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Assessing cloudiness effect on soybean yield in the Southeast Brazil

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ABSTRACT

The solar radiation is one of the most important weather variables for determining the potential yield of agricultural crops. Soybean is the main Brazilian agricultural commodity, with great social and economical importance for the country. It is well recognized that cloudiness is a limiting factor for crop growth rate. Few studies have been conducted to systematically evaluate how much cloud affect soybean yield and none, to our knowledge, is available for tropical soybean. The objective of this paper was to quantify the implications of cloudiness on soybean growth and development in tropical Brazil. To do so, experimental data associated with the simulations of the DSSAT/CROPGRO (DC) model was used, and two treatments were simulated: a) the first used measured solar radiation and b) the second used estimated solar radiation for non-cloud days. Thus, based on the model output variables (growth rate of aerial dry matter, grain yield, specific leaf weight, and light saturation point) and comparing the data with the literature review. We found that simulations exhibited an increase in the dry matter production rate of up to 23%, during days of clear sky, resulting in a yield increase between 26 and 37%. Also, the DC could simulate some adaptation in the plant when the solar radiation changes, like the specific foliar weight and the light-saturated photosynthesis rate.

Introduction

Agriculture is an activity heavily dependent on the weather, and it explains most of the production variability among the seasons in Brazil. The soybean crop is the main Brazilian agricultural commodity, and the country soybean production along the season 2018/19 exceeded 120 million tons (Conab, 2019).

Among the weather variables that interfere in agriculture productivity, solar radiation is one of the most important factors for the plant's development. Because intensity and quality of the radiation intercepted by the plant canopy regulate the photosynthesis rates, and it determines the crop potential yield (Van Ittersum, 2013; Yao, 2017). Solar radiation that reaches the canopy in the field is linked to physics, biological and geometric factors, that cause the daily oscillation of the solar radiation (Dohleman & Long, 2009; Yang, 2018).

In general, the main characteristics related to this factor, in soybean are the leaf size and weight, plant high, lateral growth, and the number of pods (Liu, 2010). Furthermore, soybean tends to decrease the photosynthetic rate and a lower the point of photo-saturation, comparing with those cultivated with higher levels of irradiance (Yang et al, 2018). But in general, this changes the crop morphology expressing shade avoidance and tolerance characteristics, pods abortion, stem elongation, increase the chlorophyll content and lowers specific foliar weight (Kokubun, 2011; Gong, 2014; Hussain, 2019). In addition, some soybean cultivars have differences response to shade-tolerance, reducing the losses in yield (Wu et al, 2017). Thus, just some peppers, that artificially modify solar radiation can be used to understand the effects of field shading (Melges,1989; Mathew, 2000; KurosakI, 2003; Liu, 2010; Gong, 2014; Wu; Gong, 2017; Yao, 2017).

Meanwhile, one of these points in the oscillation is cloudy days, which results in lower solar radiation for a certain period. To our knowledge, there is no available research related to the influence of clouds in tropical soybean.

Given the complexity of the experimental researcher in the field, process-based models can be used to isolate factors and essential relation of a complexity reality (Popper, 2005). The models DSSAT/CROPGRO (DC) presents a flexible approach to account for the responses to air temperature, day length, water deficit and nitrogen availability to the crop (Boote, 1997), and it has been largely tested for soybeans in Brazil and worldwide (Rodrigues, 2012; Salmerón & Purcell, 2016; Battisti & Sentelhas, 2017; Peart & Boote, 2018;

The objective of this paper was to quantify the cloudiness effect on tropical soybean growth and development in Brazil.

Materials and Methods

Field experiments and calibration of the *DSSAT/CROPGRO model*

Two soybean crop experiments were conducted at the experimental area of the University of São Paulo (USP), Luiz de Queiroz College of Agriculture (ESALQ), Piracicaba, São Paulo State, Brazil (latitude 22°42'S; longitude 47°30'W; 546m a.s.l). For experiments 1 (E1) and 2 (E2) were grown from December 2015 to April 2016 and from October 2017 to February 2018, respectively. In both, the same genetic material used was BRS 399-RR (GMR 6.2) and was planted with a row spacing of 0.45 m and with 18 seeds per linear meter, resulting in a plant density of 35.5 plants m^{-2}. The soil was classified as a Chromic Acrisol (E1), and a Eutric Rhodic Ferralic Nitisol (E2).

