Evidence of photosynthetic acclimation to self-shading in sugarcane canopies


Laboratory of Plant Physiology ‘Coaracy M. Franco’, Center for Agricultural and Post-Harvest Biosystems, Agronomic Institute (IAC), Campinas, SP, Brazil*
Laboratory of Crop Physiology (LCroP), Department of Plant Biology, Institute of Biology, University of Campinas (UNICAMP), Campinas, SP, Brazil**
Center R&D in Sugarcane, IAC, Ribeirão Preto, SP, Brazil***

Abstract

Increasing the efficiency of photosynthesis in sugarcane canopies is the key for improving crop yield. Herein, we evaluated the photosynthetic performance along the canopy of ten sugarcane cultivars and three Saccharum species. Canopy morphological traits were evaluated, and leaf gas exchange was measured in the first (sun-exposed, +1) and the fourth (shaded, +4) fully expanded leaves and under low- and high-light conditions. Similar photosynthetic capacity was found in leaves +1 and +4 under high light in genotypes with a high leaf area index and a high fraction of the sky blocked by the foliage (>85%). Interestingly, such canopy characteristics cause low light availability to leaves +4, suggesting the photosynthetic acclimation of these leaves to self-shading in some genotypes. We highlight IACCTC06-8126 and CTC4 as those genotypes with higher canopy photosynthetic capacity, presenting high leaf area, high photosynthetic rates in sun-exposed leaves, and high responsiveness of shaded leaves to increasing light availability.

Keywords: light; photosynthesis; plant canopy; Saccharum spp.

Introduction

Population growth increases the demand for food and renewable energy sources, challenging global agriculture for higher yield (Ray et al. 2013, Salter et al. 2019). Sugarcane (Saccharum spp.), a C4 crop, is a promising alternative due to its high biomass and sucrose production (Waclawovsky et al. 2010). Increasing the efficiency of

Highlights

● Responsiveness of shaded leaves to light was evaluated in 13 sugarcane genotypes
● CO2 uptake varied among genotypes under varying light conditions
● IACCTC06-8126 and CTC4 have high responsiveness of shaded leaves to high light

Abbreviations: CI – intercellular CO2 concentration; DAP – days after planting; g – stomatal conductance; k – instantaneous carboxylation efficiency; Lmin – leaf light absorbance; LAI – leaf area index; MTA – mean tilt angle; PEPC – phosphoenolpyruvate carboxylase; PEPCK – phosphoenolpyruvate carboxykinase; PN – photosynthetic rate; Q – photosynthetic photon flux density; R0 – dark respiration; \( \Phi_{\text{CO2}} \) – instantaneous CO2 quantum efficiency.

Acknowledgments: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES, Finance Code 001), which also provided a scholarship to RLA (grant no. 88882.444166/2019-01). NMS is a fellow of the National Program of Post-Doctorate (PNPD, CAPES, grant no. 88882.317451/2019-01) and ECM and RVR are fellows of the National Council for Scientific and Technological Development (CNPq, Brazil) and grateful to the São Paulo Research Foundation (FAPESP, Brazil, grants no. 2019/08047-2, 2019/06161-2, and 2019/27106-0). VSP received a scholarship from CNPq, LPC from CAPES (grant no. 88887.489082/2020-00) and MTM from FAPESP (grant no. 2018/09834-5).

Conflict of interest: The authors declare that they have no conflict of interest.

Received 23 August 2022
Accepted 29 September 2022
Published online 20 October 2022

*Corresponding author
e-mail: rvr@unicamp.br
photosynthesis in plant canopy is the key to higher crop yield, and studies dealing with canopy photosynthesis or even leaves under different light exposure are limited. A large proportion of the sugarcane canopy is under low light conditions due to self-shading (Marchiori et al. 2010, 2014). Photosynthetic acclimation to light-limiting conditions has been explored in sugarcane, with plants showing a shift of the main decarboxylation pathway in bundle-sheath cells towards a higher contribution of phosphoenolpyruvate carboxykinase (PEPCK) than NADP-dependent malic enzyme to maximize the quantum efficiency of CO₂ assimilation (Sales et al. 2018).

