Interference of volunteer corn in growth and chlorophyll fluorescence of bean[1]

Adalin Cezar Moraes de Aguiar[2], Diecson Ruy Orsolin da Silva[3], Claudir José Basso[3], Hilda Hildebrand Soriani[4], Bruna Dal'Pizol Novello[3], Dionei Schmidt Muraro[5]*

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ABSTRACT

Corn kernels or seeds that remain after harvest can germinate and become a troublesome volunteer plant where bean crops are grown. The objective of this study was to evaluate the effect of time of emergence of volunteer corn on growth parameters, photosynthetic pigments and chlorophyll fluorescence in bean plants, competition for soil and light and light resources. The study was conducted in completely randomised experimental design, in 2×2×2+2 factorial scheme with four replications, involving two bean cultivars in competition with volunteer corn, emerging seven days before and simultaneously with beans, besides the partitioning of the competition by soil and light, just light and two controls without competition. We measured the levels of chlorophyll a, b, total and carotenoids, parameters related to chlorophyll fluorescence and bean growth variables. Volunteer corn was more competitive when it emerged seven days before the beans. When competition was established by light resource, there was a reduction in photosynthetic pigments and morphological variables of the bean plants. When competition by soil and light resources occurred, there was a reduction not only in photosynthetic pigments and morphological characteristics, but also in the chlorophyll fluorescence variables. There were significant correlations between the growth variables of the bean plants and chlorophyll fluorescence, which makes it an important analytical tool for quantifying the stress caused by weeds.

Keywords: Phaseolus vulgaris; photosynthetic pigments; emerging time; competition; solar radiation; soil.

INTRODUCTION

Beans (Phaseolus vulgaris) are one of the most important food crops in Brazil. In order for bean plants to express their maximum yield potential, it is necessary to control limiting factors, among which competition imposed by weeds stands out (Cury et al., 2013). Beans have become an option after cropping with corn in the Southern region of Brazil. However, corn kernels or seeds that remain after harvest can germinate and become a troublesome volunteer plant where bean crops are grown. Volunteer corn growing in bean crops can cause yield losses that amount to approximately 20% for each volunteer corn plant per square meter (Sbatella et al., 2016).

Volunteer corn has a capacity to germinate at different times in the bean crop, and its time of emergence may alter the competition between it and the crop. Weeds that emerge early show good growth and have an increased effect on yield losses of crops by acquiring advantage to resources of the environment and have a high relative growth rate (Agostinetto et al., 2004). However, weeds that emerge after crops usually cause a low level of interference with crop yield (Vandevender et al., 1997).

Although the competition is integrated, studies that isolate the factors involved in competition improve understanding of the mechanisms of competition (McPhee & Aarssen, 2001). For example, changes in the red and

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2 Universidade Federal de Viçosa, Departamento de Fitotecnia, Viçosa, Minas Gerais, Brazil. adalin-cezar@hotmail.com
3 Universidade Federal de Santa Maria, Departamento de Ciências Agronômicas e Ambientais, Frederico Westphalen, Rio Grande do Sul, Brazil. diecsonros@hotmail.com; claudirbasso@gmail.com; brunadalpizoln@outlook.com
4 Universidade Federal de Santa Maria, Departamento de Engenharia Florestal, Frederico Westphalen, Rio Grande do sul, Brazil. hildasoriani@gmail.com.
5 Universidade de São Paulo, Departamento de Entomologia, Piracicaba, São Paulo, Brazil. dioneimuraro@gmail.com
* Author for correspondence: adalin-cezar@hotmail.com

far-red ratio of light, a response to light stress which can cause alterations in the root system and leaf area, directly affecting the water and nutrients supply (Ballaré, 2014).

Abiotic factors, such as water and nutrient depletion, and changes in light quality and quantity are reflected in the photosynthetic capacity of plants (Afifi & Swanton, 2012). In this case, the content of photosynthetic pigments is an important indicator of the photochemical capacity of plants (Dai et al., 2017), because chlorophyll a favors the absorption of long-wave light, chlorophyll b works for short-wave light, and carotenoids absorb light of other wave lengths as well as being endogenous antioxidants and protecting chlorophyll from photodynamic damage (Brody, 2002). In view of this, changes in photosynthesis-related parameters may be good indicators of competitive damage in plants (Dai et al., 2017).

The use of fluorescence parameters allows the evaluation of the effect of several biotic and abiotic stresses, such as water deficit (Silva et al., 2015), salinity (Yan et al., 2012), light (Schock et al., 2014), temperature (Perboni et al., 2015), insect damage (Huang et al., 2013), diseases (Costa et al., 2009) and heavy metals (Ferreira et al., 2015). However, measurement of chlorophyll fluorescence to indicate damage caused by weed competition has not been reported in the literature.