Phytosanitary treatments were based on frequent monitoring of pests, diseases, and spontaneous plants. Irrigation frequency and water amount were scheduled based on an agrometeorological water balance model ensuring full water supply. The minimum interference of limiting and reducing factors in the crop was sought to meet the concept of potential and attainable productivity, as described by Marin et al (2014).

Meteorological data were collected from the two seasons (2015/16 and 2016/17) in a weather station belonging to the Department of Biosystems Engineering of the Luiz de Queiroz College of Agriculture (ESALQ / USP), Near to the experimental area. The variables used were: air temperature (maximum and minimum), solar radiation and rainfall.

Based on the biometric data experimentally generated, the calibration process was performed by (Silva et al, 2018b). The model calibration methodology followed the procedure proposed by (Marin et al, 2011) in conjunction with the automatic calibration procedure (for fine-tuning of parameters).

Solar radiation estimation and soybean yield simulation

After the model calibration process, potential yield (Yp) was simulated based on observed weather data collected *in situ* at the ESALQ weather station (December 2015 to March 2018), thereafter called Treatment 1 (T1) and based on a hypothetical weather series for which the solar radiation where estimated such as no cloud interception, and hence representing the maximum incoming solar radiation on the crop (treatment 2, T2).

To do so, the radiation of a clear sky (Qcl, $MJ.m^{-2}.d^{-1}$) was estimated using a FORTRAN routine according to the approach described by (Spitters, 1986) (Equation 1). With this approach it was possible to analyze the response of soybean with the increase of radiation during its cycle in the region of Piracicaba - SP;

$$Q_{cl} = 0.77.Qo \qquad (1)$$

where Qo is the extraterrestrial solar radiation ($MJ.m^{-2}.d^{-1}$, Equation 2). The value of 0.77 is a factor used for days without cloudiness, where 77% of the irradiation is direct and 33% is diffused;

$$Qo = Jo.\int sen\beta dt_h \qquad (2)$$

where Jo is the solar constant (1368 $J.m^{-2}.s^{-1}$) and sin β is the sine of elevation of the Sun above the horizon, calculated by equation 3;

$$\int sen\beta dt_h = 3600[(N.sen\lambda.sen\delta + (\frac{24}{\pi}).cos\lambda.cos\delta(1-tan^2\lambda . tan^2\delta)^{½})] \quad (3)$$

where t_h is the hour of the day, λ is the local latitude and δ the solar declination, calculated by equation 4 and (N,h) is the daylength calculate by equation 5;

$$sen\,\delta = -sen(23{,}45).cos\left[\frac{360(t_d + 10)}{365}\right] \quad (4)$$

$$N = 12 + 24/180\ arcsen\ (tan\lambda - tan\delta) \quad (5)$$

where t_d is the number of days since 1 January.

To quantify the cloudiness in the treatment 1 was utilized the output variable of the model DC, cloudiness factor CLDD, calculated by equation 6, decriable by (Jones, 2010);

$$CLDD = (1 - \frac{Qg}{Qcl}) \quad (6)$$

where Qg is the solar radiation collected by a meteorological station ($MJ.m^{-2}.d^{-1}$). When CLDD, reaches the unit, higher will be the level of cloudiness in the local. The parameter was correlated with the daylength; therefore, it was possible to obtain an indicator by clear sky time length (Tcl, $h.d^{-1}$). These indicators were measured by the following equation (7).

$$Tcl = CLDD.\ N,\ (0 < CLDD < 1) \quad (7)$$

The algorithm was applied for the whole crop cycle, and the phenology was analyzed by the output data of the model and follows the standard of (Fehr & Caviness, 1977). The variables used to compare the treatments were the difference in the growth rate of aerial dry matter (ΔGRAD, $g.m^{-2}dia^{-1}$), final grain yield ($kg.m^{-2}$), the light-saturated photosynthetic rate at mid-day(P_{max}, $mg.m^{-2}.s^{-1}$) and specific leaf area ($mg.cm^{-2}$).

