Different Light Radiation Intensities on Cotton: A Physiological Approach

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Abstract~~:~~

The luminosity and the temperature are factors that act directly in the photosynthetic process, where ~~the~~ an elevation of the luminous intensity can cause a reduction ~~in~~ of the assimilation of carbon, which consequently lowers the development of the cotton. The objective of this work was to ~~know~~ assess the response of physiological parameters of cotton when subjected to different artificial light intensities. ~~A randomized complete block design was used in a 2x5 factorial scheme, with t~~Two varieties of cotton~~:~~ IMA5801B2RF ~~e~~ and IACRDN, were interacting with five artificial light intensities~~, being interacting with 5 densities of light~~: 0 (control); 500; 1000; 1500 and 2000 μmol m^{-2} s^{-1} of photosynthetically active radiation~~ (PAR)~~ provided by LED bulbs. The experiment was set in a randomized complete block design using a 2x5 factorial scheme. The ~~following~~ variables measured were ~~set:~~the rate of CO_2 assimilation ~~(A)~~,~~;~~ transpiration, ~~(E);~~ stomatal conductance, ~~(GS);~~ inner CO_2 concentration in the substomatic chamber ~~(Ci)~~, and efficient use of water (~~EUW) in~~for which a portable device of gas exchange was used. ~~(Infra-Red Gas Analyzer - IRGA, marca ADC BioScientific Ltd, modelo LC-Pro).~~ The cotton varieties responded positively ~~under~~ to different luminous intensities until reaching the point of maximum saturation between 1400 and 1600 μmol m^{-1} s^{-1} of light, which ~~provides~~ provided a better rate of CO_2 assimilation ~~(A);~~, concentration of CO_2 in the substomatic chamber ~~(Ci)~~, and efficient use of water. ~~(EUW).~~ Leaf transpiration ~~(E)~~ and stomatal conductance ~~of the cotton~~ showed a positive linear response with increasing light intensity. The ideal luminous intensity for the use of Infra-Red Gas Analyzer - IRGA was 1500 μmol m^{-1} s^{-1} ~~in~~ for the tested cotton ~~crop~~varieties.

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Keywords: *Gossypium* L .; brightness; CO_2 assimilation; photosynthesis rate

Introduction

Cotton (*Gossypium* L.) ~~Belonging~~belongs to the Malvaceae family. It ~~,~~ ~~cotton (*Gossypium* L.)~~ is cultivated as a fiber source for the production of fabrics and for ~~, as well as crushing of~~ its seeds ~~for the production of~~that produce linoleic and linolenic oils that are used in the cosmetics or animal feed industry. ~~Because~~ Therefore, it is an important crop for the Brazilian agricultural scenario, since it makes an alternative in crop rotation in the production of large crops such as corn and soybeans. ~~,~~However, cotton can suffer interference during its developmental stages due to climatic factors such as water stresses, pests and diseases and light intensity, especially in the establishment and reproduction phases [1].

Light is the primary source of energy related to photosynthesis and morphogenetic phenomena, and is one of the main factors that influence plant growth and development [2,~~;~~ 3,~~;~~ 4]. Nevertheless, ~~I~~increase in light intensity can reduce the photosynthetic activity through photoinhibition, and this response can be variable between plant species and varieties [5,~~;~~ 6]. The luminous intensity and the temperature are factors that can ~~cause the~~ limit~~ation of~~ the photosynthetic process and also contribute to the reduction of the carbon acquisition, consequently causes a reduction in rate of plant growth [7].

The plants when subjected to medium intensity light show less transpiration when compared to plants that are exposed to more intense light intensity, that is, less light is a limiting factor for leaf transpiration [8]. The importance of light intensity in the physiological process of the plant, is evidenced in its direct link in the activation of enzymes related to carbon fixation and in the control in the opening and closing in the stomatal cleft [9,~~;~~ 10,~~;~~ 11].

It is important to emphasize that the understanding in the balance of intensity levels and the duration of exposure to light that plants can be subjected to makes it an important factor to ~~know~~ understand the responses of plants to varying light stress. When exposed to direct low-intensity radiation, the plants become more efficient in carrying out their photosynthesis, since the process is started in a gradual way, which does not compromise the pathways of the electrons by the photosystems. But with the increase of this intensity of photons that affect the leaves, the plants present an elevation in the photolysis of the water, which results in a saturation of electrons, causing a reduction in the rate of assimilation of CO_2 and in the efficient use of water [12,~~;~~ 13].

In view of the above, this work had as objective to know the response of selected physiological parameters of different intensities of light radiation on cotton crop.

