.03 kg ha^{-1} N (Figure 1). This result exceeds by 2.0% and 6.33% the heights obtained with applications of 30 and 120 kg ha^{-1} N, respectively.

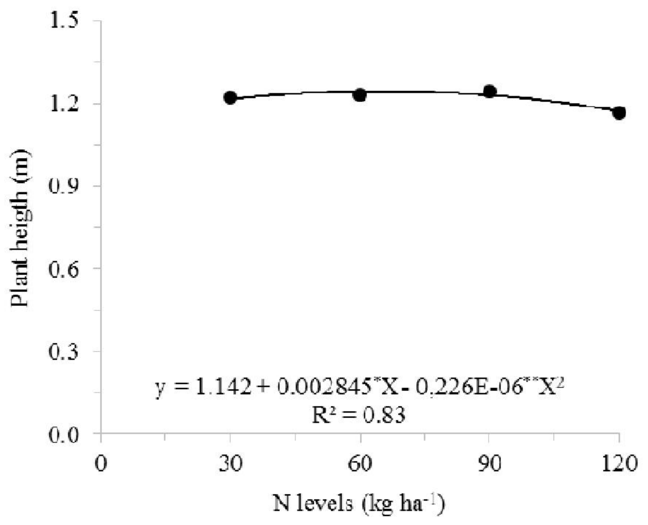

Figure 1. Plant height of sunflower depending on nitrogen levels in semiarid conditions of Paraiba State

These results are higher than those ones presented by Silva *et al.* (2009) for the cultivar H251 (0.97m), and lower than those achieved by Aquino *et al.* (2013), the average height of 1.82 m for H250 and H251 cultivars, respectively. According to Capone *et al.* (2012), plant growth is directly influenced by the time of planting, and these authors found HP ranging between 1.13 and 1.77 m in four distinct growing seasons in the Brazilian Midwest. Considering the results obtained for HP with the applications of 30 and 120 kg N ha^{-1}, associated with great resistance of crops to lodging (Heliagro, 2015), an essential feature for the reduction of losses at harvest, it is noticed the viability of the cultivars to the practice of mechanized harvesting (Tomich *et al.* 2003; Uchôa *et al*, 2011.). The sunflower cultivars show gains for SD in the order of 0.0233 mm for each kg N ha^{-1} applied to the soil, reaching a maximum diameter of 16.94 mm with the amount of 120 kg ha^{-1} (Figure 2). Comparing the results of the smallest to the highest dose of N studied, the total increment in height was 14.13% for an increase of 300% of N. Thus, it is evident that the N doses did not provide equivalent percentage gains in SD for the applied quantities.

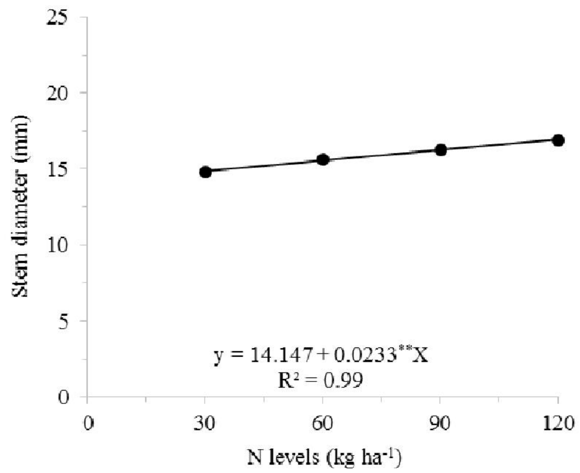

Figure 2. Stem diameter of sunflower depending on nitrogen levels in semiarid conditions of Paraiba State

However, stems thicker are considered favorable agents to the cultivation of sunflower because they decrease the lodging and the breaking of the chapter at harvesting (Carvalho *et al*., 2004).

The LA behave linearly with increasing doses of N applied to the soil with maximum area of 0.298 m² with the application of 120 kg ha^{-1}, implying in an increase of 35.88% of a minor amount of N applied (Figure 3). The leaves are of extreme importance for the sunflower because they are sources of nutrients and organic compounds in the formation of achenes (Aquino *et al*., 2013). The authors Zobiole *et al*. (2010) state that the sunflower crop when it is grown in soil without physical and nutrient limitation needs a minimum leaf area of 0.8 m² to produce potentially.