Therefore, the objective of this study was to evaluate the effect of time of emergence of volunteer corn on growth parameters, photosynthetic pigments and chlorophyll fluorescence in bean cultivars competing for soil and light and light resources.

MATERIAL AND METHODS

A greenhouse experiment was conducted during the months of November and December, 2016. The experimental design was completely randomized, in a three-factor factorial treatment arrangement with four replications. The factors consisted of two bean cultivars: IPR Gralha and Fepagro Triunfo; two volunteer corn emergence times: 7 days before and 0 days after bean emergence; two competition conditions: soil and light and just light competition. Controls without volunteer corn were used for each competition condition. The cultivars used were IPR Gralha with cycle of 93 days, and Fepagro Triunfo with cycle of 75 days. Volunteer corn F2 was used as a surrogate plant competitor. The experimental units consisted of 6.0 L plastic pots with 18.5 cm diameter, filled with substrate.

The soil and light competition treatment were obtained establishing one bean plant in the center of the pot and four volunteer corn plants equidistantly surrounding the bean plant. In the light competition treatment, four plastics cups (0.5 L) were buried equidistantly around the circumference of each pot, and the volunteer corn plants were grown on theses cups. Volunteer corn was sowed both seven days before and at the time of bean sowing, to establish the emergence time of volunteer corn in relation to bean. Similar procedure was performed for the control treatments (i.e. absence of volunteer corn). Irrigation management was performed daily according to the need of the crop.

Bean leaf discs were collected at 28 DAE (days after emergence) to determine the content of photosynthetic pigments (chlorophyll a, b, total (a + b) and carotenoids) by the extractable method. The samples were macerated with 5 mL of 80% (v / v) acetone and transferred to beakers adjusting the volume to 8 mL and then centrifuged at 4000 rpm for 3 minutes. The supernatant was transferred to test tubes and the volume was completed with 8 ml of 80% (v / v) acetone. The levels of chlorophyll a, b, total (a + b) and total carotenoids were obtained from the absorbance of the supernatant of the solution obtained by spectrophotometry at 645, 663 and 480 nm (Lichtenthaler, 1987) and the results expressed as mg g-1 of fresh dough.

Chlorophyll fluorescence parameters were measured using a pulse amplitude modulated fluorometer at 30 DAE (JUNIOR-PAM, Walz, Effeltrich, Germany). The measurement was performed early in the morning in the central leaflet of the third trifoliate leaf of the bean plants, which were adapted to dark conditions for 30 minutes using foil sheets. The minimum fluorescence level in the dark adaptation state (F0) was measured using a modulated pulse (<0.05 µmol m-2 s-1 for 1.8 µs). The maximum fluorescence in this state (Fm) was measured after the application of a pulse of actinic light saturation of 10,000 µmol m-2 s -1 for 0.6 s.

Using the fluorescence parameters, determined in both light and dark states, the following variables were calculated: the effective quantum efficiency of PSII (Y (II)) calculated by the equation Y(II) = (Fm'- F') / Fm', where Fm' and F' correspond to Fm and F0 after the second pulse of saturated light (Genty et al., 1989), and non-photochemical extinction (NPQ) (NPQ = (Fm / Fm ') – 1), which is linearly related to heat dissipation (Maxwell & Johnson, 2000).

The maximum rate of electron transport (ETR) was evaluated through light curves (ETR versus photosynthetically active radiation, PAR), where each sample was subjected to nine radiation levels (0, 125, 190, 285, 420, 625, 820, 1150 and 1500 µmol photons m-2 s-1) for 10 seconds and the curve points adjusted by the ETR = ETRmax [1-e -kQ], where k is an adjustment constant and Q is the intensity of light (Rascher et al., 2000).

The electron transport rate was calculated according to the equation: ETR = PAR x 0.84 x 0.5 x Y(II), being

PAR the applied radiation, the value 0.84 corresponding to the proportion of photons absorbed by the photosynthetic pigments, the value 0.5 corresponding to the proportion of photons absorbed by PSII in relation to the total of photons absorbed by the photosynthetic pigments and Y(II) the effective quantum yield of PSII (Edwards & Baker, 1993), being an estimate for the PSII-absorbed photon flux density.

Plant height (H), stem diameter (D) and root length (RL) was determined at 32 DAE. Plant height was measured from the base of plant to the extended tip of the last leaf. The stem diameter was measured with a caliperat 1 cm from the plant base. The root length was washed and measured from the base to the last root. After these measurements, the shoot and root were packed on paper bags and dried at 60ºC for 72 h to determine dry weight of the bean plants (DW).

