Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.15, n.4, e8494, 2020
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v15i4a8494
Protocol 8494 - 20/04/2020 • Approved in 29/06/2020

Correlations between plant height and light interception in grasses by different light meter devices

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ABSTRACT: This study tested if the type of light meter device can influence the relationships between plant canopy height with light interception (LI) and leaf area index (LAI), in different types of warm-season grasses. LI and LAI were measured using Digital Plant Canopy Imager model 120 (CI-120) (CID Bio-science®) and Plant Canopy Analyzer LAI-2000 (LI-COR®). Seven warm-season grasses were evaluated *Urochloa decumbens* (Stapf) R.D. Webster.; *Urochloa ruziziensis* (R.Germ. & C.M. Evrard) Crins; *Megathyrsus maximum* (Jacq.) B.K. Simon & S.W.L. Jacobs cv. Tanzânia, *M. maximum* (Jacq.) B.K. Simon & S.W.L. Jacobs cv. Mombaça, *Pennisetum purpureum* Schumach. cv. Mott, *P. purpureum* Schumach. cv. Taiwan A-146 2.37, *P. purpureum* Schumach. cv. Roxo. There was a predominance of non-significant correlations between canopy height with LI and LAI measured using CI-120 ($p > 0.05$). Moderate to strong correlations were obtained between canopy height with LI and LAI measured using LAI-2000 ($p < 0.01$). LAI-2000 was found to be a potential device for modelling relationships between canopy height with LI/LAI in warm-season grasses. The findings of this trial indicate that the type of light meter device has a strong influence on the correlations between canopy height and light interception in warm-season grasses.

Key words: forage growth; leaf area index; sward; tropical grasses

Correlações entre altura de planta e a interceptação luminosa em gramíneas por diferentes dispositivos medidores de luz

RESUMO: Este estudo testou se diferentes dispositivos medidores de luz podem influenciar nas relações entre a altura do dossel com a interceptação luminosa (IL) e o índice de área foliar (IAF), em diferentes tipos de gramíneas tropicais. A IL e o IAF foram medidos usando o Digital Plant Canopy Imager modelo 120 (CI-120) (CID Bio-science®) e o Plant Canopy Analyzer LAI-2000 (LI-COR®). Sete gramíneas tropicais foram avaliadas *Urochloa decumbens* (Stapf) R.D. Webster.; *Urochloa ruziziensis* (R.Germ. & C.M. Evrard) Crins; *Megathyrsus maximum* (Jacq.) B.K. Simon & S.W.L. Jacobs cv. Tanzânia, *M. maximum* (Jacq.) B.K. Simon & S.W.L. Jacobs cv. Mombaça, *Pennisetum purpureum* Schumach. cv. Mott, *P. purpureum* Schumach. cv. Taiwan A-146 2.37, *P. purpureum* Schumach. cv. Roxo. Houve predomínio de correlações não significativas entre a altura do dossel com a IL e o IAF medidos pelo CI-120 ($p > 0,05$). Foram obtidas correlações de moderadas a fortes entre a altura do dossel com a IL e o IAF medidos utilizando o LAI-2000 ($p < 0,01$). LAI-2000 apresentou-se como um dispositivo com potencial para modelar relações entre a altura do dossel com o IL e IAF em gramíneas tropicais. Os resultados deste estudo indicam que o tipo de dispositivo medidor de luz tem uma forte influência nas correlações entre a altura do dossel e a interceptação luminosa em gramíneas.

Palavras-chave: crescimento forrageiro; índice de área foliar; dossel; gramíneas tropicais

Introduction

The management of warm-season grasses at the farm level has been mostly based on easy measurable traits of the grass sward, in which the canopy height is one of the most feasible to be performed. Generally, canopy height is used by the pasture managers as a tool to specify management practices associated with harvesting and/or grazing, and it is also used to set the ideal residual canopy height after defoliation (i.e. stubble height), which is required for an adequate sward regrowth (Rodolfo et al., 2015; Pedreira et al., 2017). Although canopy height is widely used as a valuable pasture management tool, it can be a misleading parameter if it is not well correlated with others important sward growth measurements such as light interception (LI) and leaf area index (LAI). To validate canopy height as a useful tool in pasture management, it is necessary to verify its relationships with other productive or structural characteristics of the sward.

