Different Light Radiation Intensities on Cotton: A Physiological Approach

Abstract

The luminosity and the temperature are factors that act directly in the photosynthetic process, where an elevation of the luminous intensity can cause a reduction of the assimilation of carbon, which consequently lowers the development of the cotton. The objective of this work was to assess the response of physiological parameters of cotton when subjected to different artificial light intensities. Two varieties of cotton IMA5801B2RF and IACRDN, were interacting with five artificial light intensities: 0 (control); 500; 1000; 1500 and 2000 μmol m^{-2} s^{-1} of photosynthetically active radiation provided by LED bulbs. The experiment was set in a randomized complete block design using a 2x5 factorial scheme. The variables measured were the rate of CO_2 assimilation, transpiration, stomatal conductance, inner CO_2 concentration in the substomatic chamber, and efficient use of water (for which a portable device of gas exchange was used. The cotton varieties responded positively to different luminous intensities until reaching the point of maximum saturation between 1400 and 1600 μmol m^{-1} s^{-1} of light, which provided a better rate of CO_2 assimilation, concentration of CO_2 in the substomatic chamber, and efficient use of water. Leaf transpiration and stomatal conductance 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} for the tested cotton varieties.

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

Introduction

Cotton (*Gossypium* L.) belongs to the Malvaceae family. It is cultivated as a fiber source for the production of fabrics and for its seeds that produce linoleic and linolenic oils that are used in the cosmetics or animal feed industry. 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, 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 limit 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 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].

This work had as objective to know the response of selected physiological parameters of different intensities of light radiation on cotton crop.

Material and Methods

The experiment was carried out in December 2018, at the Paulista Agribusiness Technology Agency (APTA), located in the city of Adamantina, São Paulo State, latitude 21°40'24.024" S and longitude 51°8'31.088" W, 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, including 2 varieties of cotton; IMA5801B2RF and IAC-RDN, 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 area soil was classified as red-yellow Latosol [14] and its 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%
			---------------------------- $mmol_c\ dm^{-3}$ -------------------								
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.

Each block consisted of five rows of five meters in length, spaced 0.9 m between rows, distance between cotton seeds at sowing was was ? corresponding to 45 thousand plants per hectare. The soil 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 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); transpiration (E); stomata conductance (GS); inner CO_2 concentration in the substomatic chamber (Ci), 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, model LC-Pro); and efficient use of water (EUW) by applying the following arithmetic formula:

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

All variables were subjected to the analysis of variance for all parameters measured?. Means values were subjected to Scott & Knott Test [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), 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); transpiration (E); stomata conductance (GS); inner CO_2 concentration in the substomatic chamber (Ci), and the efficient use of water (EUW) H_2O^{-1}) and analysis of variance of the cotton regressions when exposed to different intensities of light radiation

Variety (V)	A	E	GS	Ci	EUW
	(μmol CO_2 m^{-2} s^{-1})	(mmol H_2O m^{-2} s^{-1})	(mol H_2O m^{-2} s^{-1})	(μmol mol^{-1})	(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))	8.04**	0.28Ns	0.06Ns	7.28**	8.47**

F(Radiation (R))			1320.22**	84.09**	42.27**	639.20**	954.15**
F (V x R)			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.

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

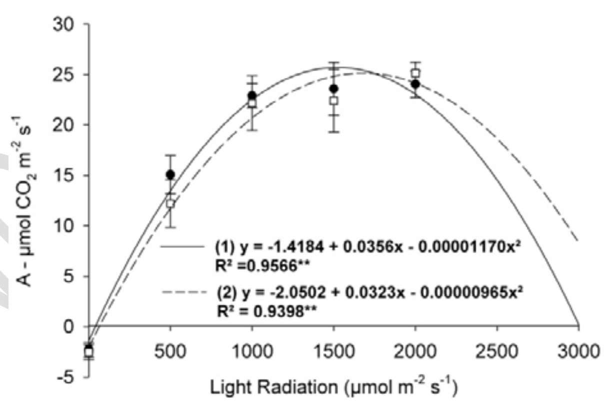

Fig 1. CO_2 assimilation rate (A) of cotton varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation

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.