The Lilliefors test was used to test for assumption of normality, and no transformation was required. Data were subjected to ANOVA by F test ($p<0.05$). The cultivar, emergence times of volunteer corn and competition conditions factors were compared by the Tukey test ($p<0.05$). The Pearson correlation matrix was also elaborated among the growth, photosynthetic pigments and Chlorophyll fluorescence parameters.

RESULTS AND DISCUSSION

Regarding competition for soil and light, there was a reduction in height of bean plants when beans were grown with volunteer corn that had emerged early compared to when beans and corn emerged simultaneously or compared to the controls (Table 1). In contrast, when in light competition, the plant height presented no change at any competition condition. With early emergence, volunteer corn had 39% higher dry biomass compared to corn which simultaneously emerged with bean plants (data not shown); thus, indicating that bean plants were suppressed in height only when volunteer corn emerged seven days earlier. The lower growth in bean height suggests that competition for soil resources occurred at higher intensities, as well as in the competition between soybean and Raphanus sativus reported by Fleck et al. (2006).

A similar reduction was observed in stem diameter and root length in soil and light competition with volunteer corn. The early emergence of volunteer corn caused a 34% reduction in stem diameter and 51% reduction in root length, while simultaneous emergence caused 18 and 26% reduction in stem diameter and root length, respectively, compared to the control without competition (Table 1). However, with light competition, the emergence time had a similar effect on root length, reducing it by approximately 20%; nevertheless, the stem diameter was reduced only when volunteer corn emerged early (15%). In relation to the two cultivars, a longer root length was observed with the cultivar Gralha compared to Triunfo when there was light competition.

The presence of volunteer corn increased the height/root length ratio of the bean compared to the control plots, but only when competing for soil and light resources (Table 1). The plants are able to perceive the presence of weeds in their early stages and redirect the flow of photoassimilates according to the quality of light radiation intercepted by the seedlings (Vidal & Merotto Jr., 2010), directing the biggest allocation of photoassimilates to the shoot part of the bean plant when in competition. This occurrence can be seen in wheat in the presence of ryegrass and turnip competitors, which also showed an increase in the relation height/root length ratio (Lamego et al., 2015).

The reduction at plant dry weight varies according to the availability of environmental resources to plants that are growing in coexistence (Rizzardi et al., 2004). The interference of volunteer corn at plant dry weight was more pronounced with soil and light competition, which was reduced by 75 and 51% when corn emerged seven days before beans and simultaneously with beans, respectively, compared to the control without competition (Table 2). Regarding the cultivars, greater plant dry weight occurred with Gralha compared to Triunfo, but only with competition for light resources. Bean cultivars competing with Bidens pilosa, Cenchrus echinatus, Euphorbia heterophylla and Commelina benghalensis showed a reduction in dry biomass of 38, 51, 50 and 61%, respectively (Cury et al., 2011).

Competition with volunteer corn plants, regardless of the time of emergence, reduced bean chlorophyll a, b and a + b, being more pronounced with soil and light competition (Table 3). A greater amount of chlorophyll a, b and a + b was produced by Triunfo leaves compared to Gralha.

Reduction in chlorophyll content of leaves is indicative of biotic or abiotic stresses that modify light absorption and photochemical efficiency, reducing CO2 assimilation and causing physiological changes in photosynthetic activity (Baker & Rosenqvist, 2004). When competing plants grow in the same location, competition for environmental resources may affect the chlorophyll content of the plants (Amaral et al., 2015). In soybean plants competing with weeds at different densities, the reduction in chlorophyll content is more accentuated when soybean plants are exposed to a high density of competitors, and this reduction may be related to the lower availability of nitrogen in the soil as a result of competition (Saberalia & Mohammadi, 2015).

There was an interaction between bean cultivars and the emergence time of volunteer corn plants in terms of the carotenoid content of leaves of the bean plants (Table 4). When the corn emerged seven days before the beans, the Triunfo cultivar had 25% higher carotenoid content than the Gralha cultivar, in total competition, while in competition for light the Triunfo cultivar was superior by 17% (Table 4). The carotenoids are important antioxidants that protect chlorophyll from photodynamic damage, consisting of an important factor related to greater stress tolerance in plants (Brody, 2002).

When competition was established by light, there was no correlation between the photosynthetic pigments bean growth variables (Supplementary Material 1). In contrast, when there was competition for soil and light resources, chlorophyll a and a + b showed positive correlations with stem diameter, root length and dry weight (Supplementary Material 2), thus showing that the reduction in photosynthetic pigments that occurs with competition is related to changes in stem diameter, root length and dry weight of bean plants.

Regarding competition for soil and light, the initial chlorophyll fluorescence (F0) in bean leaves was higher when there was competition with volunteer corn plants that had emerged early, followed by simultaneous emergence of beans and corn, and the control (Figure 1). The F0 values represent the light emitted by the excited chlorophyll a molecule, before the energy is dissipated to the PSII reaction centre (Mathis & Paillotin, 1981). Therefore, F0 increases as a result of stress in the environment, causing structural alterations in the photosynthetic pigments of PSII.