Comment [O1]: State succinctly what you mean by "..of the above,.."

Material e and Methods

The experiment was carried out in December 2018, at the Paulista Agribusiness Technology Agency (APTA), located in the city of Adamantina, State of São Paulo State, with geographic coordinates latitude 21°40'24.024" S and longitude 51°8'31.088" W, with at an altitude of approximately 420 m. The climate of the region is characterized as Aw according to Köppen, with rainy summers and dry winters; with an annual average temperature of 22.1°C and 1204 mm of rain accumulated in the year.

The experiment was carried out in randomized blocks, in a factorial scheme of 2x5, being including 2 varieties of cotton,: IMA5801B2RF and IAC-RDN, interacting with 5 densities of light: 0 (control); 500; 1000; 1500 e and 2000 μmol m^{-2} s^{-1} of photosynthetically active radiation (PAR) provided by LED bulbs.

The area soil was classified as Rred-yellow Latosol [14] and its presented the following chemical attributes are presented in (Table 1).

Table 1: Chemical attributes of the soil of the experiment area at the time of sowing of cotton.

pH (CaCl$_2$)	OM (g dm^{-3})	P mg dm^{-3}	K	Ca	Mg	H+Al	Al	SB	CEC	V%	m%
CaCl$_2$	g dm^{-3}	mg dm^{-3}	---------- mmol$_c$ dm^{-3} ----------								
4.6	12.0	26.0	2.9	8.0	4.0	20.0	1.0	14.9	34.9	43.0	6.0

SB: Sum of bases; V%: Saturation per bases; m%: Saturation per aluminum; CEC: Cation exchange capacity.

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Each block consisted of five rows of five meters in length, spaced 0.9 m between rows, where distance between cotton seeds at sowing was the cotton was sown with a population intensity of? corresponding to 45 thousand plants per hectare. The Ssoil was fertilized as the needs of cotton culture [15]. During the experiment, the cotton was watered until the soil reached field capacity, and the phytosanitary treatments of the crop were done using what and at what dosages and frequencies?.

Thirty days after the sowing, five plants were randomly selected within each replicate, where four readings were performed on the leaves fully expanded leaves from the apex of the plant, totaling 20 readings for each light intensity for the different cotton varieties. The following parameters were measured: rate of CO_2 assimilation (A) – μmol CO_2 m^{-2} s^{-1}); transpiration (E) – mmol H_2O m^{-2} s^{-1}); stomata 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 efficient use of water (EUW) by applying the following mathematical arithmetic formula:

$$EUW = \frac{A}{E}$$

All variables were subjected to the F test (p<0.05)analysis of variance for all parameters measured?and analyses of regression were applied to the intensities of artificial light, in which their standards were tested: linear, quadratic and cubic. Cotton varietiesMeans values were subjected to Scott & Knott Test, at 5% probability [16]. Analyses of regression were performed for a better understanding of the relationships between each of the CO2 assimilation rate, transpiration of cotton leaf, stomata conductance, internal CO2 concentration in the substomatic chamber and to the intensities of artificial light, in which their standards were tested: linear, quadratic and cubic. Statistic program R was used for what?[17].

Results

There was no difference between the varieties in the transpiration (E) and stomata conductance (GS) when the cotton was exposed to different light intensities (Table 2). However, the IAC-RDN variety showed a greater mean in the internal CO_2 concentration in the substamatic chamber (Ci) with a difference of 2.34% more in relation to IMA5801B2RF.

IMA5801B2RF showed higher mean values for CO_2 assimilation (A) and water efficiency (EUW), ~~with a difference of~~ 4.68% and 5.79% more, respectively, in relation to the IAC-RDN variety (Table 2).

Table 2: Mean values of rate of CO_2 assimilation (A) ~~– μmol CO_2 m^{-2} s^{-1})~~; transpiration (E) ~~– mmol H_2O m^{-2} s^{-1})~~; stomata conductance (GS) ~~– mol H_2O m^{-2} s^{-1})~~; inner CO_2 concentration in the substomatic chamber (Ci) ~~– μmol mol^{-1})~~, and the efficient use of water (EUW) ~~- mol CO_2 mol~~ H_2O^{-1}) and analysis of variance of the cotton regressions when exposed to different intensities of light radiation~~, where the models were tested: linear, quadratic and cubic.~~