In theory, about 6% of global solar radiation is converted into biomass by C₄ plants (Zhu et al. 2008), determining crop growth and yield (Lawlor 1995, Long et al. 2006, Marchiori et al. 2010). Light conversion efficiency in sugarcane may reach ~ 5.39 g MJ⁻¹ (Cruz et al. 2021, 2022), and such efficiency is driven by canopy photosynthesis and respiration, with high photosynthetic rates and low respiration (mainly maintenance respiration) enhancing biomass production (Zhu et al. 2010). Light interception efficiency is determined by the speed of canopy development, light absorption by leaves, longevity, size, and architecture of the canopy (Zhu et al. 2010, Davey et al. 2017), and is dependent on genotype and planting density (Robertson et al. 1996, Tejera et al. 2007). A significant proportion of canopy CO₂ assimilation occurs under light-limitation conditions caused by clouds and wind-induced leaf and plant shading (Kromdijk et al. 2016). The selection of plants more efficient in intercepting and converting light into biomass would be a way to increase crop yield in breeding programs (Lawlor 1995, Long et al. 2006, Marchiori et al. 2010).

Marchiori et al. (2010, 2014) highlighted the lack of information about the sugarcane canopy structure in breeding programs and showed that small variations in canopy architecture cause important changes in the photosynthesis of three commercial sugarcane cultivars under field conditions. Throughout the decades, sugarcane breeding programs have focused on the development of cultivars with high yields under stressful environments and resistance to pests and diseases. However, the physiological processes underlying the light-conversion efficiency and yield remain poorly understood in field-grown sugarcane plants (Zhu et al. 2010, Lopes et al. 2011, Moore et al. 2014). Recently, Almeida et al. (2021) reported a significant variation in photosynthesis among sugarcane genotypes and identified valuable and heritable photosynthetic traits. However, Almeida et al. (2021) evaluated only one fully expanded and sun-exposed leaf in sugarcane plants, as done by others (Irvine 1967, 1975; Jackson et al. 2016, Li et al. 2017). Then, an intriguing question arises: would shaded leaves have a photosynthetic capacity similar to the light-exposed leaves in field-grown sugarcane plants?

Herein, we aimed to evaluate the photosynthetic performance of light-exposed and shaded leaves of several sugarcane cultivars originated from crosses between 1948 and 2006 and three Saccharum species (S. officinarum, S. spontaneum, and S. robustum), emphasizing the effects of self-shading, leaf aging and addressing the physiological bases of such variability in photosynthetic traits.

Materials and methods

Plant material and experimental conditions: A field experiment was conducted between December 2018 and May 2019, with ten sugarcane cultivars and three species, grown under rainfed conditions (dystrophic red latosol) in Campinas, SP, Brazil (22°86’S, 47°08’W, 642 m a.s.l). Sugarcane hybrids and species, with their year of hybridization, progenitors, and institution responsible for breeding are listed in the table below. The experimental design was in randomized blocks, with four replications, each composed of six rows (11 m, spaced 1.5 m) of pre-sprouted plants spaced 0.45 m. Each plant was fertilized with 80 g P₂O₅, 133 g CaCO₃, 28 g KCl, and 34 g (NH₄)₂SO₄, following van Raij et al. (1996). Environmental conditions were continuously monitored by a weather station close to the experimental area. The air temperature was monitored with an HMP-45C probe (Vaisala, Helsinki, Finland) and rainfall with a tipping bucket rain gauge (model CS700, CampbellScientific, Logan, UT, USA). Data were recorded every