When there was competition for light, F0 did not change between the conditions of competition. The comparison of the cultivars showed that Triunfo presented lower value of F0 in relation to the cultivar Gralha (Figure 1). There was also less loss of transfer of excitation energy from the antenna complex to the reaction centers when competing for soil and light resources.

The values of F0 increase if the PSII reaction center is compromised, or if the transfer of excitation energy

Table 1: Plant height (H), stem diameter (D) and root length (RL) and height/root length ratio of bean cultivars (IPR Gralha and Fepagro Triunfo) as a function of the emergence time of volunteer corn plants competing for soil and light and light resources

Emergence time/ cultivar	Competing for soil and light	Competing for light
	H (cm)	
7 DBE2	42.8 (±2.36)4b1	48.6(±3.43) a
0 DBE	49.8 (±3.50) a	50.5 (±2.85) a
Control	49.7 (±2.05) a	48.2(±2.82) a
CV(%)3	7.3	6.2
Emergence time	**D (mm)**	
	4.29 (±0.38) c	5.31 (±0.15) b
0 DBE	5.32 (±0,61) b	6.07 (±0.42) a
Control	6.49 (±0.26) a	6.20 (±0.33) a
CV (%)	8.5	5.2
Emergence time	**RL (cm)**	
7 DBE	29.9 (±3.45) c	43.5 (5±.37) b
0 DBE	37.7 (±3.55) b	45.3 (±6.66) b
Control	50.9 (±6.98) a	56.3 (±8.56) a
CV (%)	15.1	14.3
Cultivar	RL (cm)	
Triunfo	39.6 (±7.88) a	43.3 (±6.79) b
Gralha	39.4 (±11.3) a	51.7 (±7.01) a
CV(%)	15.1	14.3
Emergence time	**PH/RL**	
7 DBE	1.45 (±0.19) a	1.12 (±0.18) a
0 DBE	1.33 (±0.10) a	1.14 (±0.25) a
Control	0.99 (±0.10) b	0.94 (±0.20) a
CV (%)	10.9	18.8

[1]Letters compare between emergence times of volunteer corn and bean cultivars by the Tukey test ($p \leq 0.05$). 2 7 DBE indicates emergence of corn seven days before the bean, 0 DBE indicates simultaneous emergence of corn and beans. 3CV (%), indicates coefficient of variation. 4Standard deviation of the measure.

Table 2: Dry weight of bean plants (DW) of bean cultivars (IPR Gralha and Fepagro Triunfo) as a function of the emergence time of volunteer corn plants competing for soil and light and light resources

Emergence time/ cultivar	Competing for soil and light	Competing for light
	DW (g)	
7 DBE2	3.73 (±0.69)4 c1	9.06 (±1.00) b
0 DBE	7.32 (±0.68) b	11.6 (±1.20) a
Control	14.8 (±2.26) a	11.8 (±1.28) a
CV (%)3	18.2	16.4
Cultivar	DW (g)	
Triunfo	8.41 (±3.87) a	9.98 (±1.30) b
Gralha	8.80 (±4.15) a	11.7 (±0.89) a
CV(%)	18.2	16.4

[1]Letters compare between emergence times of volunteer corn and bean cultivars by the Tukey test ($p \leq 0.05$). [2] 7 DBE indicates emergence of corn seven days before the bean, 0 DBE indicates simultaneous emergence of corn and beans. [3]CV (%), indicates coefficient of variation. [4]Standard deviation of the measure.

Table 3: Chlorophyll content a, b and a + b (mg g-1 fresh biomass) of leaves of bean cultivars (IPR Gralha and Fepagro Triunfo) as a function of the emergence time of volunteer corn plants competing for soil and light and light resources

Emergence time/ cultivar	Competing for soil and light	Competing for light
	Chlorophyll a	
7 DBE2	1.29 (±0.13)4 b1	1.41 (±0.07) b
0 DBE	1.36 (±0.09) b	1.40 (±0.05) b
Control	1.54 (±0.06) a	1.53 (±0.09) a
CV (%)3	3.6	3.2
Cultivar	Chlorophyll a	
Triunfo	1.45 (±0.09) a	1.49 (±0.08) a
Gralha	1.35 (±0.10) b	1.41 (±0.08) b
CV(%)	3.6	3.2
Emergence time	**Chlorophyll b**	
7 DBE	0.76 (±0.04) b	0.76 (±0.02) b
0 DBE	0.77 (±0.04) b	0.76 (±0.03) b
Control	0.80 (±0.01) a	0.81 (±0.03) a
CV (%)	4.2	3.4
Cultivar	**Chlorophyll b**	
Triunfo	0.79 (±0.03) a	0.79 (±0.04) a
Gralha	0.75 (±0.03) b	0.77 (±0.03) a
CV(%)	3.6	3.4
Emergence time	**Chlorophyll a+b**	
7 DBE	2.05 (±0.16) b	2.18 (±0.09) b
0 DBE	2.13 (±0.13) b	2.17 (±0.05) b
Control	2.34 (±0.06) a	2.33 (±0.10) a
CV (%)	4.6	3.0
Cultivar	**Chlorophyll a+b**	
Triunfo	2.24 (±0.12) a	2.28 (±0.09) a
Gralha	2.11 (±0.11) b	2.18 (±0.08) b
CV(%)	4.6	3.0

