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Canola yield under different irrigation frequencies and nitrogen levels in the Brazilian Cerrado

Produtividade de canola sob diferentes frequências de irrigação e doses de nitrogênio na região do Cerrado Brasileiro

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ABSTRACT

In the Brazilian Cerrado, canola is grown in the off-season. During this period, rainfall is insufficient to ensure the maximum crop yield, and irrigation is needed. Canola has a high demand for nitrogen; thus, the application of this nutrient is essential for obtaining a good crop yield. Therefore, a study was conducted at the Federal University of Grande Dourados in 2012 and 2013 using a randomized block split-plot design with four repetition treatments in the plot that consisted of three irrigation frequencies (no irrigation, weekly irrigation and irrigation three times per week). Subplots received different doses of nitrogen: 0, 30, 60, 90 and 120 kg ha^{-1} in 2012 and 0, 60, 120, 180 and 240 kg ha^{-1} in 2013. In both periods, the irrigation frequencies significantly affected plant height, dry weight, grain yield, thousand grain weight and oil content. The nitrogen levels significantly affected dry weight, thousand grain weight and oil content in 2012, as well as plant height, number of pods, dry weight, grain yield and oil yield in 2013. The highest yields were obtained when irrigation was performed three times per week, corresponding to 3,001.84 kg ha^{-1} in 2012 and 2,516.7 kg ha^{-1} in 2013.

Index terms: *Brassica napus* L.; oil seeds; tensiometry.

RESUMO

No Cerrado brasileiro, a canola está sendo cultivada na estação seca, sendo que durante este período a precipitação não é suficiente para garantir o máximo rendimento da cultura, por isso há necessidade de irrigação. A canola tem uma alta demanda de nitrogênio, portanto, a aplicação deste nutriente é essencial para a obtenção de um bom rendimento. Assim, foi realizado um estudo na Universidade Federal de Grande Dourados, em 2012 e 2013, utilizando-se um delineamento de blocos ao acaso com quatro repetições, os tratamentos na parcela composta por três frequências de irrigação (sem irrigação, irrigação semanal e irrigação três vezes por semana). As subparcelas receberam diferentes doses de nitrogênio: 0, 30, 60, 90 e 120 kg ha^{-1} em 2012; E 0, 60, 120, 180 e 240 kg ha^{-1} em 2013. Em ambos os períodos, as frequências de irrigação afetaram significativamente a altura da planta, o peso seco, o rendimento de grãos, o peso de mil grãos e o teor de óleo. Os níveis de nitrogênio afetaram significativamente o peso seco, o peso de mil grãos e o teor de óleo em 2012, assim como a altura da planta, o número de vagens, o peso seco, o rendimento de grãos e o rendimento de óleo em 2013. Os maiores rendimentos foram obtidos quando a irrigação foi realizada três vezes por semana, correspondendo a 3.001,84 kg ha-1 em 2012 e 2.516,7 kg ha^{-1} em 2013.

Termos para indexação: *Brassica napus* L.; sementes oleaginosas; tensiometria.

INTRODUCTION

Canola (*Brassica napus* L.) from the family of crucifers is the third most cultivated oilseed crop worldwide, after palm and soybean (Istanbulluoglu et al., 2010; Mousavi-Avval et al., 2011; Takashima et al., 2013). Canola can be used for human food, in industry or even as green manure (Pavlista et al., 2011; Sprague et al., 2014).

In Europe, canola is mainly used for industrial purposes such as biodiesel production. In Brazil, however, canola is used for food production (Milazzo et al., 2013) and livestock feeding, as bran or grains (Bergamin et al., 2011; França et al., 2011; Woyengo et al., 2016).

Canola is grown in Brazil, consisting of an area of 46,300 hectares concentrated mainly in the southern region, which accounts for 94% of the country's production (Bergmann et al., 2013). In 2014/2015, crop production was 52,000 tons, with an average yield of 1,168 kg ha^{-1} (CONAB, 2015).

Canola grains generally contain 38 to 50% oil (Beaudette et al., 2010; Mohammadi; Rokhzadi, 2012; Pavlista et al., 2011). Regarding thousand grain weight, the literature reports values of 2.5 to 3.8 g (Dogan et al., 2011; Kamkar et al., 2011).

Nitrogen is essential to achieve canola yield potential (Hamzei; Soltani, 2012; Kaefer et al., 2014; Kamkar et al., 2011). With higher doses of nitrogen, 60 kg ha^{-1}, El-Howeity and Asfour (2012) obtained a higher number of pods per plant and of thousand grain weight. According to Beaudette et al. (2010), the best yield results are achieved with a nitrogen level of 80 kg N ha^{-1}, whereas Dogan et al. (2011) and Kamkar et al. (2011) obtained higher yields with levels above 180 kg N ha^{-1} under irrigation.

Canola is sensitive to water stress during periods of flowering and grain filling (Dogan et al., 2011; Mohammadi; Rokhzadi, 2012). Research studies have shown a reduction in the number of pods per plant, in thousand grain weight and in yield due to water stress approximately 34, 35 and 20-45%, respectively, in two consecutive years (Faraji et al., 2009; Tohidi-Moghadam et al., 2009).

