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Physiological Parameters of Soybean Under Different Intensities of Artificial Light

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Abstract

Luminosity and temperature are factors that directly act in photosynthetic process, in which the elevation of the light intensity may provoke reduction in the assimilation of carbon, impairing the development of the soybean culture. This work aimed to know physiological parameters of soybean (*Glycine max* L. Merr.) under different intensities of artificial light. The experiment was carried out in randomized blocks, in a factorial scheme 2 × 5, being two soybean cultivars (Potência and NS6700) and five densities of light: 0 (control), 500, 1000, 1500 and 2000 µmol m^{-2} s^{-1} of photosynthetically active radiation (PAR) provided by LED bulbs, with 4 repetitions, in total of 40 plots. The following variables were set: rate of CO_2 assimilation (A), transpiration (E), stomatal conductance (gs), inner CO_2 concentration in the substomatic chamber (Ci) and water use efficiency (WUE) in which a portable device of gas exchange was used (Infra-Red Gas Analyzer-IRGA, marca ADC BioScientific Ltd, modelo LC-Pro). Seedlings of soybean positively responded under different intensities of artificial light till reach the maximum saturation point between 1400 and 1600 µmol m^{-1} s^{-1} of light, which promoted a better rate of A, Ci andWUE. E and gs presented positive linear responses by increasing the intensity of artificial light. The ideal light intensity to the use of Infra-Red Gas Analyzer-IRGA between 1400 and 1600 µmol m^{-1} s^{-1} to the soybean culture.

Keywords: *Glycine max*, luminosity, CO_2 assimilation, photosynthesis rate

1. Introduction

Soybean (*Glycine max* (L.) Merrill) has been the most cultivated segment of agrarian activity in Brazil due to the development of technologies in its production systems, which allows its cultivation throughout the country. Besides, soybean present a good adaptation to Brazilian lands, once they present good conditions to its growth, as temperature and luminosity.

Light is the primary source of energy regarding photosynthesis and morpho-genetics phenomenon, also, light is one of the main factors that influences on vegetal growth and development. By elevating the availability of light, it may occurs the intensification or even the reduction of photosynthetic activity thought the photo-inhibition entailed by the excess of light, depending on the vegetable specie (Xiong et al., 2017; Rockwell & Holbrook, 2017). Light intensity and temperature may influences on photosynthesis process and contribute to reduction of CO_2 absorption, which, consequently, impairs the growth of plants (Araújo & Deminicis, 2009).

Plants submitted to average light present lower photosynthetic rate, entailing lower values of transpiration as compared to plants exposed to more intense light, therefore, as the light intensity decrease, the lost of water to the environment also decay, as well as the transpiration rate (Vieira et al., 2015). This shows the importance of light in plant´s physiological process, once it acts in the activation of enzymes regarding carbon fixation and in the control of stomata cleft (Teixeira et al., 2015; Bellasio et al., 2017; Li et al., 2017).

The equilibrium in the levels of light intensity and its duration is an important tool to know the different responses of plants under light stress. Plants submitted to direct radiation of low intensity are more efficient in their photosynthesis, since the process is gradually commenced and did not impair the electron's ways through the photo-systems, however, as the intensity of photons increases over the leaves, plants present a higher photosynthesis rate with a lower efficient use of water and assimilation of CO_2, once these parameter are harmed by saturating electrons in photosynthetic system (Taiz & Zeiger, 2013).

It is worth noting that when the soybean is undergoing nutritional stress, the reactions processes in the photosynthesis and diffusion of CO_2 through the stomata and mesophyll act as co-regulators at the point of light compensation, while an increase occurs in the rate of breathing as reported by Singh and Reddy (2018). In this way, it is important to know the response mechanisms that leguminous plants act when they are exposed to quality and light intensities, as they can also suffer from competition with weeds for light, nutrients and water (Lisboa et al. 2018). With an exposure that leads to overlapping, an action of Gibberellins (GAs) and auxin [indole-3-acetic acid (IAA)] play important roles in mediating adaptive responses to plant shading (Yang et al., 2018). This worked aimed to know physiological parameters of soybean under different intensities of artificial light.