[1]Letters compare between emergence times of volunteer corn and bean cultivars by the Tukey test ($p \leq 0.05$). 2 7 DBE indicates emergence of corn seven days before the bean, 0 DBE indicates simultaneous emergence of corn and beans. 3CV (%), indicates coefficient of variation. 4Standard deviation of the measure.

from the antenna complex to the reaction centers is impaired (Bolhàr-Nordenkampf et al., 1989), such as in low pigment content. Similar to this, it was shown that F0 correlated negatively with chlorophyll a and a + b levels and growth parameters DC, CR and BST with soil and light competition (Supplementary Material 2). This result indicates that reductions in chlorophyll content and plant growth parameters are linked to the increase in F0, due to structural damage in the photosynthetic pigments of PSII and its efficiency in transferring the absorbed energy.

As for competition for soil and light resources, the maximum fluorescence (Fm) for bean leaves was higher when in competition with early emerging volunteer corn, compared to simultaneous emergence and absence of competition (Figure 2). In the case of light competition only, there was no variation in Fm in bean leaves between the emergence times of corn compared to the control plots (Figure 2).

Stress caused by competition can result in damage to photosynthetic tissues, resulting in alteration in non-photochemical extinction processes which modify the Fm. In

Table 4: Carotenoid content (mg g-1 fresh biomass) of leaves of bean cultivars (IPR Gralha and Fepagro Triunfo) as a function of the emergence time of volunteer corn plants competing for soil and light and light resources

	Competing for soil and light		**Competing for light**	
	Triunfo	**Gralha**	**Triunfo**	**Gralha**
7 DBE2	0.20 (±0.02)4 aA1	0.15 (±0.03) bB	0.23 (±0.09) aA	0.19 (±0.02) aA
0 DBE	0.21 (±0.01) aA	0.21 (±0.02) aA	0.25 (±0.05) aA	0.19 (±0.02) aB
Control	0.21 (±0.02) aA	0.22 (±0.02) aA	0.24 (±0.09) aA	0.23 (±0.05) aA
CV(%)3	12.7		19.0	

[1]Lowercase letters compare among emergence times of volunteer corn plants and uppercase letters compare among bean cultivars, both by Tukey's test (p ≤ 0,05). 2 7 DBE indicates emergence of corn plants seven days before the bean plants, 0 DBE indicates simultaneous emergence of corn and beans. 3CV (%), indicates coefficient of variation. 4Standard deviation of the measure.