Under irrigation, some studies show that canola grain yield can vary between 200 kg ha^{-1} and 3,200 kg ha^{-1} (Faraji et al., 2009; Pavlista et al., 2011; Tohidi-Moghadam et al., 2009). However, other authors have reported yields above 4,000 kg ha^{-1} (Dogan *et al.*, 2011; Kamkar et al., 2011).

As few research studies have been performed with canola grown off-season in the Brazilian center-west region, we assessed crop yield potential under different irrigation frequencies and nitrogen levels over two years.

MATERIAL AND METHODS

The experiment was conducted at the Experimental Station of Irrigation, Faculty of Agricultural Sciences at the Federal University of Grande Dourados, from May to September, 2012 and repeated from May to September, 2013.

The city of Dourados is located in southern Mato Grosso do Sul at a 430 m altitude (Boeni et al., 2014), 22º 13' 16" south latitude and 54º 17' 01" west longitude. According to Köppen, the region has a Cwa climate, i.e., humid mesothermal with hot summers and dry winters (Salton et al., 2014). The temperatures in the coldest month are below 18 °C, and those in the hottest month are over 22 °C. Average annual rainfall ranges from 1,250 mm to 1,500 mm.

The soil was classified as red distroferric oxisol (Santos et al., 2013) at the Laboratory of Soil Science, Faculty of Agricultural Sciences, Federal University of Grande Dourados, with a soil sample from the 0.00-0.20 m layer. Chemical analysis included an examination of the pH level, macro- and micronutrients, cation-exchange capacity at pH 7 and base saturation index (Table 1).

The environmental conditions were monitored by an automatic weather station located at the Embrapa Agropecuária Oust, in Dourados. Daily data of meteorological variables, such as minimum and average temperature (°C) and precipitation (mm) (Figure 1) were collected and compared with historical averages of meteorological information provided by Embrapa Agropecuária Oeste for the period of 2001 to 2011. Precipitation levels were higher than historical averages in June of 2012 and 2013 and in September of 2013. Total precipitation from May to September in both years was 563.4 mm, 307.2 mm in 2012 and 256.2 in 2013.

Average temperatures during crop development did not exceed 28 °C in 2012 and 26.2 °C in 2013, which were below the upper temperature limit for canola 29.5 °C (Kutcher; Warland; Brandt, 2010; Robertson et al., 2013). However, minimum temperatures below zero, -0.5 and -0.7 °C, were found 78 and 79 days after sowing in 2013, corresponding to the full-flowering period. The lower temperature limit for this developmental stage is 6.4 °C (Singh et al., 2008).

We used a randomized block split plot design with four repetitions, totaling 60 experimental plots. Three irrigation frequencies (without irrigation - SI, weekly irrigation - IS, irrigation three times per week - I3S) were used in the plots, whereas the subplots received five nitrogen levels (DN): 0, 30, 60, 90 and 120 kg ha^{-1} in 2012 and 0, 60, 120, 180 and 240 kg ha^{-1} in 2013. Urea was used as a nitrogen source.

The plots were 3 m long x 1.8 m wide (5.4 m^2) with four plantation lines, 0.45 m between rows and 0.17 m between plants. The available plot size was the two central rows discarding 0.5 m from the ends, 1.8 m^2 (0.9 mx 2 m); the remainder of the experimental plot was defined as the borders. Plots were 1.5 m apart.

Table 1: Chemical analysis of the soil at layer 0-0.20 m.

	pH	P	K	Ca	Mg	H+Al	Al	CTC	V	MO
	$CaCl_2$	mg dm^{-3}	$mmol_c$ dm^{-3}	$cmol_c$ dm^{-3}				$cmol_c$ dm^{-3}	%	%
2012	5.32	16.22	5.4	7.40	2.80	2.18	0	12.92	83.1	5.9
2013	5.00	12.89	4.1	12.92	4.23	2.11	0.36	19.7	89.3	6.1