Among the main sward traits used in pasture management, LI and LAI have been used to measure the growth and development of warm-season grasses (Rodolfo et al., 2015; Pedreira et al., 2017; Silva et al., 2018). LI and LAI are canopy traits directly correlated with the plant growth and morphophysiological status (e.g. photosynthetic rate). An important application of the LI and LAI values in pasture management is what is called, residual LAI, which is the total amount of photosynthetic active tissues left after grass harvesting by grazing or cutting. Adequate residual LAI is extremely important to avoid situations such as overgrazing (Hao et al., 2018). LI and LAI can be measured through direct and indirect methodologies (Jonckheere et al., 2004; Casa et al., 2019). The direct methods are extremely time/labour consuming because they generally require entire harvesting and/or scan of all the leaf area present in a given delimited area of soil covered by the plant canopy. Direct methods for accessing LI and LAI are generally not suitable for use at farm level conditions, and even at field/glasshouse research trials. On the other hand, indirect measurements of LI and LAI that are based on the use of portable devices, have high costs associated with the acquisition of this type of equipment. This fact makes light meter devices an inaccessible and unfeasible technology for most of the farmers and grass manager worldwide.

Indirect measurements of LI and LAI can be performed using different types of devices. In general, these light meter devices are based on different methodological approaches to estimate LI and LAI (Jonckheere et al., 2004; Garrigues et al., 2008). These methodological differences between devices might lead to inaccurate results of LI and LAI estimative for a given crop or forage cultivar (Wilhelm et al., 2000; He et al., 2007; Garrigues et al., 2008; Casa et al., 2019). Considering the possible divergences in the results from the measurements of LI and LAI between different types of devices, there is a need to evaluate which type of equipment is best suited for use in the studies with different forage cultivars and plant growth modelling. Also, it is necessary to establish relationships between LI and LAI with easy sward measurements (e.g. canopy height), as indirect measurements of LI and LAI are still unfeasible technology at the farm level, due to the high costs of these devices.

This study investigated if the type of light meter device can influence the magnitude of the correlations found in the relationship between canopy height and light interception, for a set of seven of warm-season grasses with different plant size and growth habits.

Materials and Methods

Site and experimental characterization

The experiment was conducted in the forage collection fields at the Universidade Federal Rural de Pernambuco (UFRPE), in the city of Recife, Pernambuco-Brazil, with coordinates 8º02’07 S and 34º54’15 W, at sea level. The climate is Am’s (tropical hot and humid) according to the classification of Köppen. The mean annual rainfall is 2,418 mm, with the annual means of temperature: minimum and maximum of 21.8 and 29.1 °C, respectively (INMET, 2015). The soil of the site was classified as yellow podzolic and yellow latosol. Soil samples were taken and analyzed prior the beginning of the experiment, and had the following characteristics: pH (water/1: 2.5) = 6.3 ± 0.1; P (mg dm^{-3}) Mehlich 1 = 322 ± 167; K^+ (cmolc dm^{-3}) = 0.15 ± 0.1; Ca^{+2} (cmolc dm^{-3}) = 6.6 ± 1.8; Mg^{+2}(cmolc dm^{-3}) = 1.01 ± 0.3; Na (cmolc dm^{-3}) = 0.09 ± 0.02; H+Al (cmolc dm^{-3}) = 3.2 ± 0.2; Organic Carbon (g kg^{-1}) = 14.0 ± 3.3; Organic matter (g kg^{-1}) = 24.1 ± 5.7. The experimental area has been maintained for more than twenty years as a forage collection. Periodically inorganic and/or organic fertilizers (e.g. poultry/cattle manure) have been applied to maintain minimum levels of fertility for the warm-season grasses plots.

Seven warm-season grasses were evaluated in this trial: *Urochloa decumbens* (Stapf) R.D.Webster.; *Urochloa ruziziensis* (R.Germ. & C.M.Evrard) Crins; *Megathyrsus maximum* (Jacq.) B.K. Simon & S.W.L. Jacobs cv. Tanzânia; *Megathyrsus maximum (*Jacq.*)* B.K. Simon & S.W.L; Jacobs cv. Mombaça, *Pennisetum purpureum* (Schumach.) cv. Mott, *Pennisetum purpureum* (Schumach.) cv. Taiwan A-146 2.37 (Viana et al., 2018), *Pennisetum purpureum* (Schumach.) cv. Roxo. Each cultivar analyzed was kept in plots with a dimension size of 2.8 x 1.8 m. Each cultivar had four replicates within each plot. The division of measured zones within each plot was established using four quadrants of approximately 1m^2 each. Weed species were controlled by hand-pulling when their growth was detected. The grass plots were considered as pure cultures.

