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CROP SCIENCE

Estimating the light conversion efficiency by sugarcane: the segmented approach

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Abstract: The classical method to estimate the light conversion efficiency (ε_c) gives a single value for the whole crop cycle (ε_{co}) but does not reveal any variation along the growing season. We proposed the segmented approach to uncover such variations along sugarcane (*Saccharum* sp. hybrid) growth cycle. Our analyses revealed that longer sampling intervals could overestimate ε_{co} and that the segmented light conversion efficiency (ε_{cs}) varied between 0.09 and 5.39 g MJ^{-1} during the crop cycle. The ε_{cs} would provide insights on how the environment affects ε_c and how to increase biomass production through crop management practices.

Key words: Biomass, growth, *Saccharum*, segmentation.

INTRODUCTION

Biomass production is the final product of the light energy that reaches plant canopy during the growing season times two fundamental efficiencies (Zhu et al. 2010): light interception efficiency (ε_i); and light conversion efficiency into biomass (ε_c). This latter is estimated as the ratio between biomass accumulated and the light intercepted during the season. While measuring light interception is simple, non-destructive and can be even automated (Robertson et al. 1996, Cruz et al. 2021), the quantification of biomass is a laborious process, which limits the frequency of data sampling along the crop cycle and then the estimation of ε_c. Usually, a single ε_c value is estimated for the whole growing season (Robertson et al. 1996, Muchow et al. 1997, Singels & Smit 2002, Olivier et al. 2016). However, any variation of ε_c along the crop cycle remains hidden with such oversimplification and we are not able to understand how environmental and physiological conditions affect ε_c or even if crops reach the theoretical ε_c values during the crop season. Herein, we propose the segmented approach to estimate ε_c and its seasonal variation, discussing the importance of ε_c segmentation for understanding physiological processes driving biomass production by sugarcane.

MATERIALS AND METHODS

The incident solar radiation (Q_i) in Campinas SP, Brazil (22°52' S, 47°04' W, altitude 665 m a.s.l.) from May 2019 to May 2020 was taken as reference (Figure 1a). Q_i was monitored with a pyranometer (model SP Lite, Kipp & Zonen, Delft, Netherlands) at 2 m above soil surface and data were recorded every 1-hour by a datalogger model CR1000 (Campbell-Scientific, Logan UT, USA). Following Cruz et al. (2021), we assumed a variation of ε_i along the crop cycle, as shown in Figure S1 – Supplementary Material. Finally, we integrated daily Q_i along the crop cycle and used ε_i dynamics (Figure S1) to estimate the radiation intercepted by the canopy (Q_{int}, Figure 1b), as follows:

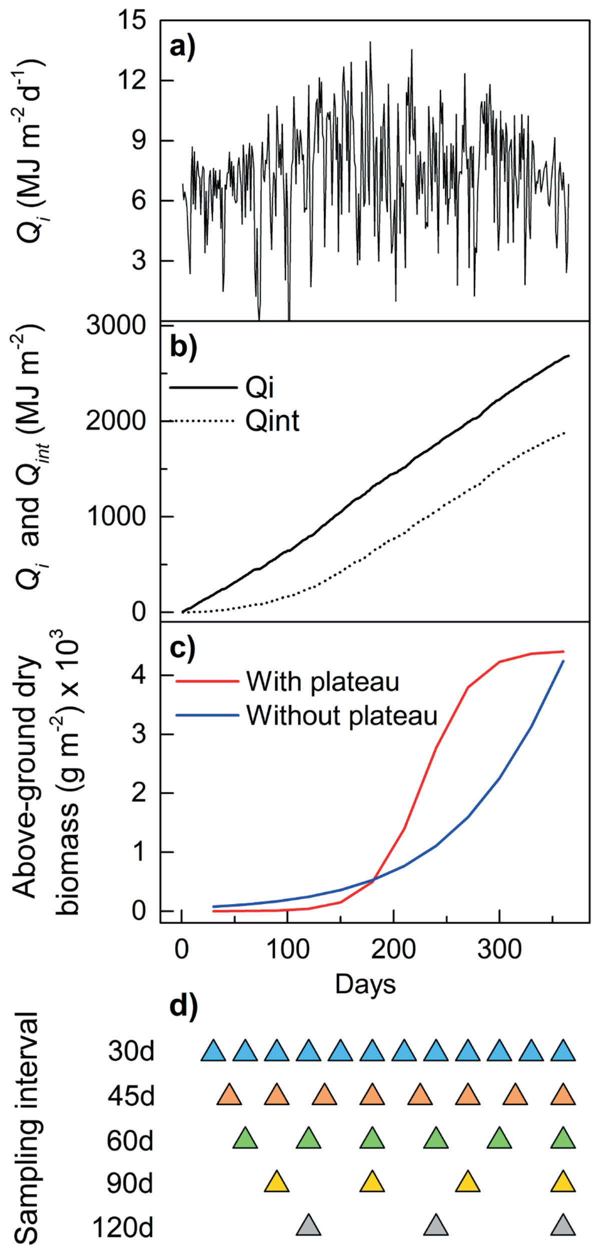

Figure 1. a) **Daily incident solar radiation (*Q_i*) along crop cycle in Campinas SP, Brazil and b) cumulative *Q_i* along the crop cycle and cumulative intercepted *Q_i* (*Q_{int}*) when considering the variation of light interception efficiency. c) Above-ground dry biomass of sugarcane estimated by a logistic function with biomass accumulation dynamics with (red) or without (blue) a plateau. In d), triangles indicate the sampling intervals of 30 (30d, in light blue), 45 (45d, in orange), 60 (60d, in green), 90 (90d, in yellow) and 120 (120d, in gray) days.**

$$Q_{int} = Q_i \times \varepsilon_i \quad (1)$$

The time course of above-ground dry biomass production by crops can be described by a logistic curve:

$$f(t) = \frac{w_{max}}{\left(1 + e^{-k \times (t - tm)}\right)} \quad (2)$$

where *f(t)* is the biomass production over time, w_{max} is the maximum dry biomass produced, *k* is the curve growth rate, *t* is the time and *tm* is the inflection point of the curve, as done by Cruz et al. (2021). At 365 days, the logistic curve can reach a plateau or not and these two situations were addressed by using two biomass accumulation dynamics: with a plateau (w_{max} = 4419 g m^{-2}, k = 0.043 d^{-1}, tm = 228 d), and without a plateau: w_{max} = 15688 g m^{-2}, k = 0.013 d^{-1}, tm = 435 d). Such model parameters were obtained from Cruz et al. (2021), which observed differences in biomass production among genotypes and due to water availability. Based on those dynamics, biomass production was estimated in intervals of 30 (30d), 45 (45d), 60 (60d), 90 (90d) and 120 (120d) days in a 365-days crop cycle (Figure 1c-d).

The ε_c was taken as the slope of the linear regression fitted to the correlation between Q_{int} and biomass along the crop cycle, using cumulative values. Firstly, we estimated ε_c for the whole cycle (ε_{co}), considering each sampling interval. Secondly, the segmented ε_c (ε_{cs}) was estimated using three consecutive evaluations of biomass production. For sampling interval 120d, only ε_{co} was estimated. Graphic representations on how ε_{co} and ε_{cs} were estimated and varied due to sampling intervals are shown in the Figure S2 – Supplementary Material.

RESULTS AND DISCUSSION

At the early growth phase of the crop cycle, sugarcane shows a slow growth (Figure 1c), which is associated with slow leaf production causing slow tillering, delayed stem elongation and low biomass accumulation (Allison et al. 2007). Such slow growth phase caused the lowest ε_{cs} values irrespective of the biomass accumulation dynamics, and we were able to notice this with sampling intervals varying between 30 and 60 days (Figure 2 and Figure S2). These sampling intervals also revealed the highest ε_{cs} values reached when plants are at the maximum growth phase, which occurred between 180 and 270 days for the biomass accumulation dynamics with a plateau and after 300 days for the dynamics without a plateau (Figure 2 and Figure S2). When evaluating the sampling interval of 90 days, the biomass accumulation dynamics differed and changes in ε_{cs} were noticed only when the dynamics does not reach a plateau (Figure S2f).

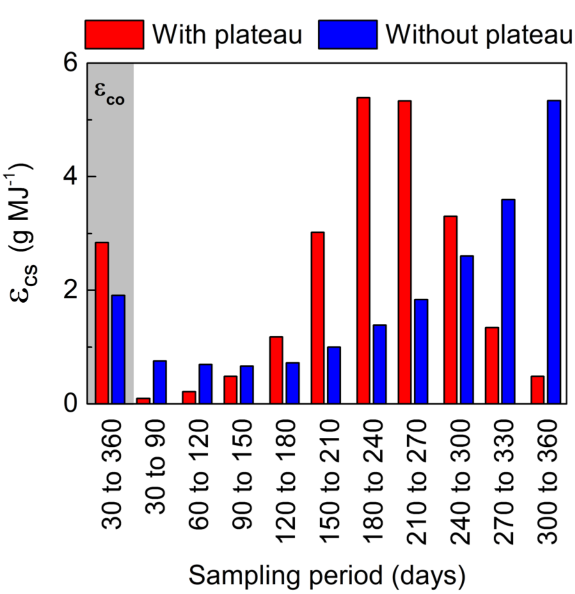

Figure 2. Light conversion efficiency estimated for the whole cycle (ε_{co}, from 30 to 360 days, gray area) and segmented along the crop cycle (ε_{cs}). We considered a sampling interval of 30 days and biomass accumulation dynamics with (red) and without (blue) a plateau.