2. Material and Methods

The experiment was carried out in November 2018, at Integrated College Stella Maris, in Andradina, São Paulo State, Brazil. The experiment was carried out in randomized blocks, in a factorial scheme of 2 × 5, being two soybean cultivars (Potência and NS6700) and five densities of light: 0 (control), 500, 1000, 1500 and 2000 μmol m^{-2} s^{-1} of photosynthetically active radiation (PAR) provided by LED bulbs, with 4 repetitions were, in total of 40 plots.

Vases, with the capacity of 7 dm^3, were filled with soil obtained from the 0-0.3m-layer. The soil was classified as Hidroferric Red Latosol (Embrapa, 2013) and presented the following chemical attributes (Table 1):

Table 1. Chemical attributes of soil at the moment of experiment placing

pH	MO	P	K	Ca	Mg	H+Al	Al	SB	CTC	V%	m%	B	Cu	Fe	Mn	Zn
$CaCl_2$	g dm^{-3}	mg dm^{-3}	------------------- $mmol_c$ dm^{-3} -------------------									------------ mg dm^{-3} ------------				
5.9	11	21	2.0	19	7	15	0	28	43	65	0	0.21	1	25	9	3.4

Note. SB: Sum of bases; V%: Saturation per bases; m%: Saturation per aluminum.

Soil was fertilized as the needs of soybean culture, according to Raij et al. (1996). During the experiment, all the plots were watered till reach the field capacity (Casaroli & Lier, 2008), and culture treatments were done.

At the V4 development stage, the following parameter were set: rate of CO_2 assimilation (A-μmol CO_2 m^{-2} s^{-1}); transpiration (E-mmol H_2O m^{-2} s^{-1}); stomatal conductance (gs-mol H_2O m^{-2} s^{-1}); inner CO_2 concentration in the substomatic chamber (Ci-μmol mol^{-1}), with 380 ppm of CO_2, under 28 °C temperature of chamber, a portable device of gas exchange was used (Infra-Red Gas Analyzer-IRGA, ADC BioScientific Ltd, modelo LC-Pro); and water use efficiency (WUE-A/E).

All variables were submitted to the F test ($p < 0.05$) and analysis of regression were applied to the intensities of artificial light, in which their standards were tested: linear, quadratic and cubic. Soybean cultivars were submitted to Tukey test, at 5% probability (Banzatto & Kronka, 2013). Statistic program Assistat 7.7 was used (Silva & Azevedo, 2016).

3. Results

Potência cultivar displayed the highest rate of CO_2 assimilation, 21% bigger than NS6700 (Table 2).

Table 2. Average values of rate of CO_2 assimilation (A-μmol CO_2 m^{-2} s^{-1}); transpiration (E-mmol H_2O m^{-2} s^{-1}); stomatal conductance (GS-mol H_2O m^{-2} s^{-1}); inner CO_2 concentration in the substomatic chamber (Ci-μmol mol^{-1}); water use efficiency (WUE) of soybean under different intensities of artificial light

Cultivar (C)	A	E	gs	Ci	WUE
Potência	7.75a	4.24a	0.24a	306.88a	1.77a
NS6700	6.12b	3.56b	0.17b	304.05a	1.61b
CV (%)	19.68	15.17	22.85	9.04	33.29
Cultivar (C)	85.45**	80.38**	120.39**	0.63ns	4.78*
Radiation (R)	548.31**	121.90**	28.29**	152.31**	207.99**
C × R	11.95**	0,24ns	1.13ns	4.21**	4.88**

Note. MSD: Minimum significant difference. CV: Coefficient of variation. OM: Overall mean. F: value of F calculated in the analysis of variance; ns $p = 0.05$; * $0.01 \leq p < 0.05$; ** $p < 0.01$. The averages in the column followed by the same letter do not differ statistically from each other. The Tukey test was applied at 5% probability level.

Again, Potência highlights with the greater leaf transpiration, with a 16%-rate, as well as stomatal conductance, which present values around 30% higher in Potência cultivar. No difference between Potência and NS6700 were observed regarding inner CO_2 concentration in the substomatic chamber. Potência presented a higher efficient use of water with a difference around 9% as compared to NS6700. By considering light intensities over soybean cultivars, both presented quadratic and linear responses (Table 3).