Results and Discussion

The soybean crop in E1 showed the vegetative period initiated in the 5th day after planting (DAP), and such phase was no correlation between the difference in treatments, with and without cloudiness (R^2 = 0.234). However, from the reproductive stage (R1), DAP 36, until the onset of physiological maturation (R7), DAP 91, there was a high correlation between the difference of the two treatments given the ΔGRAD in a relation of Tcl (R^2 = 0.885, Figure 1).

Similar to observed in E1, the soybean crop grown along 16/17 season showed a lower correlation in the vegetative stage between ΔGRAD and Tcl, started in 5 DAP and end at 35 DAP (R^2 = 0.14, Figure 2). During the reproductive stages, the Tcl explained 77% of the variance of the ΔGRAD (R= ² 0.768), that stage began at 36 DAP and 104 DAP.

For both experiments, on days, when the crop was in the vegetative stage, there was no significance between Tcl and ΔGRAD. Meanwhile, at the reproductive stage, the Tcl has a significance, showing a decrease of aerial biomass, accepting the hypothesis (P>0.001) for both seasons.

Figure 1. Relationship between the difference of the growth rate of aerial dry matter (ΔGRAD) and clear sky time length (Tcl) for (A) vegetative stage and (B) reproductive stage in experiment 1 (E1).

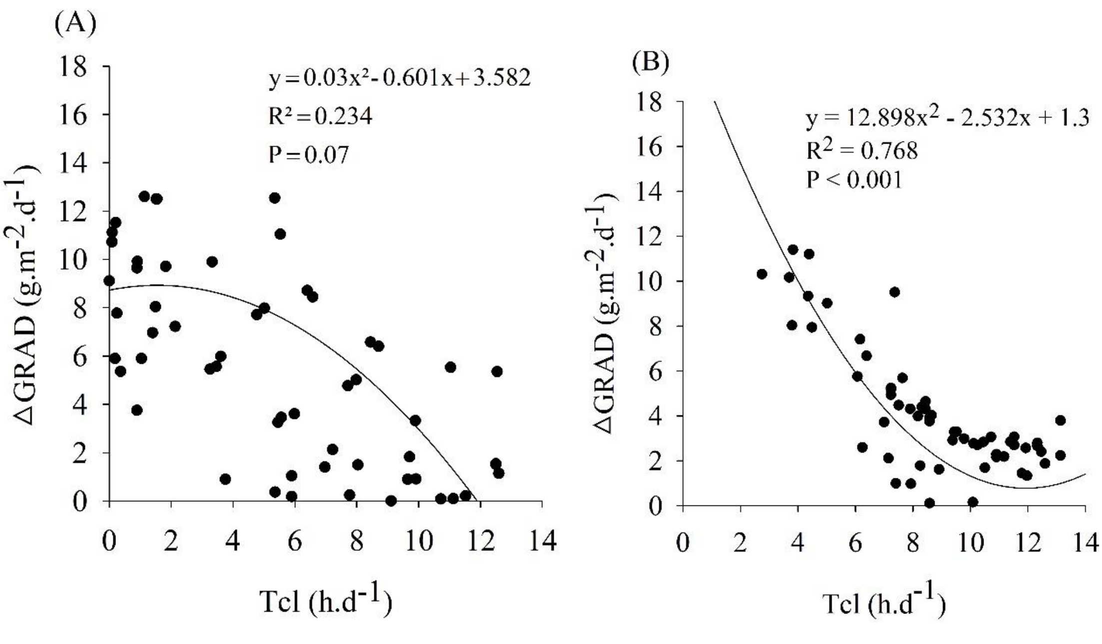
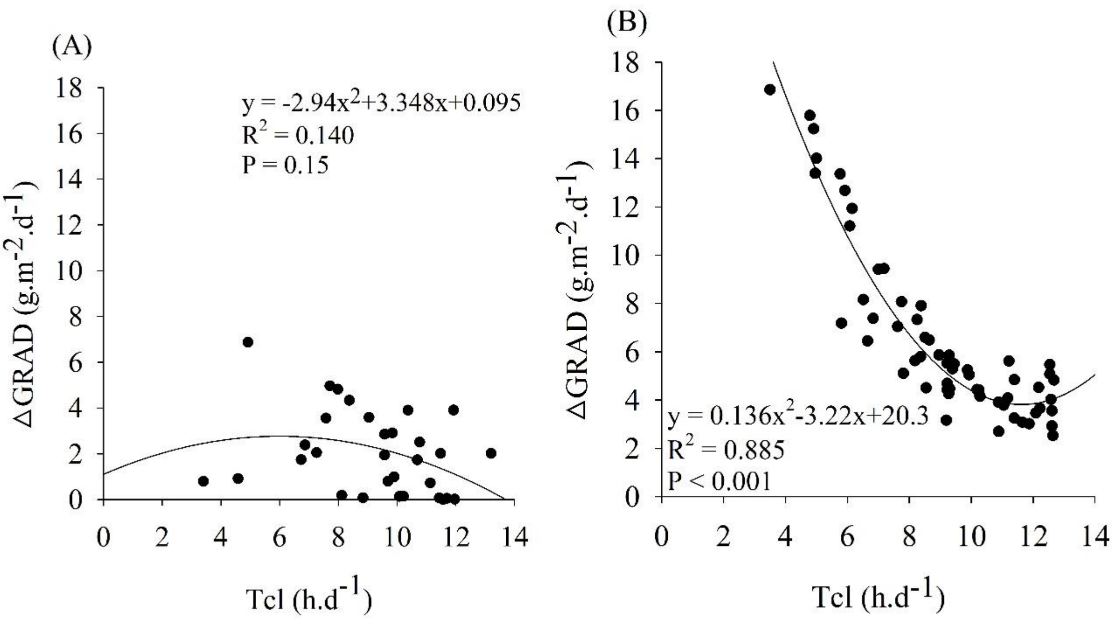