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Year</th>
<th>Progenitors</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAC48-65</td>
<td>1948</td>
<td>CP27108 × ?</td>
<td>IAC</td>
</tr>
<tr>
<td>SP70-1143</td>
<td>1970</td>
<td>IAC48-65 × ?</td>
<td>Copersucar</td>
</tr>
<tr>
<td>SP80-3280</td>
<td>1980</td>
<td>SP7-088 × H57-5028</td>
<td>Copersucar</td>
</tr>
<tr>
<td>RB83-5486</td>
<td>1983</td>
<td>L60-14 × ?</td>
<td>RIDESA</td>
</tr>
<tr>
<td>IAC87-3396</td>
<td>1987</td>
<td>SP70-1143 × Co 740</td>
<td>IAC</td>
</tr>
<tr>
<td>CTC4 (92-4221)</td>
<td>1992</td>
<td>SP83-5073 × ?</td>
<td>CTC</td>
</tr>
<tr>
<td>ICASP94-2094</td>
<td>1994</td>
<td>SP84-7017 × ?</td>
<td>IAC/Copersucar</td>
</tr>
<tr>
<td>ICASP95-5000</td>
<td>1995</td>
<td>SP84-2066 × SP80-85</td>
<td>IAC</td>
</tr>
<tr>
<td>ICASP01-5503</td>
<td>2001</td>
<td>IACSP95-2312 × CTC9</td>
<td>IAC</td>
</tr>
<tr>
<td>IACCTC06-8126</td>
<td>2006</td>
<td>IACSP95-5000 × IACSP96-6114</td>
<td>IAC</td>
</tr>
<tr>
<td>S. officinarum (Don Cico)</td>
<td></td>
<td>Noble species</td>
<td></td>
</tr>
<tr>
<td>S. spontaneum (19-95)</td>
<td></td>
<td>Wild species</td>
<td></td>
</tr>
<tr>
<td>S. robustum (NG 57-055)</td>
<td></td>
<td>Wild species</td>
<td></td>
</tr>
</tbody>
</table>
Plant canopy: Leaf area index (LAI), mean tilt angle of the foliage (MTA), and the fraction of the sky that is not blocked by the foliage (visible sky ratio – indicates the absorption of diffuse, short-wave light < 490 nm) were measured with the LI-2000C (LICOR Inc., Lincoln, NE, USA), following the manufacturer’s instructions. Photosynthetic photon flux density (Q) reaching the first (sun-exposed) and the fourth (shaded) fully expanded leaves was measured between 12:00 and 13:00 h with a linear quantum sensor (model LI-191R-BNC-2, LICOR, Lincoln, NE, USA) arranged at 90° with planting line. The first and fourth fully expanded leaves are leaf +1 and leaf +4, respectively, following the Kuijper system of leaf classification (Cheavegatti-Gianotto et al. 2011). The number of tillers per plant was also counted.

Leaf gas exchange: Leaf gas exchange was measured using a commercial infrared gas analyzer (LI-6400XT, LI-COR, NE, USA), following the manufacturer’s instructions. Photosynthesis (Pn), stomatal conductance (gs), and intercellular CO2 concentration (Ci) were measured with the LI-2000C (LICOR Inc., Lincoln, NE, USA) in +1 and +4 leaves. Measurements were taken between 8:00 and 15:00 h, under low [200 μmol(photon) m−2 s−1, at leaf +4] and high [2,000 μmol(photon) m−2 s−1, at leaf +1 and leaf +4] light intensity (Q), air CO2 partial pressure of 40 Pa, cuvette temperature of 25°C, and natural variation of air relative humidity. Data were recorded after temporal stability and when the total coefficient of variation was lower than 5%. Photosynthetic rate (Pn), stomatal conductance (gs), and intercellular CO2 concentration (Ci) were measured. Leaf light absorbance (Labs) was estimated by following the LICOR protocol ‘Estimating Light Absorbance in the 6400-40 Leaf Chamber Fluorometer Using an External Quantum Technical Sensor – Note #128’, https://licor.app.boxenterprise.net/s/9bgi9yao5y57d7dwjnts8c. We estimated the instantaneous carboxylation efficiency (k = Pn/Ci) and the instantaneous CO2 quantum efficiency [ΦCO2 = (Pn + R0)/Q × Labs] (Edwards and Baker 1993). Dark respiration (R0) was obtained from Almeida et al. (2021), and we assumed that leaves +1 and +4 have similar R0 (unpublished data).