Table 3. Variance analysis of regression of soybean under different intensities of artificial light. Standards linearand quadratic

			Middle Square				
Cultivar	FV	GL	A	E	GS	Ci	EUW
Potência	Radiation	4	1911.1148	90.0987	0.1690	79273.5744	61.7382
	Residue	116	3.0952	0.4492	0.0034	1355.5129	0.5546
	Regression	1	Q**	L**	L**	Q**	Q**
NS6700	Radiation	4	1037.6705	75.7576	0.0811	113618.8148	75.6684
	Residue	116	1.4142	0.3513	0.0020	240.8550	0.1325
	Regression	1	Q**	L**	L**	Q**	Q**

Note. Ns: $p \geq 0.05$; *$0.01 \leq p < 0.05$; ** $p < 0.01$. L: polynomial of 1st degree. Q: polynomial of 2nd degree. Rate of CO_2 assimilation (A-μmol CO_2 m^{-2} s^{-1}); transpiration (E-mmol H_2O m^{-2} s^{-1}); stomatal conductance (GS-mol H_2O m^{-2} s^{-1}); inner CO_2 concentration in the substomatic chamber (Ci-μmol mol^{-1})

It was found a quadratic response in the two soybean cultivars, in the parameter assimilation rate of CO_2, with the increase of light intensity in levels between 1400 and 1600 μmol m^{-1} s^{-1} of light provided the highest maximum values (Figure 1); values above these maximum points may impair photosynthesis of plants.

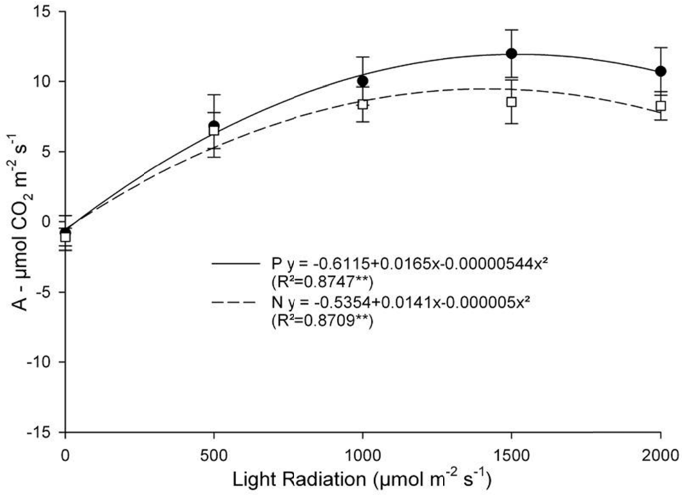

Figure 1. Rate of CO_2 assimilation (A-µmol CO_2 m^{-2} s^{-1}) of soybean leafs as submitted to different light intensities

Note. P = Potência; N = NS6700.

On the other hand, regarding Transpiration of leaf (E), cultivars displayed a positive linear response by increasing the light intensity, with an increase of approximately 14% in every 500 µmol m^{-1} s^{-1} of increased light (Figure 2).

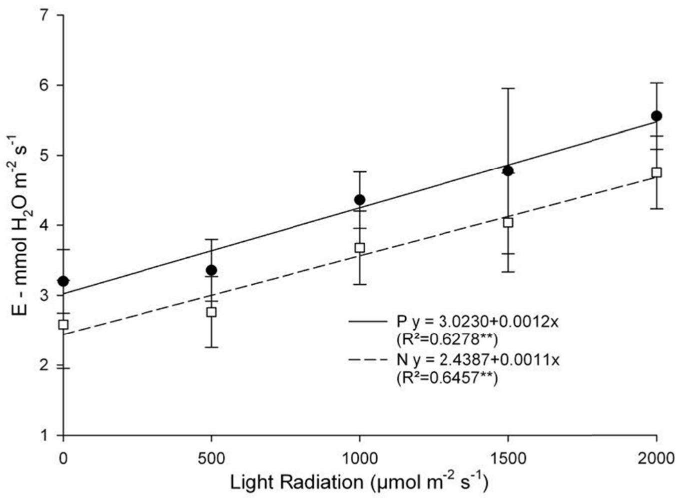

Figure 2. Transpiration (E) of soybean leaves as submitted to different light intensities

Note. P = Potência; N = NS6700.