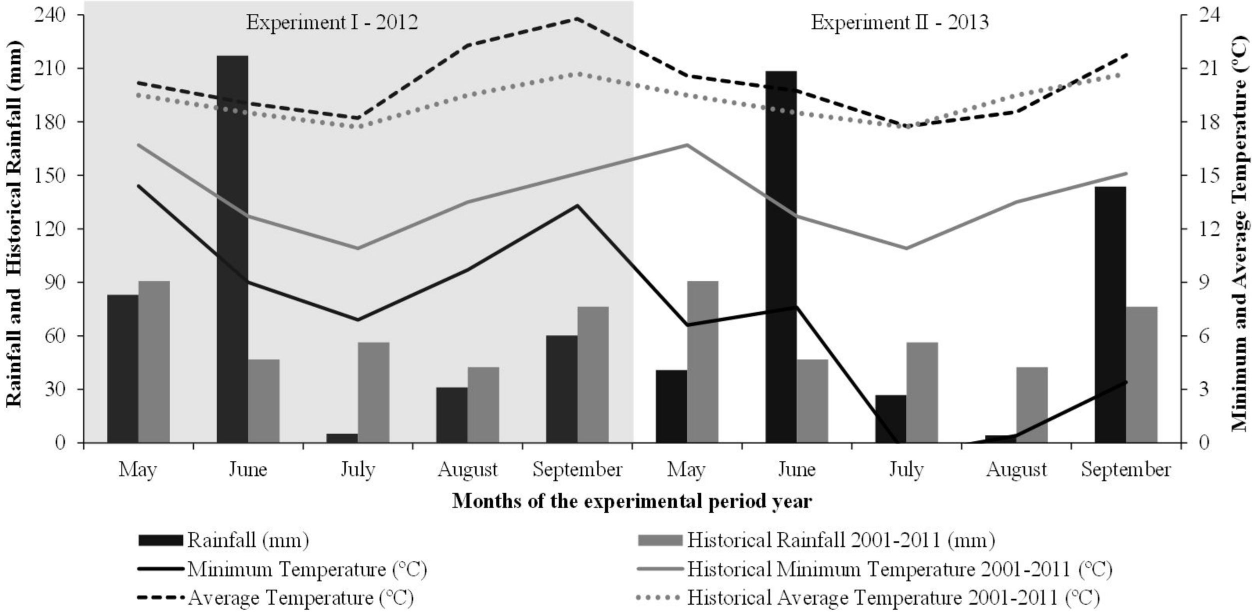

Figure 1: Precipitation values (mm), values of minimum, average and maximum temperature (°C) during the experimental period of canola and their historical averages for 2001-2011.

We used Hyola 61, an early spring hybrid well suited for direct harvesting. Direct seeding was performed on May 7, 2012 and 2013. Sowing fertilization was implemented according to soil analysis for yielding 2.000 kg ha^{-1} using 200 kg ha^{-1} fertilizer 10-15-15.

After emergence and plant establishment, manual pruning was performed 21 days after sowing (DAS 21), when plants had two fully expanded true leaves (Chavarria et al., 2011). Nitrogen fertilization was performed when plants had four true leaves (24 DAS).

Weed control was done by hand, and insect control was performed annually through two applications of a benzoylurea insecticide and one application of pyrethroid; both dosages were 80 ml ha^{-1} to control *Diabrotica speciosa* (South American rootworm) and defoliate caterpillars.

The plots were irrigated by drip tapes installed between plant rows. Irrigation management was conducted by reading the water tension in soil tensiometers installed at a depth of 0.20 m. Irrigation depth (LI) was determined by the difference between volumetric water content at field capacity (Θ_{cc}), tension corresponding with 10 kPa and current soil moisture (Θ_a) multiplied by the effective root depth, 0.40 m. Θ_a values were estimated by the soil water retention curve adjusted by the Filgueiras (2016) equation:

$$\theta a = 0.200 + \left[\frac{(0.589 - 0.200)}{\left[1 + (0.5485\sigma_a)^{19.322}\right]^{0.026}} \right]; \left(R^2 = 0.99 \ e \ P \langle \ 0.01\right)$$

where Θ_{a} = current soil moisture (cm^3 cm^{-3}) and σ_a = current soil water tension (kPa).

Readings of soil water tension were made on Mondays, Wednesdays and Fridays. All treatments received 20 mm of irrigation before starting the treatments.

Values of soil water tensions during treatments differed throughout the experiment (Figure 2). In treatments where irrigation was performed more frequently, three times a week (I3S), and soil water tension remained close to field capacity. In non-irrigated (SI) treatments, water deficit increased soil water tension, which means a higher depletion of water in the soil especially after crop full flowering, when rainfall decreased (Figure 1 and Table 2).

During the experimental period, the plots irrigated three times per week received more irrigation procedures, 29 in 2012 and 18 in 2013 (Table 2).

In 2012, the deepest irrigation, 166.3 mm, was found in the third stage of crop development, between the stage of full flowering and physiological maturity. The bulk of natural precipitation in both 2012 and 2013 was recorded between sowing and crop flowering (Table 2).

Most cultures are more sensitive to water stress between flowering and grain filling (Dogan et al., 2011; Dogan; Kirnak; Copur, 2007; Hamzei; Soltani, 2012).

At the end of each experimental cycle we evaluated the morphological components, namely, plant height (cm), number of branches and aboveground dry weight (g plant^{-1}), and the productive components, namely, number of pods, thousand grain weight (g), grain yield (kg ha^{-1}), oil content of grain (%) and oil yield (kg ha^{-1}).

The components were subjected to an analysis of variance at 5% probability. In cases of significant differences, we applied the Tukey test for irrigation frequencies and conducted a regression analysis for nitrogen levels.

RESULTS AND DISCUSSION

All components were affected by different irrigation frequencies except for the number of branches and the number of pods in 2012 (p>0.01). When the influence of nitrogen on morphological components was analyzed, only dry matter was affected in 2012, and the number of branches was not affected in 2013. Productive components, thousand grain weight and oil content were affected by nitrogen rates in 2012, and the opposite occurred in 2013.