Figure 2. Relationship between the difference of the growth rate of aerial dry matter (ΔGRAD) and clear sky time length (Tcl) for (A) vegetative stage and (B) reproductive stage in experiment 1 (E1).



The Qg for soybean, sowed in December in season 15/16, were 20,82 $MJ.m^{-2}.d^{-1}$ and 30,35 $MJ.m^{-2}.d^{-1}$,when disregarding the cloudiness. In E2, sowed in October, the values were 21,38 $MJ.m^{-2}.d^{-1}$ and 31,52 $MJ.m^{-2}.d^{-1}$ for treatments 1 and 2, respectively (table 2).

This difference of solar radiance results for T2 an increase of aerial dry mass, for both experiments, at all phenological stages. In E1, during the vegetative stage, was reported the highest rise in accumulated dry weight, in proportions throughout the cycle, with 34%. Meanwhile, the period of R1 to R3 was shown a slight increase, of 14% in season 15/16 and 29% for season 16/17 for T1. In the grain fill stage to maturation, there was a rise of dry matter accumulation of 29% in E1 and 16% for E2, is this the larger increase in dry matter accumulation in the mass unit ($kg.ha^{-1}$).

Therefore, this resulted in E1 and E2, respectively, the final yield of 5402 $kg.ha^{-1}$ and 4989 kg .ha-1 for T1. And for the T2, the final yield was 7403 $kg.ha^{-1}$ (E1), and 6267 $kg.ha^{-1}$ (E2). In addition, experiments with soybean, artificially shaded, in field condition had a decrease in the yield of 35% to 87% (Kurosaki & Yumoto, 2003; Liu, 2010). Meanwhile, Mathew et al (2000) grow soybean with a light enhancement, of 25%, in field condition after the stage V5 and R3, with that the increase of the yield was between 32% and 225%. Both correlated several factors to the difference in productivity, but the main was the number of pods per plant. For this experiment, the model showed an increase in the number of pods of 14% (E1) and 25% (E2).

Even with an enhancement in solar radiation when the CLDD was taken (Table 2), the light-saturated rate of photosynthetic (P_{max}) of soybean at mid-day, increased at the T2 (Figure 3), both for sunlit and shaded leaf. Yao (2017) obtained the same results for P_{max}. In addition to that, when the unshaded treatment was exposed to lower levels of solar radiation, the photosynthetic rate decrease comparing to shaded plants. Therefore, it becomes apparent how soybean can adapt and become more efficient in the environment of its development.

Table 1. Accumulated shoot dry matter values in ($kg.ha^{-1}$) for the different stages of soybean development.