Stomatal conductance (gs) of both cultivars also presented a positive linear response with the elevation of the light intensity, with an increase of approximately 11% in every 500 µmol m^{-1} s^{-1} of increased light (Figure 3).

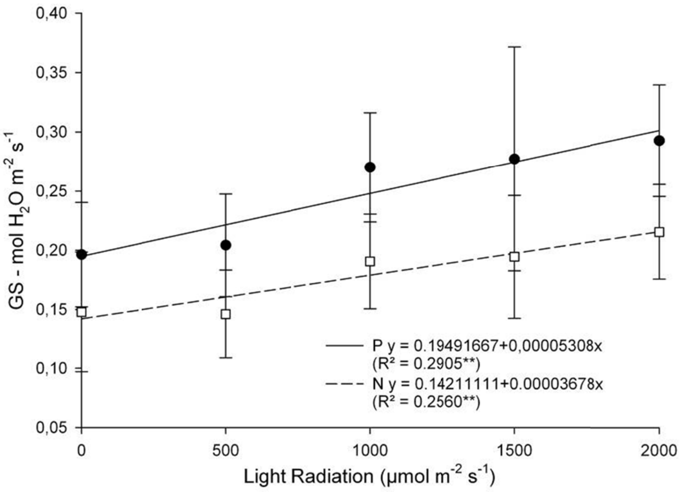

Figure 3. Stomatal conductance (gs) of soybean leaves as submitted to different light intensities

Note. P = Potência; N = NS6700.

A quadratic negative response was observed regarding the inner concentration of CO_2 in substomatic chamber (Ci) in soybean leafs as exposed to different intensities of artificial light between 1300 and 1420 µmol m^{-1} s^{-1} of light, however, intensities higher than these values promoted and elevation in this parameter (Figure 4).

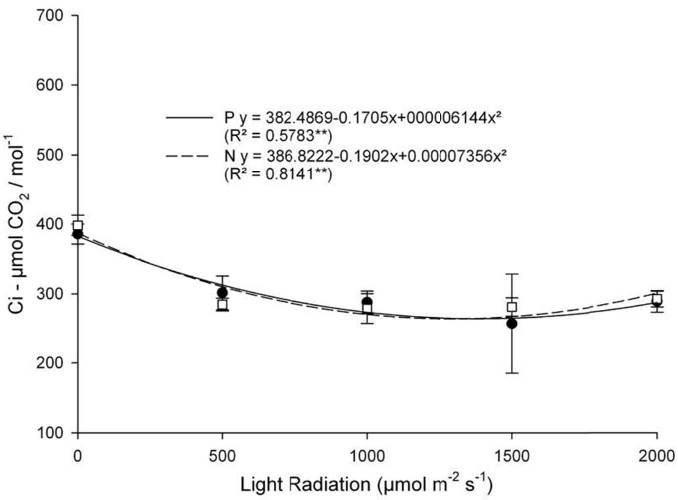

Figure 4. Inner concentration of CO_2 in substomatic chamber (Ci) of soybean leaves as submitted to different light intensities

Note. P = Potência; N = NS6700.

The parameter water use efficiency (WUE) of soybean presented quadratic positive response between the intensities 1210 and 1833 µmol m^{-1} s^{-1}, above this value, it was impaired (Figure 5).

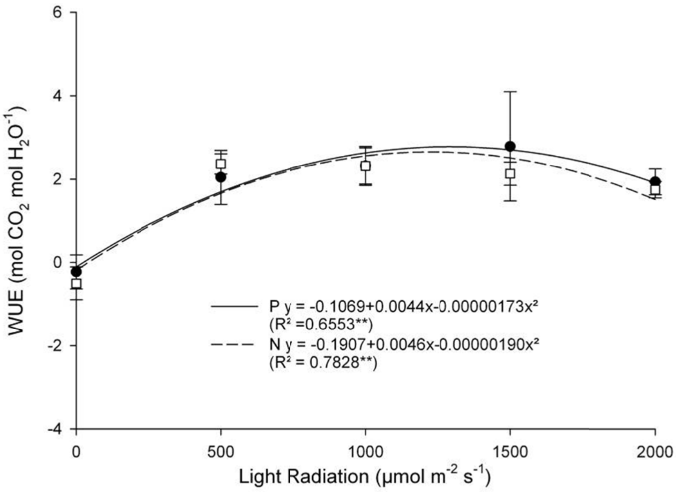

Figure 5. Water use efficiency (WUE) of soybean leaves as submitted to different light intensities

Note. P = Potência; N = NS6700.