Morphological and productive components of canola are generally affected by irrigation (Figure 3). Bilibio et al. (2011), Dogan et al. (2011), Kamkar et al. (2011) and Sharghi et al. (2011) studied the effects of different levels of water stress (0, 30 and 60% of canola crop evapotranspiration) and found that number of branches, number of pods, dry weight, yield and oil content were significantly affected. Istanbulluoglu et al. (2010) evaluated the effect of supplemental irrigation applied at different stages of canola development and found

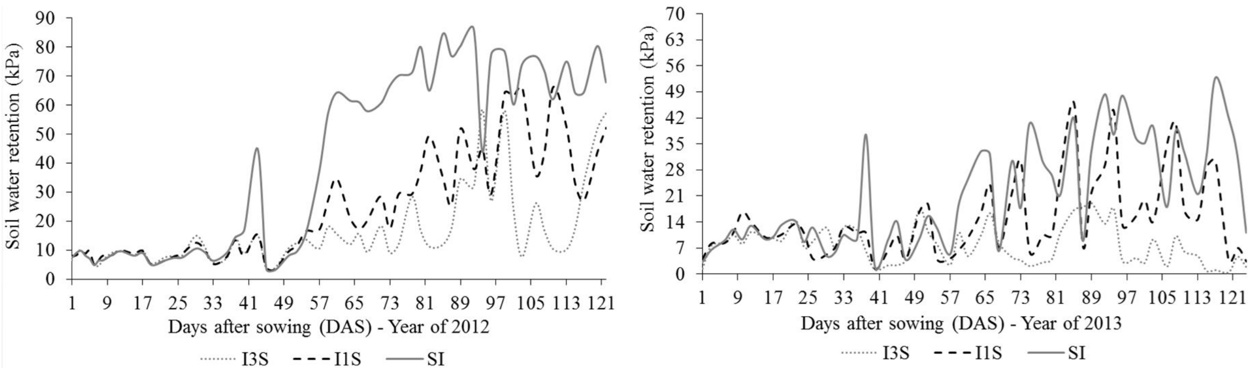

Figure 2: Values of soil water tension in the canola crop considering different irrigation frequencies in experiment 1 (2012) and experiment 2 (2013).

Table 2: Irrigation depths (mm) and rainfall during the experiment. UFGD, Dourados-MS, 2012/2013.

	DAS	Phenological (stages)	I3S (mm)	EI (nº)	IS (mm)	EI (nº)	P (mm)
2012	01 - 67	Phase I	83.4	12	37.1	3	303.6
	68 - 89	Phase II	95.3	8	102.8	4	1.6
	90 - 114	Phase III	166.3	9	117.8	4	2
Total			345	29	257.7	11	307.2
2013	01 - 67	Phase I	55.9	11	48.2	6	225.4
	68 - 89	Phase II	41.2	4	23.9	2	26.6
	90 - 114	Phase III	19.5	3	95.3	4	4.2
Total			116.5	18	167.3	12	256.2

*Phase I – sowing to beginning of flowering; Phase II – beginning of flowering to full flowering; Phase III – full flowering to physiological maturity; EI – irrigation events; P – Precipitation.

significant differences in morphological components, yield and oil content but not in thousand grain weight.

The overall averages for morphological components in 2012 were as follows: plant height: 124.31 cm, number of branches: 6.81, dry weight of shoots: 19.24 g plant^{-1} or 7271.73 kg ha^{-1}. Overall averages for productive components were: number of pods: 156.71 plant^{-1}, yield: 2351.21 kg ha^{-1}, thousand grain weight: 3.37 g, oil content 39.49% and oil yield: 854.81 kg ha^{-1}. Already, in 2013, the overall averages for morphological components were as follows: plant height: 93.96 cm, number of branches: 26.46; dry weight of shoots: 71.74 g plant^{-1} or 27,102.09 kg ha^{-1}. The overall averages for productive components were as follows: number of pods: 399.26 plant^{-1}, yield: 1513.79 kg ha^{-1}, thousand grain weight: 2.70 g, oil content 19.30%, oil yield: 406.39 kg ha^{-1}.

The averages found in both years closely match the results of Bilibio et al. (2011) in a study of canola under