Variety (V)	A (μmol CO_2 m^{-2} s^{-1})	E (mmol H_2O m^{-2} s^{-1})	GS (mol H_2O m^{-2} s^{-1})	Ci (μmol mol^{-1})	EUW (mol CO_2 mol H_2O^{-1})
IMA5801B2RF	16.66a	3.48	0.53	275.63b	4.49a
IAC-RDN	15.88b	3.45	0.53	282.24a	4.23b
CV%	12.07	11.54	26.20	6.21	14.38
OM	16.27	3.46	0.53	278.93	4.36
F(Variety (V)) ~~of F~~	8.04**	0.28Ns	0.06Ns	7.28**	8.47**
F(Radiation (R)) ~~of F~~	1320.22**	84.09**	42.27**	639.20**	954.15**
F (V x R) ~~of F~~	5.36**	0.76Ns	1.73Ns	4.06**	4.36**

	VF	DF	Regressions middle square				
IMA5801B2RF	Radiation	4	2394.8730	26.7034	1.7038	137064.375	264.5401
	Residue	96	2.8655	0.1641	0.0201	264.7738	0.3051
	Regression	1	Q**	L**	L**	Q**	Q**
IAC-RDN	Radiation	4	1628.0518	24.4440	1.5699	88253.0035	188.8543
	Residue	96	5.7066	0.1602	0.0192	378.7123	0.5611
	Regression	1	Q**	L**	L**	Q**	Q**

CV: Coefficient of variation. OM: Overall mean. F: value of F calculated in the analysis of variance; Ns p=0.05; *0.01 ≤~~=<~~p < 0.05; **p < 0.01. The averages in the column followed by the same letter do not differ statistically from each other. The Scott & Knott test was applied at a 5% probability level. Ns- p~~>=~~≥ 0.05; *0.01 ≤~~=<~~ p < 0.05; ** p < 0.01. VF: Variation factor; DF: Degrees of freedom. L: polynomial of 1st degree. Q: polynomial of 2nd degree.

~~There was no difference between the varieties in the transpiration (E) and stomatal conductance (GS) parameters when the cotton was exposed to different light intensities (Table 2). However, the IAC-RDN variety showed a greater mean in the internal CO_2 concentration in the substamatic chamber (Ci) with a difference of 2.34% more in relation to IMA5801B2RF.~~

When the light intensities ~~are~~ were taken into account, the varieties responded in a similar way ~~in~~ for all the parameters evaluated (Table 2). The

Comment [O2]: This is true invention.

varieties presented a positive quadratic response to the CO_2 assimilation rate, (Figure 1), where the IMA5801B2RF variety presented a maximum point up to 1521 µmol m^{-2} s^{-1} while the IAC-RDN variety had a maximum point of 1673 µmol m^{-2} s^{-1}.

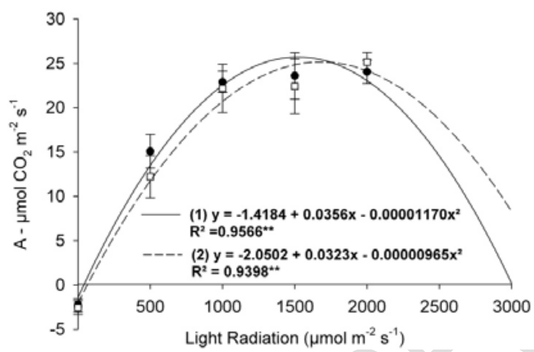

Fig 1. CO_2 assimilation rate (A) of cotton varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation~~of the cotton when exposed to different intensities of light radiation.~~

~~*(1) IMA5801B2RF e (2) IAC-RDN.*~~

While there was an increase in light intensity, the cotton varieties presented a positive linear response to the transpiration parameter of the leaf (E) as shown in Figure 2.~~,~~ ~~already in Figure 1~~.

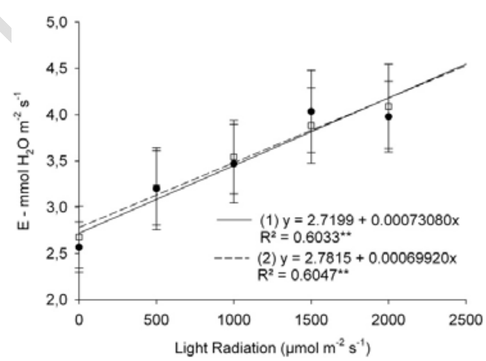

Fig. 2. Transpiration of cotton leaf (E) from varieties IMA5801B2RF (1) and IAC-RDN (2) ~~when~~ exposed to different intensities of light radiation~~.~~

~~(1) IMA5801B2RF e (2) IAC-RDN.~~

Similarly, the varieties exhibited a positive response to the increase in light intensity ~~on~~ for stomata conductance (GS) ~~leaf perspiration (E)~~ (Figure 3). Again, the understanding of these responses regarding leaf water loss with increase in the luminous intensity is important in the determination of the point of maximum response of this variable. This becomes an important tool in the decision making in the cotton cultivation, since it can guarantee a better understanding of the water availability requirements.