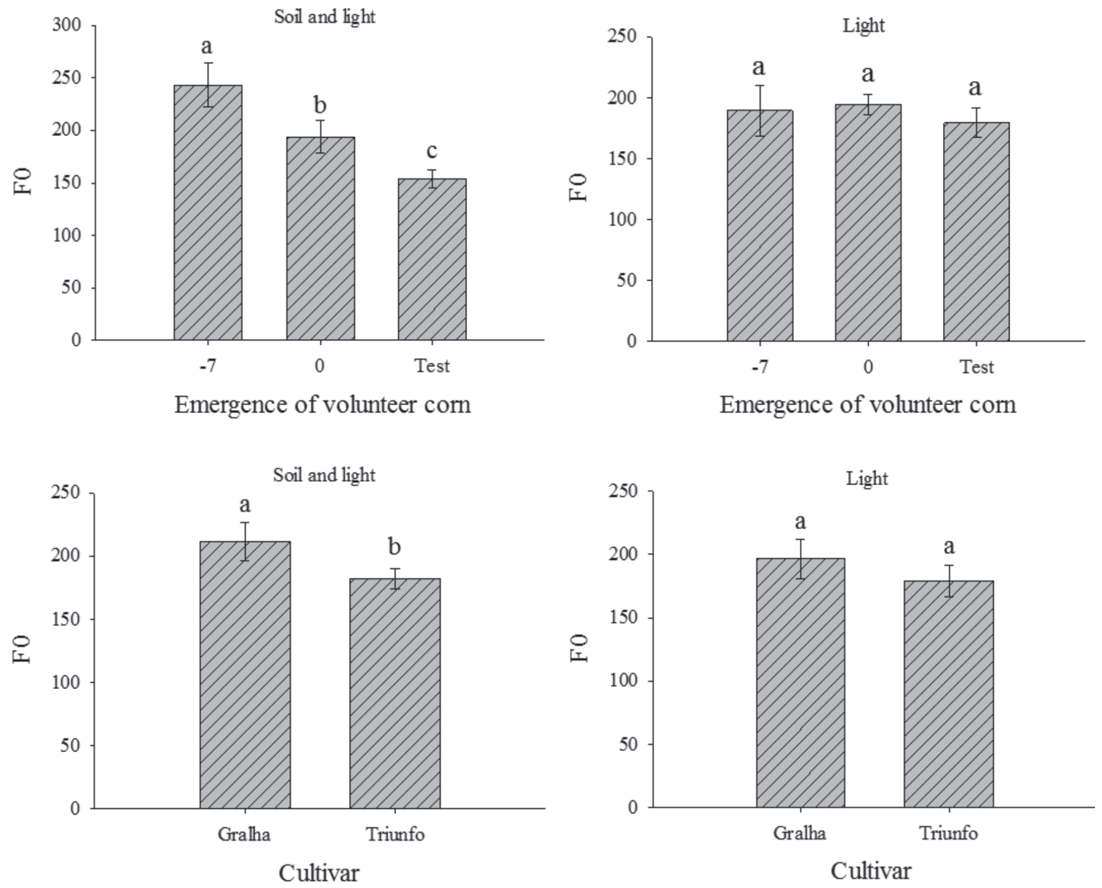

Figure 1: Initial fluorescence (F0) of leaves of bean plants in competition for soil and light and only light with volunteer corn plants, emerged seven days before (7 DBE) and simultaneously (0 DBE). Lowercase letters compare between emergence time of volunteer corn plants or bean cultivars, by the Tukey test ($p < 0.05$).

many situations of stress, the increase in non-photochemical extinction can be accompanied by photo-inactivation of the PSII reaction centers which then dissipate the excitation energy as heat instead of as photochemistry (i.e. electron transfer between photosystems), shown by the increase in Fm (Baker, 2008). Photo-inactivation can lead to oxidation, which in turn promotes damage and loss of PSII reaction centers (Aro et al., 1993).

As with F0, the Fm value correlated negatively with the growth parameters of plant height, stem diameter, root length, dry weight and content of chlorophyll a, a+b and carotenoids (Supplementary Material 2). Increased stress in the photosynthetic tissues caused by competition may have reduced the growth and mass accumulation of bean plants, however, this was only seen with soil and light competition (Supplementary Material 2).

The effective quantum efficiency of PSII (YII) and the electron transport rate (ETR) presented the same pattern, displaying a linear correlation (0.99). Likewise, both YII and ETR were reduced in bean plants when volunteer corn plants emerged early. However, regarding competition for soil and light resources, there were no differences compared to the control when volunteer corn and bean plants emerged simultaneously (Figure 2, Figure 3). These changes were not apparent when there was only competition for light resources. Similar results were reported by Lassouane & Lutts (2016), who showed that, under low light intensity, the photosynthetic apparatus of P. aculeata was not damaged by water stress.

Reductions in ETR observed with competition for soil and light resources when corn plants emerged early may result from the degradation of chlorophylls, which reduces the efficiency of collection by the antenna complex, as indicated by the value of F0 and also the reduction in the efficiency of the YII.

There are few studies in the literature that demonstrate the relationship between chlorophyll fluorescence and weed interference in crops. However, the stresses observed in this relationship may be similar to those reported by Korres et al. (2017), who found that the ETR was reduced under nutritional and light stress in Amaranthus palmeri, which can be linked to photo-inhibition or caused by limited NADP or ATP for the Calvin cycle and/or reduced carboxylation capacity. Therefore, the stress