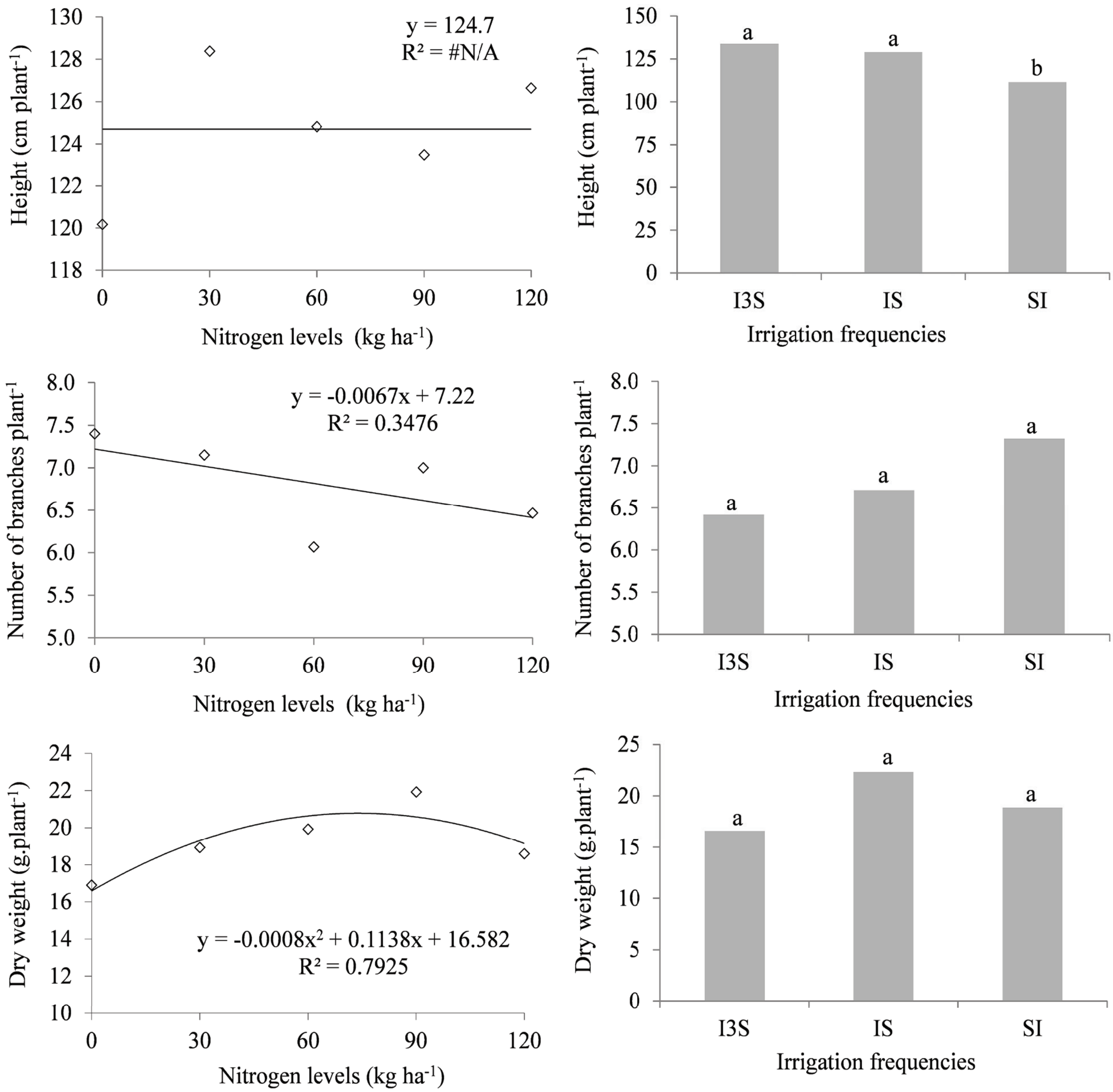

Figure 3: Effect of different nitrogen levels and irrigation frequencies on morphological components of canola.

different levels of water deficit. The authors obtained the following average components: plant height: 117.53 cm plant^{-1}, number of branches: 9.76 plant^{-1}, number of pods: 353.85 plant^{-1}, dry weight: 41.53 g plant^{-1}, yield: 7.89 g plant^{-1} equivalent to 3.156 kg ha^{-1} and oil content: 37.75%.

The data also agree with the findings of Dogan et al. (2011) in a study conducted with supplemental irrigation. The authors found average plant heights of 147.7 and 164 cm in the first year and 141.3 and 159 cm in the second year of the experiment. The authors also found a thousand grain weight ranging from 2.8 to 3.3 g in 2006-2007 and from 2.5 to 3.2 g in 2008-2009. Productivity in 2006-2007 was 1,094 to 3,944 kg ha^{-1}, and that in 2008-2009 was 1,333 to 3,880 kg ha^{-1}. The lower values refer to non-irrigated treatments, whereas the larger values refer to treatments receiving supplemental irrigation corresponding to 100% of Class A pan evaporation.

Regarding different levels of nitrogen, we found significant differences in dry weight, thousand grain weight and oil content in 2012 (Table 3). In 2013, the components plant height, number of pods, dry weight and yield were significantly influenced by different levels of nitrogen (Figure 3 and Figure 4).

Beaudette et al. (2010) evaluated the effect of different cropping systems and nitrogen levels (0, 40, 80 and 120 kg N ha^{-1}) on the yield of four canola cultivars in Canada. The highest productivity was obtained at a level of 80 kg ha^{-1}, equivalent to 2.800 kg ha^{-1}. However, unlike us, those authors found that the oil content of grain decreased as the amount of nitrogen increased, which was offset by an increase in crop yield.