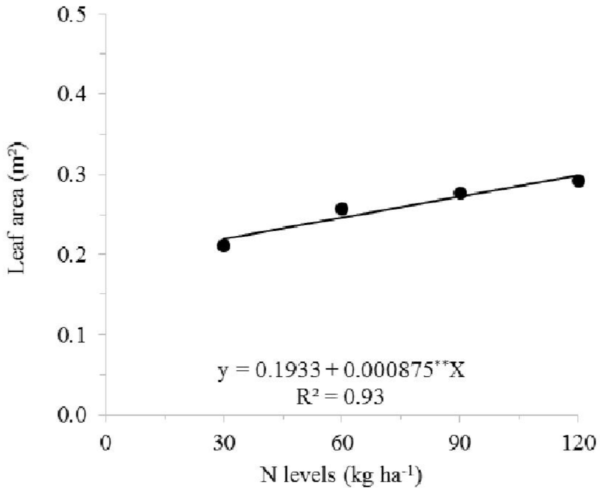

Figure 3. Leaf area of sunflower depending on nitrogen levels in semiarid conditions of Paraiba State

It was observed that the LAI ranges from 1.046 m² m^{-2} with the application of 30 kg N ha^{-1} to 1.421 m²$m^{-2}$with the application of 120 kg N ha^{-1}; resulting, thus, in an increase of 35.90 %, from the lowest to the highest dose of N tested (Figure 4). It is noteworthy that for the lowest dose of N (<LAI), it would be necessary to increase the planting density in 1/3 approximately to obtain the same content provided by 120 kg N ha^{-1}, since the plants received 30 kg N ha^{-1} occupied a larger area than necessary compared plants subjected to maximum dose of N. According to Bezerra *et al*. (2014), reducing the spacing and/or plants adversely affect sunflower growth, with the exception of LAI, which increases at higher plant densities. The same authors found no negative effect of planting density between 30,000 and 75,000 plants per hectare on the productivity of cv. Embrapa 122; however, they noted that the site of cultivation is decisive in the vegetative and productive behavior of sunflower seeds of this variety. The authors Alves *et al*. (2014), evaluating spatial arrangements for sunflower, 0.5x0.3 m and 0.9x0.3 m, observed that higher planting density (0.15 m²) obtained 80.35% increase in achenes productivity compared with lower density (0.27 m²). The same authors observed that the LA per plant varied, from the smallest to the largest occupied area of 0.449 to 0.577 m², and the LAI was 2.99 to 2.14 m² m^{-2}, respectively, showing that the productivity of sunflower is correlated more strongly with the LAI. The sunflower cultivars differed significantly for total mass of achenes per plant (TMA) and the cv. H251 obtained the highest yield compared to cv. H250. However, no cultivars differed from each other for the seed mass 250 (M250) (Table 2). Nitrogen, both alone and in interaction with the cultivars had a significant effect ($p<0.01$) as the TMA was applied to the soil. In contrast, boron both isolated and in interaction with the other factors did not significantly influence the productive characteristics of sunflower. Corroborating the results, Oliveira *et al*. (2014) found no effect of N rates from 0 to 200 kg ha^{-1} on the M250; however, on the TMA, cultivar H251 showed better results when compared to H250.

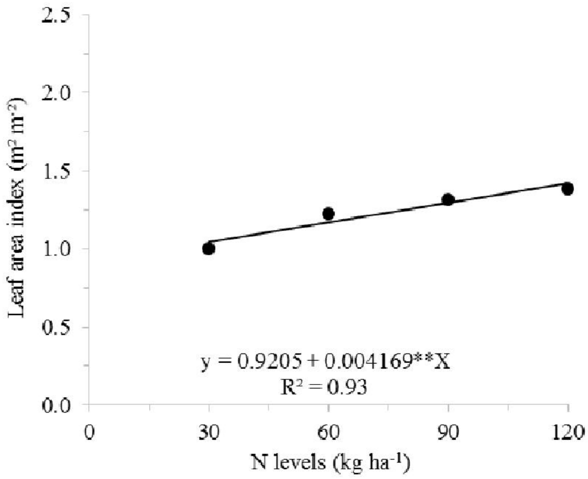

Figure 4. Leaf area index sunflower depending on nitrogen levels in semiarid conditions of Paraiba State