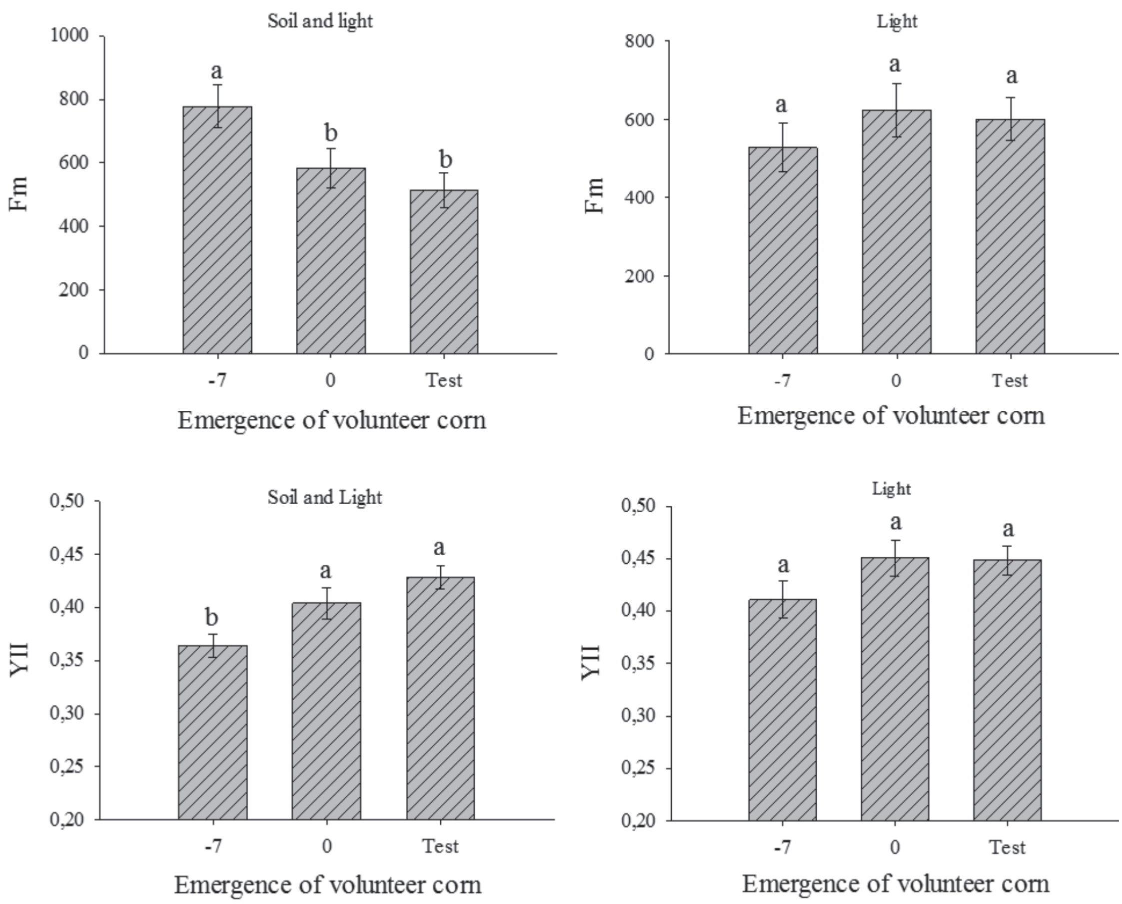

Figure 2: Maximum fluorescence (Fm) and effective quantum yield of PSII (Y II) of leaves of bean plants in competition for soil and light and only light with volunteer corn plants, emerged seven days before (7 DBE) and simultaneously (0 DBE). Lowercase letters compare between emergence time of volunteer corn plants or bean cultivars, by the Tukey test ($p < 0.05$)

caused by weed interference can be predicted by the use of chlorophyll fluorescence in plants.

ETR and YII showed positive correlation with the growth parameters of plant height, stem diameter, root length and dry weight when there was competition for soil and light resources, and with stem diameter when the competition was for light only (Supplementary Material 2). On the other hand, ETR and YII showed no correlation with photosynthetic pigments in any competition conditions.

The non-photochemical extinction (NPQ) of the bean plants increased when there was soil and light competition with early emerging volunteer corn, the emergence being anticipated in relation to the control; however, when competition was established by light NPQ was not altered (Figure 3).

NPQ is related to heat dissipation. NPQ's main collaborator is called the extinction of the high energy state and is considered essential to protecting the leaf from light-induced damage (Horton et al., 1996). In a competitive environment, a high NPQ in the bean plants probably indicates that these plants display a greater dissipation of light energy absorbed in the form of thermal energy insteadof using it for the production of chemical energy in the form of ATP and NADPH (Zanandrea et al., 2006), reducing the Calvin cycle and, consequently, plant growth. This result corroborates findings for growth parameters, as can be seen by the negative correlation between NPQ and plant growth parameters, such as stem diameter, root length and dry weight (Supplementary Material 2).

The alteration in NPQ is related to the stress suffered by the plant. Increases in saline stress, water stress and luminous stress in plants have been proved to increase the NPQ, indicating that some excess of excitation energy was dissipated thermally as a result of the stress (Lassouane & Lutts, 2016; Yan et al., 2012).