Hamzei and Soltani, (2012) evaluated the effect of different regimes of irrigation and nitrogen levels on the dry weight of shoots and the yields of canola in Iran. The authors found that the parameters were significantly influenced by the different treatments applied: 80 kg N ha^{-1}, 120 kg N ha^{-1} and 160 kg N ha^{-1}. The application of 120 kg N ha^{-1} provided maximum grain yield, 3.250 kg ha^{-1}.

Werner et al. (2013) evaluated the effect of different levels of nitrogen ranging from 0 to 75 kg N ha^{-1} on the vegetative and productive components of canola in Paraná, Brazil. The authors found no significant difference between parameters except for the oil content of grain, which decreased with increasing nitrogen levels.

Significant interactions between irrigation frequencies and nitrogen levels were found only for thousand grain weight and oil content in 2012 and for the number of pods in 2013. Kamkar et al. (2011) found a significant interaction for different irrigation regimes and nitrogen levels only for grain yield.

Through regression analysis for different nitrogen levels applied in 2012, we found that variation in dry weight (g plant^{-1}) can be explained by a quadratic model, as shown in Figure 4, indicating that dry weight increased as the nitrogen level increased. The highest dry weight was obtained with 90 kg nitrogen ha^{-1}, equivalent to an average dry weight of 21.91 g plant^{-1}.

Variation in the thousand grain weight and oil content at different nitrogen levels can be explained by linear regression (Figure 4). The thousand grain weight increased by 0.0049 grams for each unit change in nitrogen level, while the oil content of grains increased by 0.0239% for each unit change.

In addition, regression analysis regarding different nitrogen levels applied in 2013 showed that changes in plant height, number of pods, dry weight and yield can be explained by a linear regression regarding the treatments, as shown in Figure 5. Plant height increased by 0.0646 cm for each unit change in nitrogen level, while the number of pods increased by 1.4082 pods plant^{-1} for each unit change. Finally, dry weight had an increase of 0.2218 grams for each unit change in nitrogen level, while yield increased by 3.9858 kg of grains for each unit change. Beaudette et al (2010) found a linear equation between grain yield and levels of nitrogen in a study conducted in Canada. The highest yield was 2,800 kg ha^{-1}, obtained with 80 kg ha^{-1} of nitrogen.

Conjoint analysis of the experiments carried out in 2012 and 2013 (Table 3) showed no significant effect on the variables of plant height and yield. However, there was a significant difference between 2012 and 2013 for the number of branches, number of pods, dry weight of shoots and thousand grain weight. Dogan et al. (2011) found no significant difference between the years 2006-2007 and 2008-2009 with supplementary irrigation for plant height and yield of canola in Turkey. Sharghi et al. (2011) found no significant difference in grain yield and number of grains per pod of canola subjected to two irrigation schemes (irrigation after evaporation of 60 mm of water in Tank Class A and discontinuation of irrigation at flowering) for two years, 2008-2009 and 2009-2010, in Iran.

The highest average yield of canola, 2,613.83 k ha^{-1}, was obtained with irrigation, especially when the irrigation was applied more frequently, i.e., three times a week. Similar results were obtained by Hamzei and Soltani (2012), who found higher yields of canola, 3,640 kg ha^{-1} and 3,960 kg ha^{-1} with 4,500 m^3 and 7,500 m^3 of water ha^{-1}, respectively, compared to a yield of 2,130 kg ha^{-1} with 3,000 m^3 of water ha^{-1}. Istanbulluoglu et al. (2010) observed higher productivity, 4,800 kg ha^{-1}, with irrigation at flowering, grain filling and maturation of canola in Turkey.

Table 3: Morphological and productive components of canola cultivation in two years.

Year	Irrigation			Nitrogen levels		
	I3S	IS	NI	0	60	120
Plant height (cm)						
2012	133.41a	129.50a	107.50b	119.83a	124.41a	126.16a
2013	104.00a	86.75ab	78.91b	87.75a	87.33a	94.58a
Average 2 years	118.70a	108.12a	93.20b	103.79a	105.87a	110.37a
Number of branches						
2012	6.36aB	6.46aB	7.10aA	7.40aB	6.06aB	6.46aB
2013	27.08aA	38.91aA	8.50bA	19.33aA	28.41aA	26.750aA
Average 2 years	16.72b	22.69a	7.80c	13.36a	17.24a	16.60a
Number of pods						
2012	141.16aB	177.88aB	153.05aA	158.56aB	161.51aB	152.01aB
2013	501.25aA	385.41aA	37.66bB	242.91bA	311.25abA	370.16aA
Average 2 years	321.20a	281.65a	95.35b	200.74b	236.38ab	261.09a
Dry weight (g plant^{-1})						
2012	16.25bB	20.80aB	18.34abA	16.89bB	19.92aB	18.59abB
2013	74.04aA	75.12aA	23.44bA	49.01aA	52.25aA	71.33aA
Average 2 years	45.14a	47.96a	20.89b	32.95b	36.08ab	44.96a
Yield (kg ha^{-1})						
2012	2999.33a	2730.42a	1262.04b	2214.21a	2454.42a	2323.15a
2013	2228.33a	1520.37a	30.92b	968.61b	1541.75a	1269.25ab
Average 2 years	2613.83a	2125.39b	646.48c	1591.41b	1998.09a	1796.20ab
Thousand grain weight (g)						
2012	3.71aA	3.32bA	2.94cA	3.04c	3.33b	3.61a
2013	3.77aA	3.30aA	0.90bB	2.53a	2.97a	2.47a
Average 2 years	3.74a	3.31a	1.92b	2.78a	3.15a	3.04a
Oil content (%)						
2012	40.64aA	39.56bA	38.31cA	38.05c	39.42b	41.03a
2013	28.44aA	28.83aA	0.00bB	19.77a	20.14a	17.36a
Average 2 years	34.54a	34.19a	19.15b	28.91a	29.78a	29.19a
Oil yield (kg ha^{-1})						
2012	1115.50a	986.75a	442.77b	772.14a	891.29a	881.60a
2013	581.95a	440.34a	0.00b	258.36b	424.82a	339.11ab
Average 2 years	848.73a	713.55a	221.38b	515.25b	658.05a	610.35ab