The height and light measurements were carried out at intervals of 15 days along 10 months. Harvestings were performed in periods of 45 days for *U. decumbens* and *U. ruziziensis*; and 60 days for taller grasses (*M. maximum* cv. Tanzânia, *M. maximum* cv.; *P. purpureum* cv. Mott, *P. purpureum* Taiwan A-146 2.37, *P. purpureum* cv. Roxo), targeting the regrowth of the sward. All *Pennisetum* spp.

were cut at soil level, *Panicum* spp. at stubble height of 15-20 cm, and *Urochloa* spp. 5-cm stubble height. After cutting, an interval of 15 days was given before new measurements of height and light interception were taken.

Light interception and leaf area index measurements

The canopy height of grasses was measured based on the distance from the soil to the highest leaf inflexion of each grass sward. LI and LAI were measured using two devices based on indirect measurements of light interception. Digital Plant Canopy Imager model 120 (CI-120) from CID Bio-science® Camas-WA USA, which uses hemispherical images captured below the canopy to calculate the gap-fraction (Norman & Campbell, 1989); and Plant Canopy Analyser LAI-2000 (LI-COR®) Lincoln-NE USA, which bases its measurements on the difference between the diffuse radiation above and below the canopy (Welles & Norman 1991).

In the measurements with the LAI-2000, one reading was taken above the canopy and three basal measurements. The threshold value of the CI-120 was adjusted to 50, which was suitable to avoid over or underestimation of the LAI at the light conditions of the experimental site (Figure 1). The LI from LAI-2000 was obtained as the inverse of diffuse non-interceptance. The measurements of CI-120 and LAI-2000 were at the same point and time where the canopy height was measured. For both devices, the readings below the sward had the lenses positioned at the base of the plant canopy, just above the soil. Measurements were taken during the early morning (before 8 a.m.) or late afternoon (4:00 to 6:00 p.m.), to avoid exposure of the LAI-2000 to direct solar radiation.

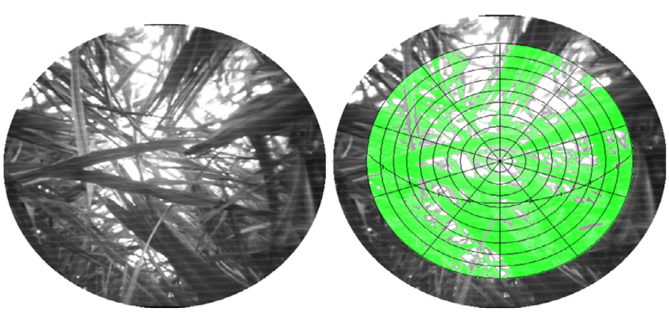

Figure 1. Hemispherical images captured below the canopy using CI-120. Threshold 50. Cultivar: *Megathyrsus maximum* cv. Tanzânia.

Statistical analysis

Pearson correlations (r) between canopy height, LI and LAI were performed using PROC CORR procedure in SAS 9.3 (Statistical Analysis System), at the significance levels of 1 and 5% probability. The correlation magnitudes were classified according: if $|r| \leq 0.20$, no correlation; $0.20 < |r| \leq 0.50$, weak correlation; $0.40 < |r| \leq 0.60$, moderate correlation; $0.60 < |r| \leq 0.80$ strong correlation; if $|r| > 0.80$ very strong correlation. Regression analyses were performed between canopy height, LI and LAI. Linear, exponential, quadratic, logarithmic and power regressions were verified for best-fit, and the equation choice was based on the greatest coefficient of determination (R^2).