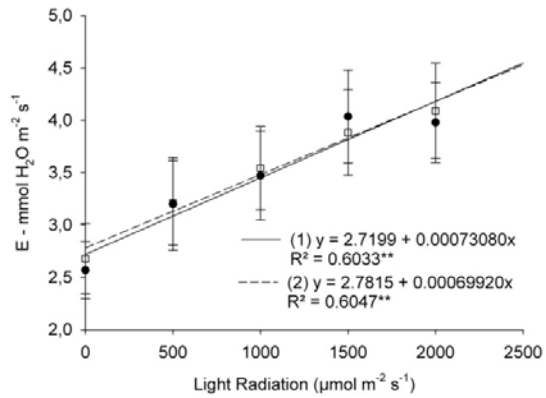

Fig. 2. Transpiration of cotton leaf (E) from varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation

Similarly, the varieties exhibited a positive response to the increase in light intensity for stomata conductance (GS) (Figure 3).

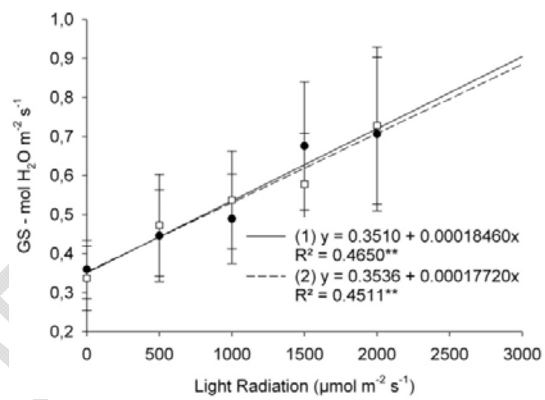

Fig. 3. Stomata conductance (GS) of cotton varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation

In contrast, the internal CO_2 concentration in the sub-static chamber (Ci) of the cotton varieties presented negative quadratic responses 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.

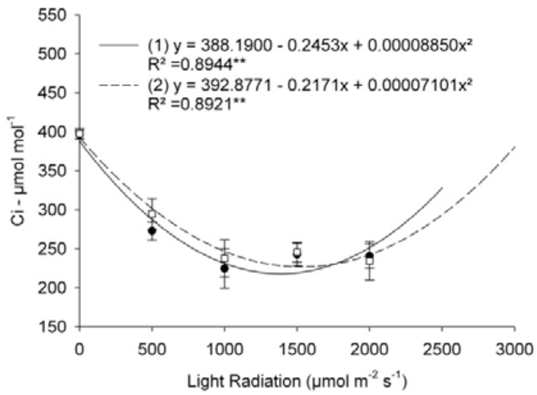

Fig. 4. Internal CO_2 concentration in the substomatic chamber (Ci) of cotton varieties IMA5801B2RF (1) and IAC-RDN (2) exposed to different intensities of light radiation

With the increase in the intensity of the light radiation on the leaves, the cotton varieties presented a quadratic positive response to the parameter EUW (water efficient use) (Figure 5), where the maximum points were 1375 µmol m^{-2} s^{-1} for the variety IMA5801B2RF and 1489 µmol m^{-2} s^{-1} for IAC-RDN.

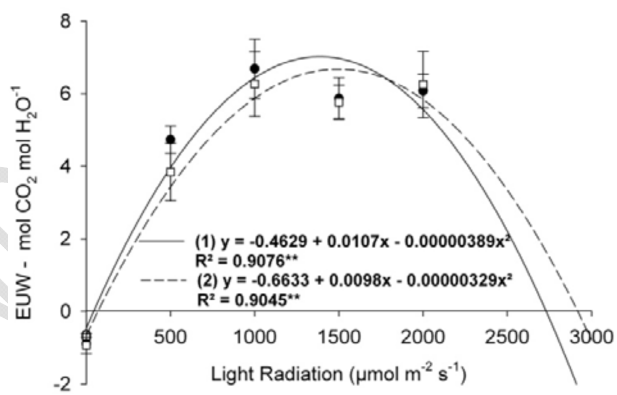

Figure 5: Efficient use of water (EUW) when exposed to different intensities of light radiation.

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

Negative correlations were observed between the internal CO_2 concentration 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**			
GS	-0.3943**	0.94156**		
A	-0.9432**	0.79094**	0.64496**	
EUW	-0.9955**	0.61386**	0.44222**	0.96071**

Ns-p ≥ 0.05; *0.01 ≤ p < 0.05; **p < 0.01. rate of CO_2 assimilation (A), transpiration (E), stomata conductance (GS), inner CO_2 concentration in the substomatic chamber (Ci – μmol mol^{-1}), and the efficient use of water (EUW)

DISCUSSION

The plant can respond in different ways 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 study, the ideal intensity observed 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 intensity of light energy, which influences the CO_2 assimilation rate of the leaves [18] 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 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]. 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.

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 variety [3, 4, 5, 6]. As previously mentioned, stomata conductance 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]. This showed that the light intensity influenced positively only until its saturation as pointed out earlier. This saturation of light caused an increase in the photolysis of the water which might have led to the saturation of electrons in the photosystem.