Comment [O3]: The result is being discussed before the section **Discussion**

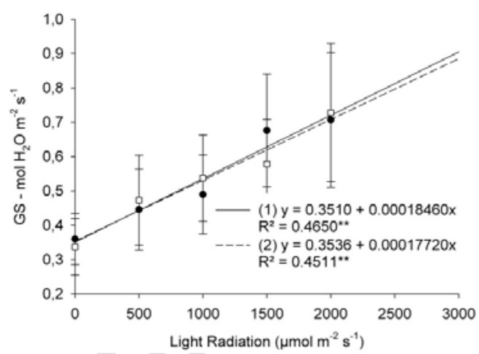

Fig. 3. Stomata~~l~~ conductance (GS) of cotton varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation~~when exposed to different intensities of light radiation.~~

~~(1) IMA5801B2RF e (2) IAC-RDN.~~

In contrast, the internal CO_2 concentration in the sub-static chamber (Ci) of the cotton ~~cultivars~~ varieties presented negative quadratic responses ~~when there was an~~to increases in light intensity, where a minimum point of 1385 µmol m^{-2} s^{-1} was observed in the variety IMA5801B2RF and 1528 µmol m^{-2} s^{-1} for the IAC-RDN variety, as shown in Figure 4.

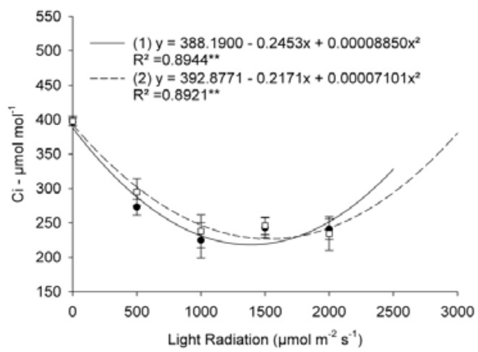

Fig. 4. Internal CO_2 concentration in the substomatic chamber (Ci) of ~~the~~ cotton varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation~~when exposed to different intensities of light radiation.~~

~~*(1) IMA5801B2RF e (2) IAC-RDN.*~~

With the increase in the intensity of the light radiation on the leaves, the cotton varieties presented a quadratic positive response ~~in~~ to the parameter EUW (water efficient use) (Figure 5), where the maximum points ~~of~~ were 1375 µmol m^{-2} s^{-1} ~~in~~ for the variety IMA5801B2RF and 1489 µmol m^{-2} s^{-1} ~~in~~ for the IAC-RDN. This ~~shows~~ showed that the light intensity ~~influences~~ influenced positively only until its saturation as pointed out earlier. This saturation of light ~~causes~~ caused an increase in the photolysis of the water which ~~may~~ might have led to the saturation of electrons in the photosystem.

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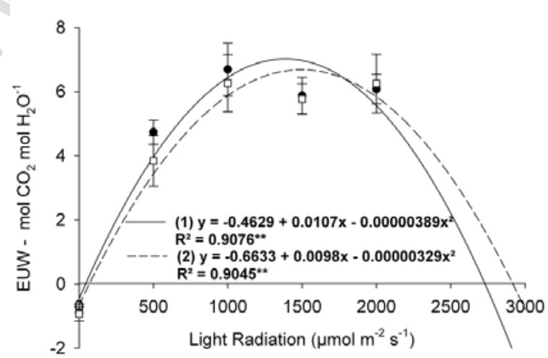

Figure 5: Uso eficiente da água (EUW) do algodoeiro quando exposto em

diferentes intensidades de radiação luminosa~~.~~

(1) IMA5801B2RF ~~e~~ and (2) IAC-RDN.

Comment [O5]: To translate the title in English

Negative correlations were observed between the internal CO_2 concentration ~~variable~~ in the substomatic chamber (Ci) interacting with leaf transpiration (E),~~;~~ stomatal conductance (GS),~~;~~ rate of assimilation of CO_2 (A), and water use efficiency (EUW) as shown in Table 3.

Table 3: Pearson correlation coefficient *r* values among the analyzed variables of cotton when submitted to different light intensity.