A significant negative correlation was observed in inner concentration of CO_2 in substomatal chamber with the parameters transpiration (E), rate of CO_2 assimilation and efficient use of water, however, a correlation with stomatal conductance (GS) were not observed (Table 4).

Table 4. R^2 values of Pearson's correlation between analyzed parameters of soybean under different light intensities

	Ci	E	GS	A
E	-0.2538**	-		
	< 0.0001			
GS	-0.0895Ns	0.90781**	-	
	0.1670	< 0.0001		
A	-0.8365**	0.65941**	0.52988**	-
	< 0.0001	< 0.0001	< 0.0001	
WUE	-0.9831**	0.25136**	0.133465*	0.86138**
	< 0.0001	< 0.0001	0.0388	< 0.0001

Note. Ns: $p \geq 0.05$; * $0.01 \leq p < 0.05$; ** $p < 0.01$. Rate of CO_2 assimilation (A-μmol CO_2 m^{-2} s^{-1}); transpiration (E-mmol H_2O $m^{-2}s^{-1}$); stomatal conductance (GS-mol H_2O m^{-2} s^{-1}); inner concentration of CO_2 in substomatal chamber (Ci-μmol mol^{-1}) and water use efficiency (WUE).

Positives correlations were observed between the parameters in which water is involved such as transpiration, rate of CO_2 assimilation, stomatal conductance and efficient use o water.

4. Discussion

It is important to study the amount and intensity of light that are provided to plants during its initial development, because photosynthetic complex, that involves PSII and PSI, is impaired when the light intensity is above of that is necessary to plants perform its biochemical reactions of photosynthesis (Taiz & Zeiger, 2013). That way, the most suitable intensity of light to soybean leaves perform its photosynthesis is around 1500 μmol m^{-1} s^{-1}, so that, even the moment of the day influences in rate of CO_2 assimilation (Kim et al., 2019), as Figure 1 shows.

It was expected the negative correlation between rate of CO_2 assimilation and inner concentration of CO_2 in stomatal chamber, as Figure 4 shows, the parameters presented opposite responses. When the rate of CO_2 assimilation is lower than the inner concentration of CO_2, it demonstrates that the passage of CO_2 through is stomatal cleft is not occurring, that way the stomatas are closed, entailing a CO_2 concentration in substomatal chambers, as Figures 1 and 4 shows.

The opening of stomata cleft can be proved with the values found in stomata conductance (gs), as Figure 3 shows, in which the light intensity acts in stomatas. Other factors also are linked to opening and closure of stomatal clefts such as nutritional stress and herbivory (Reis et al., 2018; Reis et al., 2017; Meza-Canales et al., 2017; Shrestha et al., 2018), H_2O availability in the system soil-plant-atmosphere (Bellasio et al., 2017; Li et al., 2017) and inner morphology of plants (Stewart et al., 2017; Feldman et al., 2017; Xiong et al., 2017; Rockwell & Holbrook, 2017). These factors influences in leaves transpiration (Figure 3), that shows similar and linear responses between these two parameters, presenting a positive correlation between them.

As the gas exchanges occurs through the stomata, the plant needs hydrostatic pressure to perform the efficient use of water in the photosynthetic system, directly influencing on the initial development of different species of vegetables in the initial phase of its substrate establishment (Xiong et al., 2018; Li et al., 2017; Araújo & Deminicis, 2009).

Seedlings of soybean positively responded under different intensities of artificial light till reach the maximum saturation point between 1400 and 1600 μmol m^{-1} s^{-1}, which promoted a better rate of CO_2 assimilation (A), concentration in the substomatic chamber (Ci) and efficient use of water (EUW). Transpiration (E) and stomata conductance (gs) presented positive linear responses by increasing the intensity of artificial light. The ideal light intensity to the use of Infra-Red Gas Analyzer-IRGA between 1400 and 1600 μmol m^{-1} s^{-1}.

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