Thus, more in-depth studies are needed on the relationship between these variables, since species and varieties present different responses between them.

CONCLUSION

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.

REFERENCES

1. Echer FR, Zanfolin PRL, Moreira ACM, Santos ACP, Gorni PH. Root growth and carbohydrate partitioning in cotton subjected to shading in the initial phase. Ciência Rural. 2016; 49(1):1-8. http://dx.doi.org/10.1590/0103-8478cr20180749
2. Holt JS. Plant response to light: a potencial tool for weed management. Weed Science. 1995; 43: 474-482.
3. Stewart, JJ, Polutchko SK, Adams Iii, WW, Cohu CM, Coleman A, Wenzl CA, Demmig-Adams B. Light, temperature and tocopherol status influence foliar vascular anatomy and leaf function in Arabidopsis thaliana. Physiologia Plantarum. 2017; 160(1):98-110. http://dx.doi.org/10.1111/ppl.12543
4. Feldman AB, Leung H, Baraoidan M, Elmido-Mabilangan A, Canicosa I, Quick WP, Sheehy J, Murchie EH. Increasing leaf vein density via

mutagenesis in rice results in an enhanced rate of photosynthesis, smaller cell sizes and can reduce interveinal mesophyll cell number. Frontiers In Plant Science. 2017; 8:1-10. http://dx.doi.org/10.3389/fpls.2017.01883

5. Xiong D, Douthe C, Flexas J. Differential coordination of stomatal conductance, mesophyll conductance, and leaf hydraulic conductance in response to changing light across species. Plant, Cell & Environment. 2018; 41(2):436-450. http://dx.doi.org/10.1111/pce.13111
6. Rockwell FE, Holbrook NM. Leaf Hydraulic Architecture and Stomatal Conductance: A Functional Perspective. Plant Physiology. 2017; 174(4):1996-2007. http://dx.doi.org/10.1104/pp.17.00303
7. Araújo SAC, Deminicis BB. Photoinhibition of the Photosynthesis. Brazilian Journal of Biosciences. 2006; 7(4): 463-472. In Portuguese
8. Vieira TO, Degli-Esposti MSO, Souza GM, Rabelo GR, Vitória AP. Photoacclimation capacity in seedling and sapling of *Siparuna guianensis* (Siparunaeae): Response to irradiance gradient in tropical forest. Photosynthetica. 2015; 53(1):11-22. http://dx.doi.org/10.1007/s11099-015-0073-x
9. Teixeira MC, Vieira TO, Almeida TCM, Vitória AP. Photoinhibition in Atlantic Forest native species: short-term acclimative responses to high irradiance. Theoretical And Experimental Plant Physiology. 2015; 27(3-4):183-189. http://dx.doi.org/10.1007/s40626-015-0043-5
10. Bellasio C, Quirk J, Buckley TN, Beerling DJ. A dynamic hydro-mechanical and biochemical model of stomatal conductance for C4 photosynthesis. Plant Physiology. 2017; 175(1):104-119. http://dx.doi.org/10.1104/pp.17.00666
11. Li Y, Li H, Li Y, Zhang S. Improving water-use efficiency by decreasing stomatal conductance and transpiration rate to maintain higher ear photosynthetic rate in drought-resistant wheat. The Crop Journal. 2017; 5(3):231-239. http://dx.doi.org/10.1016/j.cj.2017.01.001
12. Atroch EMAC, Soares AM, Alvarenga AA, Castro EM. Growth, chlorophyll content, biomass distribution and anatomical characteristics of young plants of *Bauhinia forficata* link submitted to shading. Ciência e Agrotecnologia. 2001; 25(4):853-862. In Portuguese

13. Taiz L, E Zeiger. Fisiologia vegetal. 5. ed. Porto Alegre: Artmed. 2013; 918p.
14. Embrapa – Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos**.** 3.ed. Brasília. 2013; 353p.
15. Raij B, Cantarella H, Quaggio JÁ, Furlani AMC. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas: IAC. 1996; 285p.
16. Banzatto DA, Kronka SN. Experimentação Agrícola. 4.ed. Funep. 2013; 237p.
17. R Development Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2009. ISBN 3-900051-07-0, URL http://www.R-project.org
18. Kim S, Nusinow DA, Sorkin ML, Pruneda-Paz J, Wang X. Interaction and regulation between lipid mediator phosphatidic acid and circadian clock regulators in Arabidopsis. The Plant Cell. 2019; 1-58. http://dx.doi.org/10.1105/tpc.18.00675