(1)In each row, values followed by the same lowercase letter do not differ significantly at 5% probability by Tukey test; in each column, the capital letter compares 2012 to 2013.

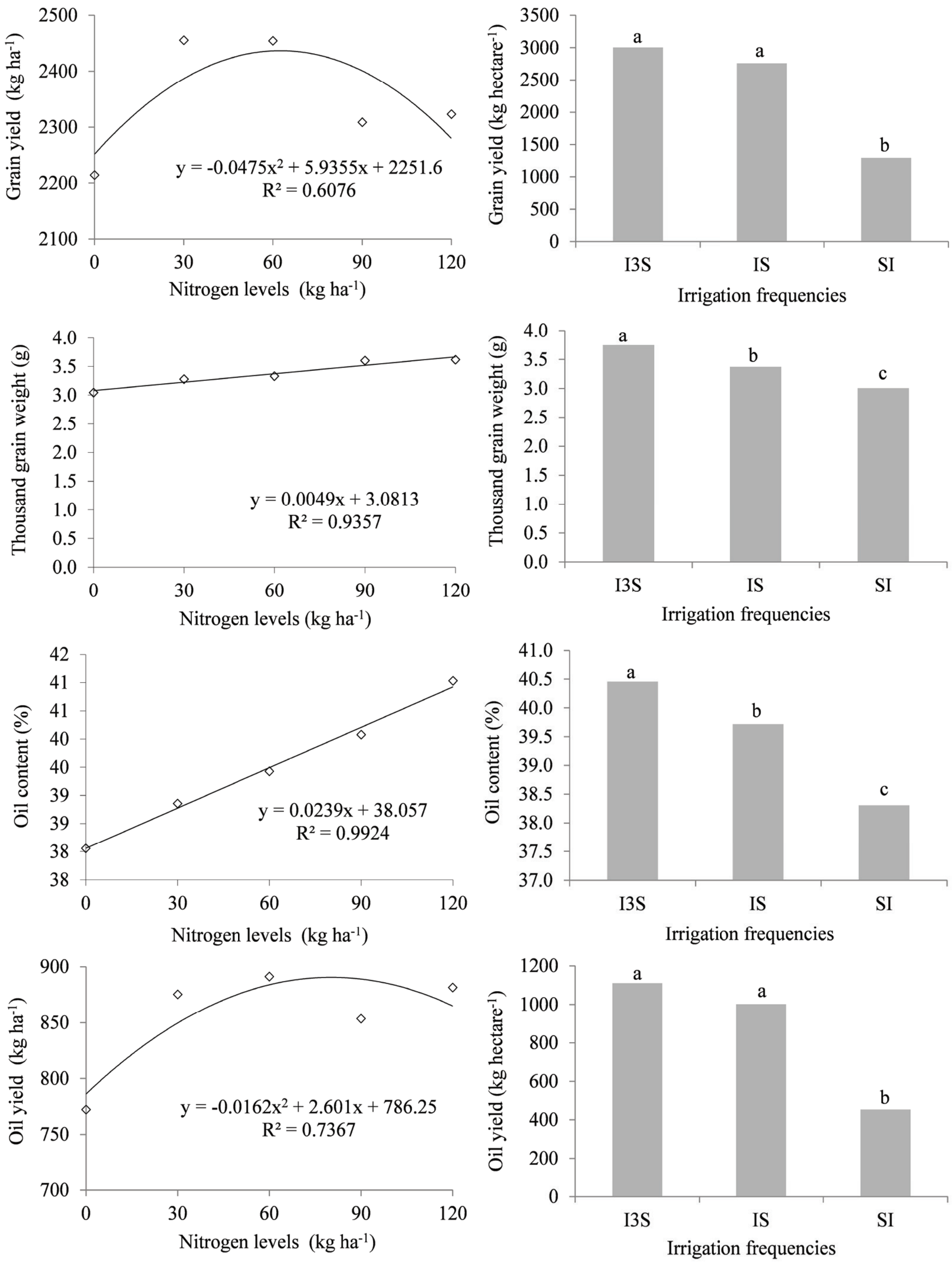

Figure 4: Effect of different nitrogen levels and irrigation frequencies on productive components of canola.