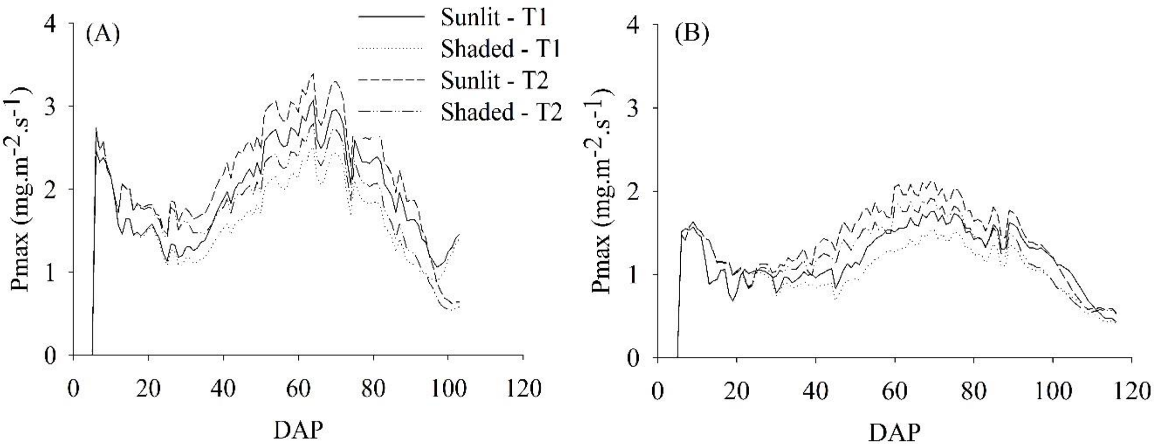
	Experiment 1		Experiment 2	
Stage	T1	T2	T1	T2
Ve-R1	946	1434	825	1272
R1-R4	6200	7186	4,440	6222
R5-R7	4440	6222	8,799	10449
Harvest	9727	12566	8,177	10033

Table 2. Measured global solar radiation (Qg), clear skies solar radiation (Qcl) ($MJ.m^{-2}.d^{-1}$) and the coefficient of cloudiness (CLDD), for the different development stages of soybean.

	Experiment 1			Experiment 2		
Stage	Qg	Qcl	CLDD	Qg	Qcl	CLDD
Ve-R1	19.56	31.81	0.38	22.04	31.44	0.30
R1-R4	25.74	30.92	0.17	22.09	31.96	0.31
R5-R7	18.01	28.67	0.37	20.57	31.36	0.37
Total	20.82	30.35	0.32	21.38	31.52	0.32

The P_{max} is related to the specific weight of leaves (SWL, $mg.m^{-2}$) and as a function of the concentration of nitrogen

Figure 3. Light-saturated photosynthetic rate (P_{max}) at mid-day for sunlit and shaded leaves, along the soybean cycle in days after planting. (A) E1 and (B) E2.



in leaf. Considering that the simulation is done in a potential situation the P_{max} was just a function of the SWL, so the treatment subjected to a lower level of radiation had a decrease in SWL (Figure 4). Thus, the values of specific foliar area (SFA, $m^2.g^{-1}$) simulated were the inverse of the SWL, this way the plant that received higher radiation had lower SFA. Yang et al (2018), also reported the same ratio of SFA decreasing as a function of higher radiation levels.

Consequently, plants subjected to this adaptation increase the surface area of the mesophyll cells per unit of foliar area, resulting in a high ratio of the surface and volume inside the leaf. This, in turn, causes the decrease of the resistance of the mesophyll to the flow of CO_2, enabling higher photosynthetic rates (Marchiori, 2014; Terashima, 2011). Thus, the DC was able to detect the modification in the development of soybean caused by different levels of radiation for the region of Piracicaba-SP. Still, the DC calculates the photosynthetic and the plant's solar radiation interception hourly, following the model of hedge-row, describe by (Boote & Pickering, 1994). With this the daily data were estimated to hourly by the models of (Parton & Logan, 1981; Kimball & Bellamy, 1986) for air temperature, (Erbs, 1982; Spitters, 1986) for radiation and the diffuse and direct radiation fraction.

In this way, the DC calculates the light absorbed by the canopy of the plant as a function of the photon flux density of direct and diffuse radiation, absorbed by the sunlit leaves and shaded leaves. The diffuse radiation is divided into three categories. The direct radiation converted to diffuse by cloudiness and scattering, ground reflected radiation and canopy reflected radiation using the Goudriaan (1977) model which uses the plant population dynamics. This approach makes the model more sensitive to the responses of the environment and plant physiology (Tsuji & Hoogenboom, 2013).