Results and Discussion

The degree of the correlations between the canopy height of the grasses with the values of LI and LAI varied substantially between the devices, with a predominance of not significant ($p > 0.01$) and weak correlations $r \leq 0.20$ in light measurements using CI-120 (Table 1). Moderate to very strong positive correlations were found in the relationships between canopy height and measurements of LI taken using LAI-2000 ($p < 0.01$) (Table 1). Among seven cultivars evaluated with CI-120, only three showed significant correlations between canopy height with LI, *U. decumbens* with a strong correlation (r=0.64) ($p < 0.01$), and *M. maximum* cv. Tanzânia and *M. maximum* cv. Mombaça weak correlations (r=0.31 and 0.32, respectively) ($p < 0.05$). *U. decumbens* showed a very strong correlation between canopy height and LI measured using LAI-2000, and the other species/cultivars moderate correlations ($p < 0.01$). Correlations between the canopy height and LAI values displayed similarities with the results found for LI, a predominance of not significant correlations in CI-120 ($p > 0.05$), and significant correlations using LAI-2000 ($p < 0.01$). However, the correlations between canopy height and LAI using LAI-2000, in general, were much stronger than those shown in the relationships between canopy height and LI. Most of the cultivars had strong correlations between canopy height and LAI measured using LAI-2000; *P. purpureum* Taiwan A-146 2.37 displayed a moderate correlation (r=0.57).

Based on the strong correlation results between canopy height with LI and LAI measured by the LAI-2000, regression equations were then generated for this device (Table 2). Six of the cultivars evaluated displayed logarithmic regressions for the relationship between canopy height and LI, however, in four of them, the R^2 values were under 0.50. *U. decumbens* displayed a linear function between canopy height and LI with a considerable R^2 value (0.69). The equations between canopy height and LAI measured using LAI-2000, had values of R^2 greater than 0.50 for most of the cultivars, with a predominance of best-fitted logarithmic regressions. *M. maximum* cv. Tanzânia and *M. maximum* cv. Mombaça displayed best-fitted linear regressions, and *U. decumbens* an exponential one.

Table 1. Correlation (r) coefficients between canopy height with light interception (LI) and leaf area index (LAI) measured with CI-120 and LAI-2000, in warm-season grasses with different growth habits.

Cultivar	CI-120		LAI-2000	
	LI	LAI	LI	LAI
U. decumbens	0.64**	0.56**	0.83**	0.74**
U. ruziziensis	0.24ns	0.09ns	0.58**	0.71**
M. maximum cv. Tanzânia	0.31*	0.27*	0.50**	0.77**
M. maximum cv. Mombaça	0.32*	0.34*	0.42**	0.73**
P. purpureum cv. Mott	0.07ns	-0.07ns	0.58**	0.67**
P. purpureum Taiwan A-146 2.37	0.04ns	-0.13ns	0.44**	0.57**
P. purpureum cv. Roxo	0.19ns	0.11ns	0.45**	0.65**

** Significant at ($p < 0.01$); * Significant at ($0.01 \leq p < 0.05$); ns = not significant ($p \geq 0.05$).

Table 2. Regression equations between canopy height with light interception (LI) and leaf area index (LAI) measured with LAI-2000, and estimated canopy height (cm) to reach critical LAI in warm-season grasses with different growth habits.

Cultivars	LI	R^2	Critical LAI Heigth (cm)	LAI	R^2
U. decumbens	Y = 0.95x + 26.3	0.69	72.5	$Y = 0.36e^{0.0333x}$	0.70
U. ruziziensis	Y = 20.2 ln(x) + 4.1	0.39	89.6	Y = 1.4 ln(x) - 2.8	0.51
M. maximum cv. Tanzânia	Y = 18.2 ln(x) – 0.4	0.30	188.4	Y = 0.02x + 0.6	0.60
M. maximum cv. Mombaça	Y = 17.3 ln(x) + 4.7	0.20	183.6	Y = 0.02x + 0.6	0.54
P. purpureum cv. Mott	Y = 25.9 ln(x) – 23.6	0.64	97.8	Y = 1.3 ln(x) - 2.4	0.55
P. purpureum Taiwan A-146 2.37	Y = 17.3 ln(x) + 12.9	0.45	114.6	Y = 1.2 ln(x) - 1.8	0.49
P. purpureum cv. Roxo	Y = 14.1 ln(x) + 18.9	0.49	218.3	Y = 0.8 ln(x) - 0.9	0.58

The critical LAI values, or the LAI values when the grass canopy reached 95% of LI measured using LAI-2000 can be observed in Table 2. There was some degree of convergence in the estimated canopy height to reach the critical LAI between cultivars from the same species with closely related growth habits and canopy heights, as found for *M. maximum* cv. Tanzânia and *M. maximum* cv. Mombaça (188.4 and 183.6 cm, respectively). On the other hand, cultivars from the same species but with different plant sizes such as *Pennisetum purpureum* cv. Mott and *Pennisetum purpureum* cv. Roxo showed a substantial disproportion of more than 1m in the canopy height to reach their critical LAI (97.8 and 218.2 cm, respectively).