On the other hand, the lowest yield (30.92 kg ha^{-1}) was obtained in non-irrigated plots during the second year. This is due to reduced water stress as a result of natural rainfall and the occurrence of frost during flowering; these are the factors that compromised grain yield in this treatment. Takashima et al. (2013) also found that the occurrence of frost during flowering is one of the main factors limiting canola development in Argentina.

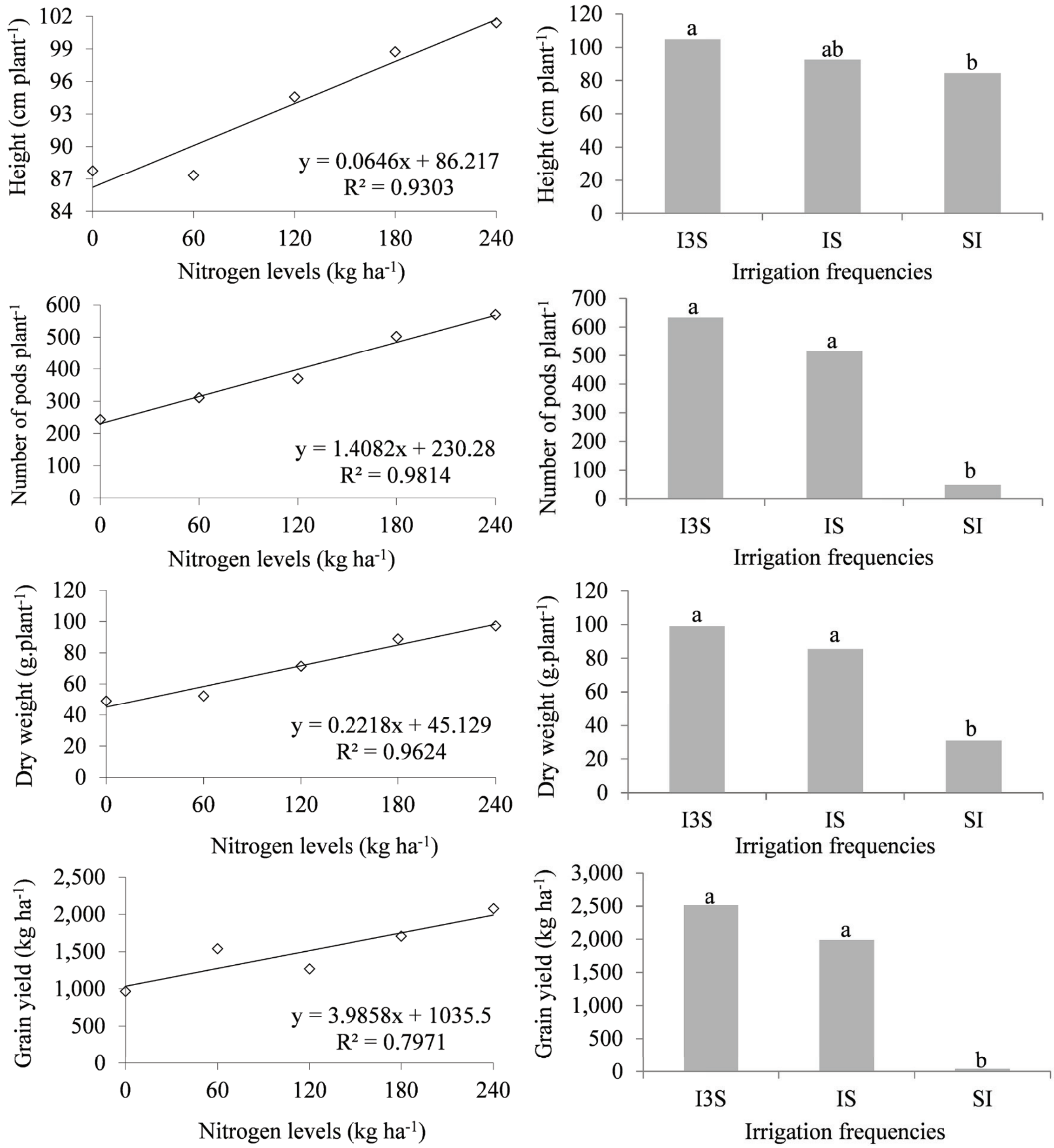

Figure 5: Effect of different nitrogen levels and irrigation frequencies on the morphological components of canola.

CONCLUSIONS

Additional irrigation should be used in the Brazilian Cerrado to ensure a maximum yield potential of canola, as the highest grain yield in this study, 2,999.33 kg ha^{-1}, was obtained through irrigation performed three times a week. Canola yields demonstrated a positive result with increasing levels of nitrogen, which shows the importance of using this nitrogen for achieving high levels of grain yield and oil. Considering two years of evaluation, the highest grain yield was obtained with 60 kg ha^{-1} of nitrogen.

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