Table 2. Analysis of variance for mass of 250 achenes (g) and total mass of achenes (g) under nitrogen and boron fertilizers with two sunflower varieties in semiarid conditions of Paraiba State

		Square Means	
Source of variation	DF	M250 (g)	TMA (g)
Block	2	0.55462^{ns}	73.249757^{**}
Cultivar(C)	1	0.50750^{ns}	$1,328.33760^{**}$
Nitrogen(N)	3	0.69198^{ns}	169.06715^{**}
Linear effect	1	1.73280^{ns}	263.73675^{**}
Quadraticeffect	1	0.27735^{ns}	176.63801^{**}
Boron(B)	3	1.66020^{ns}	14.18122^{ns}
Linear effect	1	4.52408^{ns}	5.26264^{ns}
Quadraticeffect	1	0.24401^{ns}	37.00167^{ns}
CxN	3	1.23519^{ns}	34.63925^{**}
CxB	3	1.11181^{ns}	7.90416^{ns}
NxB	9	1.09987^{ns}	6.48310^{ns}
CxNxB	9	1.39334^{ns}	6.61187^{ns}
Error	62	1.50174	7.49458
CV(%)		12.79	8.94
		Means	
H250		9.51a	26.91 b
H251		9.65a	34.35 a

ns (Non significant), * and ** (Significant at 5% and 1% probability, respectively). Means followed by the same letters do not differ statistically by the F test at 5% probability.

The TMA evidenced by cv. H250 increased concurrently with the increase of N to the soil, achieving maximum yield (29.48 g) with application of 120 kg ha^{-1}, which resulted in a gain of 21.11% when compared to the yield with application of 30 kg ha^{-1} (Figure 5).

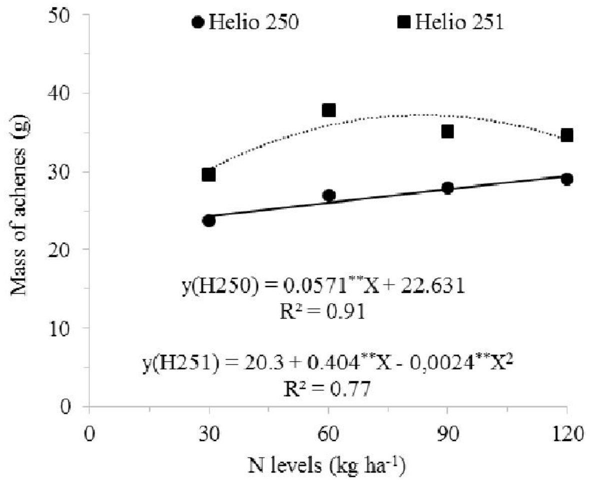

Figure 5. Mass of achenes per plant of sunflower depending on nitrogen levels in semiarid conditions of Paraiba State