Correlations between equivalent LI measurements from CI-120 and LAI-2000 showed significant results for all cultivars evaluated ($p < 0.01$) (Table 3). The correlation magnitudes were classified as strong for *U. decumbens*, *M. maximum* cv. Tanzânia, *P. purpureum* cv. Mott and *P. purpureum* cv. Taiwan A-146 2.37, and moderate for other species. For equivalent LAI measurements generated using CI-120 and LAI-2000, the correlations were weaker than found between their LI (Table 3). *U. ruziziensis* showed a non-significant correlation ($p > 0.05$) and *P. purpureum* cv. Roxo weak correlation ($p < 0.05$). *M. maximum* cv. Mombaça was the only cultivar that showed a strong correlation ($p < 0.01$). Other cultivars showed a moderate correlation ($p < 0.01$). The relationship between LAI and LI in each equipment analyzed separately, showed exponential regressions models, CI-120 ($R^2 = 0.70$) and LAI-2000 ($R^2 = 0.94$) (Figure 2). In CI-120, LI values ranged from 33 to 98%, and in LAI-2000 between 9.6 and 100%, respectively.

Table 3. Correlation coefficients between equivalent measurements of light interception (LI) and leaf area index (LAI) generated using CI-120 and LAI-2000, in warm-season grasses with different growth habits.

Cultivars	CI-120 / LAI-2000	
	LI	LAI
U. decumbens	0.77**	0.56**
U. ruziziensis	0.53**	0.23ns
M. maximum cv. Tanzânia	0.66**	0.47**
M. maximum cv. Mombaça	0.53**	0.60**
P. purpureum cv. Mott	0.78**	0.49**
P.purpureum Taiwan A-146 2.37	0.75**	0.42**
P. purpureum cv. Roxo	0.58**	0.35*

** Significant at ($p < 0.01$); * Significant at ($0.01 \leq p < 0.05$); ns = not significant ($p \geq 0.05$).

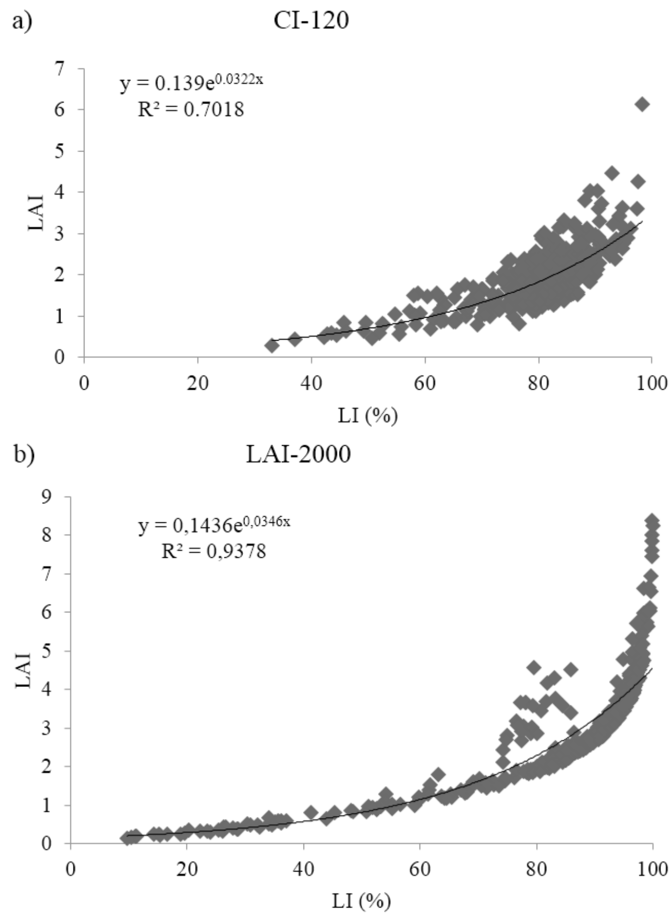

Figure 2. Relationship between leaf area index (LAI) and light interception (LI%) in CI-120 (a) and LAI-2000 (b), for a range of different types of warm-season grasses.