Regarding competition for light, correlation between growth parameters, photosynthetic pigments and chlorophyll fluorescence was low and mostly non-significant (Supplementary Material 1). However, when there was competition for soil and light resources, there was a moderate positive correlation (from 0.4 to 0.6) between growth parameters and photosynthetic pigments and a moderate to strong correlation (from 0.4 to 0.6 and 0.7 to

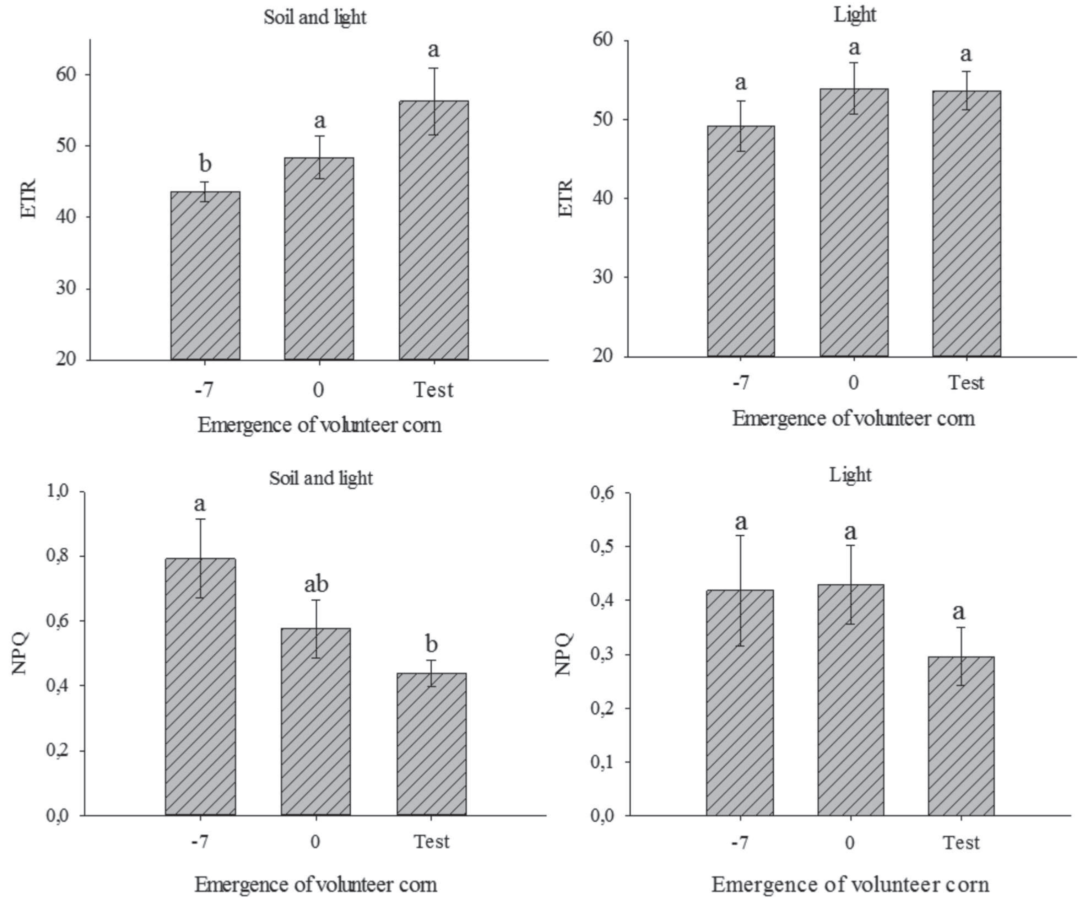

Figure 3: Electron transport rate (ETR) and non-photochemical extinction (NPQ) of leaves of bean plants in competition for soil and light and only light with volunteer corn plants, emerged seven days before (7 DBE) and simultaneously (0 DBE). Lowercase letters compare between emergence time of volunteer corn plants or bean cultivars, by the Tukey test ($p < 0.05$)

1) between growth parameters and chlorophyll fluorescence, being negative for F0, Fm and NPQ and positive for YII and ETR (Supplementary Material 2). Among the photosynthetic pigments and chlorophyll fluorescence, the correlations range from weak to moderate (from 0.4 to 0.6), being negative for F0 and Chl a and Chl a + b, negative for Fm and Chl a, a + b and carotenoids and negative for NPQ and carotenoids.

Chlorophyll fluorescence is a fast and non-destructive parameter that correlates directly with growth variables of plants grown under conditions of competition; therefore, it may serve as an important analytical tool to demonstrate stress caused by weed interference.

CONCLUSION

Volunteer corn plants interfere negatively with bean plants, being more competitive when emerging before the bean plants.

Competition with volunteer corn plants for soil and light resources causes great stress on growth, photosynthetic pigments and chlorophyll fluorescence parameters in bean plants. The competition for light resources causes a reduction in growth and photosynthetic pigments in bean plants.

There is a significant correlation between growth variables and chlorophyll fluorescence in bean plants, which makes it an important analytical tool that can be used to demonstrate stress caused by weed interference.

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