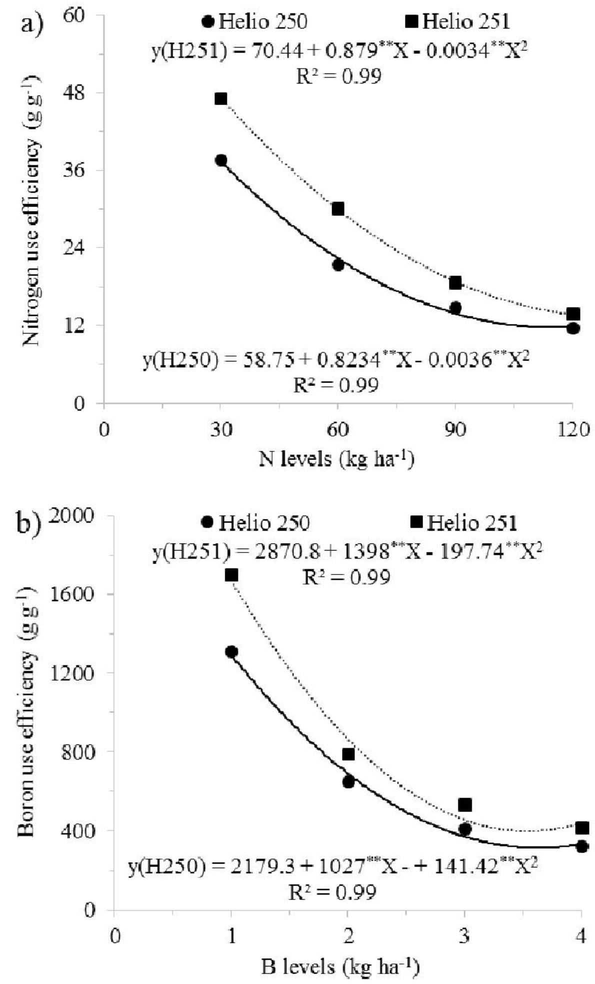

Figure 6. Nitrogen and boron use efficiency to mass of sunflower seeds depending on nitrogen and boron levels in semiarid conditions of Paraiba State

Otherwise, cv. H251 showed maximum efficiency with the amount of 83.56 kg N ha^{-1}, resulting in the production of 37.24 g of seeds for each plant. Multiplying the maximum yield obtained per plant, for cv. H250 and H251, the planting density used in the experimental area (0.7 x 0.3 m), the achieved yields would be 1403.95 and 1773.23 kg ha^{-1}, respectively. The yields of achenes found for the H251 are above the Brazilian productivity for 2015, 1379 kg ha^{-1}, (IBGE, 2016). Oliveira *et al*. (2014) found no effect of N between 0 and 200 kg ha^{-1} on yield of three sunflower cultivars. However, the same authors found statistically significant differences in productivity between H250 and H251 cultivars, finding income of 1436.2 kg ha^{-1} and 1884.5 kg ha^{-1}, respectively, revealing behaviors similar to those obtained in this study. The behavior of nitrogen (NUE) and boron (BUE) use efficiency on the total mass of achenes (TMA) of cultivars studied was similar for both cultivars, with diminishing returns for each fertilizer gram applied as higher doses of nutrients in the soil were increased (Figure 6). For the cv. H250, it was observed that most of the nitrogen use efficiency (NUE) was provided by applying 30 kg ha^{-1}, noting yield 37.29 g of achenes per gram of N applied. However, the maximum dose tested (120 kg ha^{-1}) presented a yield of 11.78 g g^{-1}, with a reduction of 68.4% in lower production for the highest dose tested (Figure 6a).

Similarly, cv. H251 had the highest NUE (44.13 g g^{-1}N) with application of 30 kg ha^{-1}, confirming a reduction of 70.46% when compared to NUE (13.92 g g^{-1}) found with the application of 120 kg ha^{-1}. Regarding to the BUE on TMA, there was variation in the production rate of 1670.54 g achenes per gram of B for cv. H250, by applying 1 kg ha^{-1} B, 442.64 g g^{-1} with application of 4 kg ha^{-1}, resulting in a reduction of 73.5% (Figure 6b).Under this context, the cv. H251 showed decrease of 74.18% in BUE on the TMA between the lowest and highest dose tested. However, when comparing the BUE obtained by applying 3 kg ha^{-1} with evidenced by the maximum dose tested, it was found decreasing of 3.02% and 9.98 g g^{-1} for cultivars H250 and H251, respectively. Similarly, Sant'ana *et al*. (2011) found reduction in nitrogen use efficiency by beans, for agronomic and physiological efficiencies in increments of N in the soil between 30 and 240 kg ha^{-1}. The authors Baligar and Fageria (2015) argue that increasing the efficient use of nutrients by the plant is associated with application of appropriate fertilizer rates, effective sources, installment and use of methods.

Conclusion

- The cultivar Helio 251 showed greater plant height, stem diameter and mass achenes.
- The maximum plant height is obtained with 63.03 kg N ha^{-1}. The stem diameter, leaf area and sunflower leaf area index increase linearly with applications of N up to 120 kg ha^{-1}.
- The maximum production of achenes of cv. H250 is achieved with the application of 120 kg ha^{-1}, while the cv. H251 is obtained with 83.56 kg ha^{-1}.
- The application of boron to 4 kg ha^{-1} does not result in significant effect on the vegetative growth and production of sunflower achenes on soil and weather conditions outlined in this study.
- The highest use efficiency of the B and N are obtained by sunflowers with the applications 1 and 30 kg ha^{-1}, respectively.

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