Conclusions

By comparing observed data with simulated outputs, it was found that DC model was able partly mimic morpho-physiological adaptations of soybean crop exposed to higher solar radiation levels, such as the changes on the specific foliar weight and light-saturated point in sunlit and shaded leaves. There was a correlation between the time of clear skies and soybean yield patterns. Cloudiness limits the rate of dry matter accumulation: by reducing the solar radiation around 22 and 29%, resulted in 26 to 37% reduced yield, respectively.

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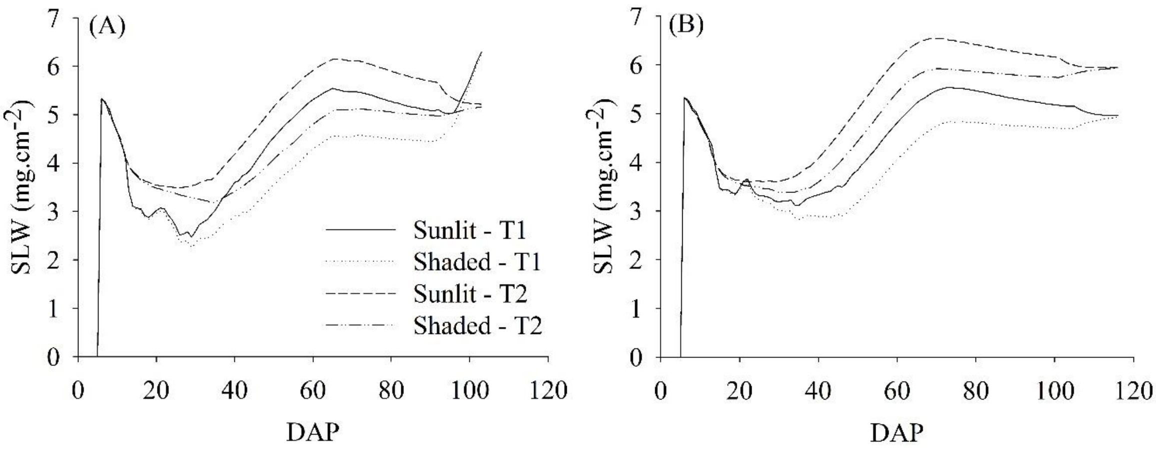
Figure 4. Specific foliar weight (SLW) of the sunlit and shaded leaf, along the soybean cycle in days after planting in the (A) experiment 1 (E1) and (B) experiment 2 (E2).



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Quantificando a influência nebulosidade na produtividade potencial da soja no sudeste brasileiro

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INFORMAÇÕES

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RESUMO

A radiação solar é uma das variáveis climáticas mais importantes para determinar a produtividade potencial das culturas agrícolas. A soja é a principal *commodity* agrícola brasileira, com grande importância social e econômica para o país. É bem reconhecido que a nebulosidade é um fator limitante da taxa de crescimento das culturas. Poucos estudos foram realizados para avaliar sistematicamente o quanto dias nublados afetam o rendimento da soja e nenhum, até onde sabemos, está disponível para a soja tropical. O objetivo deste trabalho foi quantificar as implicações da nebulosidade no crescimento e desenvolvimento da soja no Brasil tropical. Para tanto, foram utilizados dados experimentais associados às simulações do modelo DSSAT/CROPGRO (DC), e dois tratamentos foram simulados: a) o primeiro usou a radiação solar medida e b) o segundo usou a radiação solar estimada para dias sem nuvens. Assim, com base nas variáveis de saída do modelo (taxa de produção de matéria seca aérea, produtividade, peso específico das folhas e ponto de saturação da luz) e com dados da literatura. Descobrimos que as simulações exibiram um aumento na taxa de produção de matéria seca de até 23%, durante dias de céu limpo, resultando em um aumento de rendimento entre 26 e 37%. Além disso, o DC conseguiu simular alguma adaptação na planta quando a radiação solar muda, como modificações no peso foliar e na taxa de fotossíntese saturada.

REFERENCIAÇÃO

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