	Ci	E	GS	A
E	-0.5733** ~~< 0.0001~~	~~---~~		
GS	-0.3943** ~~< 0.0001~~	0.94156** ~~< 0.0001~~	~~---~~	
A	-0.9432** ~~< 0.0001~~	0.79094** ~~< 0.0001~~	0.64496** ~~< 0.0001~~	~~---~~
EUW	-0.9955** ~~< 0.0001~~	0.61386** ~~< 0.0001~~	0.44222** ~~< 0.0001~~	0.96071** ~~< 0.0001~~

Ns-p ≥~~>=~~ 0.05; *0.01 ≤~~=<~~ 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});~~ stomata conductance (GS), ~~– mol H_2O m^{-2} s^{-1});~~ inner CO_2 concentration in the substomatic chamber (Ci – μmol mol^{-1}), and the efficient use of water (EUW) ~~– *mol CO_2 mol H_2O^{-1}).*~~

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However, positive correlations were observed between the variable leaf transpiration (E) interacting with the stomatal conductance (GS),~~;~~ rate of assimilation of CO_2 (A), and efficient use of water (EUW). In the same way, stomatal conductance (GS) presented a positive correlation with CO_2 assimilation rate (A) and water efficiency (EUW) and, finally, the rate of assimilation of CO_2 (A) with the efficient use of water (EUW) showed a positive correlation as shown in Table 3.

Comment [O6]: This is a repetition in the presentation of the results i.e. presentation using Table 3 and presentation by the highlighted text.

Such a style is avoided in a scientific writing.

DISCUSSION

The plant can respond in different ways ~~with the~~to a change of the environment in which it was inserted, where the luminosity is restrictive to the development of the plant, since the quality and the luminous intensities that affect the leaves alter the responses in the PSII and PSI complexes of the photosystem. This can cause changes in the photolysis of the water, which consequently results in the release of electrons during photosynthesis due to the increase or restriction of the photons that are affecting the plant [13].~~;~~ In this ~~way~~study, the ideal intensity observed ~~is~~ was approximately 1500 μmol m^{-1} s^{-1} light falling on the leaves of the cotton plant.

It is worth noting that, even at different periods of the day, a variation occurs in the ~~incidence~~ intensity of light energy, which influences the CO_2 assimilation rate of the leaves [18] ~~demonstrate~~ demonstrating this phenomenon that occurs naturally during the day.

The significant negative correlation between the internal concentration of CO_2 in the sub-static chamber (Ci) and the other variables as shown in Table 4 was already expected, since the internal concentration of CO_2 is reduced while the carbon fixation in the dry matter of the cotton occurs via Rubisco molecule, which results in the elevation of the CO_2 assimilation rate (A). In this way, this interaction can be verified when one observes Figure 1 and Table 2, where the absence of light on the leaves caused a negative assimilation rate (A), while the internal CO_2 concentration was high (Figure 4). And with the increase in light radiation, the stomata were opened, consequently causing an increase in the transpiration rate (E) (Figure 2) and the stomata~~l~~ conductance (GS) (Figure 3) and thus led to a reduction in concentration (Ci) due to a possible dilution effect, where CO_2 at high internal concentrations is released to the environment due to the stomatal opening and its fixation in the dry mass [13].

It is worth mentioning that the understanding of the mechanism of opening and closing the stomatal cleft can be compromised or enhanced with nutritional stress factors (Table 1), and the availability of H_2O in the soil-plant-atmosphere system [10,~~;~~ 11] and even internal morphology of the leaves of each species and ~~varieties~~ variety [3,~~;~~ 4,~~;~~ 5,~~;~~ 6]. As previously mentioned, stomata~~l~~ conductance ~~presents~~ presented a positive correlation with the other variables (Table 3).

The positive correlation between the CO_2 assimilation rate (A) interacting with the use of leaf transpiration (E) was already expected, since the relationship between these two variables yields the efficient use of water (EUW), which was elevated with the increase of light radiation between 1300 and 1500 μmol m^{-2} s^{-1} (Figure 5). When gas exchange occurs through the stomatal cleft, the plant needs a hydrostatic pressure (Kleaf) to efficiently use water (EUW) in the photosynthetic system, where water stress directly influences development in different plant species in the initial phase [5, 11, 7]. Thus, more in-depth studies are needed on the relationship between these variables, since species and varieties present different responses between them.

CONCLUSIONS

The two cotton varieties responded positively under different light intensities up to the maximum saturation point between 1400 and 1600 μmol m^{-1} s^{-1} of light. This provided a better rate of assimilation of CO_2 (A), concentration of CO_2 in the substamatic chamber (Ci), and efficient use of water (EUW).

Leaf transpiration (E) and stomatal conductance of the cotton showed a positive linear response with increasing light intensity.

The ideal luminous intensity for the use of Infra-Red Gas Analyzer - IRGA was 1500 μmol m^{-1} s^{-1} in the cotton crop.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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