The magnitude of the correlations found between the canopy height with LI and LAI based on the indirect measurements were strongly dependent on the type of device used. In this study, LAI-2000 was more suitable than CI-120 for establishing stronger relationships between the canopy height and LI/LAI values in the set of different types of warm-season grasses evaluated. In many studies, the canopy height of warm-season grasses has been utilized and validated as a predictor of LI or LAI values generated by LAI-2000 or its update LAI-2200 (Pedreira et al., 2017; Pedreira et al., 2018; Tamele et al., 2018). For CI-120, only one previous study was found in the literature correlating canopy height with LI and LAI in warm-season grasses (Coêlho et al., 2014).

This study analysed a set of ten warm-season grasses and only four showed significant correlations for the relationship between canopy height and LI, and only one species showed a significant moderate correlation between the canopy height and LAI values measured using CI-120.

These stronger correlations found for the relationship between canopy height and LAI-2000 measurements, do not necessarily indicate that this device is the most accurate to measure the real values of LI and LAI. However, once LI and LAI measurements from LAI-2000 displayed good levels of validation towards an accurate direct measurement of LAI and LI, this equipment or its new updates (e.g. LAI-2200) can be considered as a potential device for generating models for the growth of warm-season grasses based on the relationship between canopy height, LI and LAI.

The stronger correlations between canopy height and LAI measured using LAI-2000, in comparison to the correlation between canopy height and LI in the same device, probably was because most of the cultivars showed logarithmical functions in their relationships between canopy and LI, with lower R^2 (Table 2). The equations and graphs indicate that LI reaches its plateau values earlier than LAI, which can be observed in the exponential graphs generated by the relationship between LI and LAI (Figure 2). Tamele et al. (2018) also reported that the relationship between LI and LAI can be described by exponential models. In their trial, these authors observed an increase in LAI when LI had already reached its plateau. Most of the swards were reaching their critical LAI (95% LI), but still growing in height and accumulating forage. These results indicate that generalizations of theory related to the critical LAI (95% LI) and its application to the sward harvesting must be carefully analysed because when using indirect methods such as the light meter devices, maybe at the time that the plants reach 95% of LI they might be still growing and accumulating mass efficiently. It is recommended to correlate their critical LAI with direct methods for measuring LAI, and with productive and qualitative traits for a better decision of the ideal harvesting time.

Despite divergent results found for the correlations between canopy height and LI/LAI in both devices, LAI-2000 and CI-120 showed strong levels of correlation for the same LI measurements. Concerning the LAI, correlations of moderate magnitude indicate that LAI-2000 and CI-120 differ more when estimating the same LAI values than the LI, which might be associated with the calculation that each device uses for estimating the LAI. In previous studies comparing different types of devices, different values for the same LAI measurements were reported (Wilhelm et al., 2000; He et al., 2007; Garrigues et al., 2008; Casa et al., 2019). The use of indirect estimation of LAI, in general, differ from the actual values of direct measurements, they can be under or overestimated, and adjustments are generally necessary. Considering the frequent divergences in LAI results between different devices, it is strongly recommended in future studies correlating different types of devices with the direct measurements of LI and LAI for each type of crop/cultivar. Also, it is necessary to correlate LI and LAI other easy measurable swards traits (e.g. sward mass), including in its fresh forage mass.

Conclusions

The efficacy of the utilization of plant canopy height as a predictor of the values of light interception (LI) and leaf area index (LAI) in different types of warm-season grasses is strongly dependent on the light meter device used for measuring the LI and LAI.

The choice of a light meter device plays a vital impact on the outcoming of the results in scientific trials, which can affect directly plant growth modelling proposals and their applications. In our trial, LAI-2000 demonstrated to be a potential device for modelling relations between canopy height with LI and LAI in warm-season grasses.

It is recommended to carefully choose the type of light meter device when proposing growth/management models based on indirect light measurements.

For future studies, it is recommended to test indirect light meter devices against direct measurements individually for each type of crop/cultivar being modelled.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) – Grants. For the postdoctoral scholarship of the Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (FACEPE), grant number BFP-0126-5.04/19.

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