Our analyses revealed that ε_{cs} varied between 0.09 and 5.39 g MJ^{-1} during the crop cycle, when considering both dynamics of biomass accumulation (Figure 2). Such variation is completely lost when only a single value for ε_c (ε_{co}, in our case) is estimated. For instance, the dynamics of biomass accumulation without a plateau, we have ε_{co} of 1.91 g MJ^{-1} while ε_{cs} varies in more than 8 times – between 0.66 and 5.34 g MJ^{-1}.

Overall, the sampling interval affected the estimation of ε_{co} only when considering the biomass dynamics without a plateau. Long sampling interval hidden the growth periods with low biomass accumulation, and then ε_{co} was overestimated as the sampling interval increased (Figure 3 and Figure S2b). Such overestimation was not noticed when the biomass accumulation follows a dynamics with a plateau because an additional phase of slow growth occurs at the end of crop cycle (Figure 3 and Figure S2a).

The reduced growth phenomena (RGP), a reason for the curve plateau (Figure 1c), is a decrease in biomass accumulation at the end of the crop cycle likely induced by lodging, low specific leaf nitrogen, feedback inhibition of photosynthesis by high sugar content, high respiratory demand (Park et al. 2005, van Heerden et al. 2010) or even flowering (Olivier et al. 2016). We were able to notice RGP with sampling interval varying between 30 and 60 days, with a decrease in ε_{cs} after 270 days (Figure 2 and Figure S2). Cruz et al. (2021) reported that energy cane (*Saccharum* sp. hybrid) produced tillers from rhizomes at the end of crop cycle, which maintained the biomass accumulation and then avoided RGP and the curve plateau. Such information about the occurrence of RPG cannot be accessed when only ε_{co} is estimated, suggesting that the segmented approach is an alternative to uncover environmental

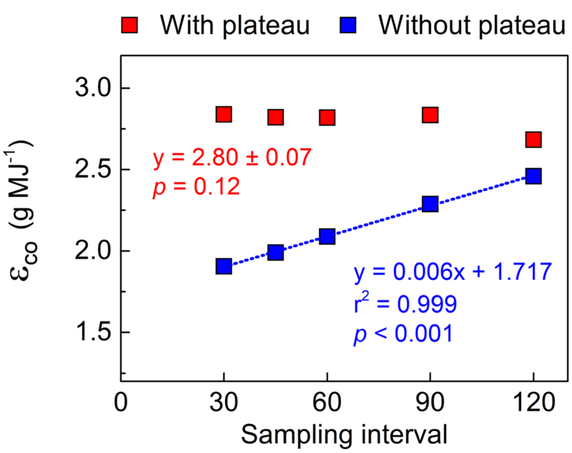

Figure 3. Light conversion efficiency estimated for the whole cycle (ε_{co}) considering each sampling interval and biomass accumulation dynamics with (red) and without (blue) a plateau. For the dynamics with a plateau, there was no significant trend and 'y' represents the mean value of ε_{co} (*n*=5) ± SD. *p* means the statistical significance of the linear regression, indicating strong evidence against the null hypothesis when < 0.05.

and physiological processes driving biomass accumulation. Consistently, the biomass accumulation dynamics without a plateau showed an increase in ε_{cs} along the crop cycle (Figure 2).

Overall, the differences between ε_{co} and ε_{cs} showed herein were also found in field experiments previously (Donaldson et al. 2008, Park et al. 2005, Cruz et al. 2021). In fact, ε_{co} is a single value summarizing the light conversion efficiency of the whole cycle and it does not reveal the variation of ε_c along the growing season, resulting in loss of information about plant development and physiological processes driving biomass accumulation, such as photosynthesis and respiration. The information about the variation of ε_c along the crop season combined with monitoring of plant physiological status and environmental conditions would provide insights about how to improve biomass accumulation during the phenological phases or periods of low ε_c through agricultural practices. Although strategies to deal with RGP had shown no positive or inconclusive results (Park et al. 2005, van Heerden et al. 2010), this is a gap to be filled by future research in crop breeding and managing (van Heerden et al. 2010). For instance, we already know that sugarcane genotypes differ in leaf nitrogen dynamics along the growing season (J.R. Magalhães Filho, unpublished data) and one would argue that extra nitrogen supply could maintain or even improve sugarcane photosynthesis (Cerqueira et al. 2019) and then avoid decreases in ε_c when leaf nitrogen imbalance is a potential cause of low ε_c.

CONCLUSIONS

Our segmented approach revealed the variation of ε_c along the crop season, which can uncover important information about how biomass accumulation is dependent on light conversion efficiency. As canopy photosynthesis and respiration are the key physiological processes determining ε_c, strategies involving biotechnology or even agricultural practices can be tested on specific phenological phases to avoid decreases in ε_c and then improve biomass production. From a practical perspective, our analyses suggest a short sampling interval (30 days) and segmentation of ε_c for capturing more insightful information about the crop dynamics in a changing environment.

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SUPPLEMENTARY MATERIAL

Figures S1, S2

How to cite

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