Data analyses: The data were analyzed using Bayesian statistics and mean values were compared using the Bayes factor (BF10). when 1 < BF10 < 3, there is weak support for the alternative hypothesis (H1); 3 < BF10 < 10 indicates positive support for H1; and BF10 > 10 indicates strong support to the alternative hypothesis, following Miranda et al. (2021). Correlations between traits were evaluated through Spearman’s coefficient. All analyses were done using the R software (R Core Team 2021; version 4.1.1, R-project, packages ‘Hmisc’, ‘Corrplot’, and ‘Readxl’) and the software JASP (JASP Team 2021; version 0.15, Amsterdam, The Netherlands).

Results

Plant canopy and light availability: We found a significant variation for LAI (BF10 = 27.6), tillering (BF10 = 1.3 × 106), sky ratio (BF10 = 8.6), and light intensity reaching leaves +4 (BF10 = 956.6). IACCTC06-8126 presented the highest LAI (Fig. 1A), while S. spontaneum presented the highest tillering (Fig. 1B). For the sky ratio, IACCTC06-8126 presented lower values than that of S. spontaneum, S. officinarum, SP70-1143, IACSP01-5503, and IAC48-65 (Fig. 1C). The light intensity measured at leaves +1 (upper canopy) did not vary among genotypes and was 1,450 μmol(photon) m−2 s−1 (on average). The light availability for leaves +4 was the lowest in IACCTC06-8126 and the highest in IACSP01-5503 (Fig. 1D). For the mean tilt angle of the foliage, we found the lowest values in IACCTC06-8126 (BF10 = 6.60), with an overall variation between 38 and 63° (Fig. 2S, supplement).

Leaf gas exchange: Significant variation among genotypes was found for photosynthetic rates (Pn) measured in leaves +1 (index ‘+1’; BF10 = 7.1 × 106) and +4 (index ‘+4’, BF10 = 2.2 × 106) under high light [index ‘H’, Q = 2,000 μmol(photon) m−2 s−1] and in leaves +4 (BF10 = 1.9 × 106) under low light [index ‘L’, Q = 200 μmol(photon) m−2 s−1]. Differences between Pn+1H and Pn+4H were noticed in S. spontaneum, S. robus- tum, S. officinarum, SP80-3280, IACSP01-5503, and RB83-5486 (Fig. 2A). We found differences between Pn+1H and Pn+4L for all genotypes (Fig. 3A, supplement). In addition, gs+1H also differed between genotypes (BF10 = 69.9) while gs+1H and gs+4H did not (BF10 = 0.9 and 2.38, respectively), as shown in Figs. 2B and 3B. Differences between gs+1H and gs+4H were found for IACSP94-2094 and SP80-3280, while between gs+1H and gs+4L for IACSP94-2094 and RB83-5486 (Figs. 2B, 3B, 3S).

Significant variation was also noticed among genotypes for ΦCO2+1H, ΦCO2+4H, and ΦCO2+4L (BF10 = 9.88 × 106, 1.54 × 105, and 156.96, respectively), with differences in ΦCO2+1H between leaves +1 and +4 for S. spontaneum, S. officinarum, SP80-3280, IACSP01-5503, and RB83-5486 (Fig. 2C). There was a large variation in ΦCO2+4H among genotypes (Fig. 3C). Regarding the instantaneous carboxylation efficiency (k), differences between genotypes were found only on leaf +4 under high light (BF10 = 289.2) and variations between k+1H and k+4H were found in IACSP94-2094 (k+1H > k+4H) and SP80-3280 (k+4H < k+1H), with no variation in SP70-1143 for k+1H and k+4H (Figs. 2D, 3D).

The ratio between photosynthetic rates measured on leaves +4 and +1 under high light (Pn+4L:+4H, ΦCO2+4L:+4H, and k+4L:+4H also varied (BF10 = 3.5 × 106, 156.96, and 63.03, respectively) among genotypes, with the highest
Fig. 1. Leaf area index (LAI) (A), tillering (B), visible sky ratio – fraction of the sky that is not blocked by the foliage (C), and photosynthetic photon flux density on leaf +4 (Q) (D) of thirteen sugarcane genotypes. Different letters indicate statistical differences between genotypes (BF_{10} > 3, n = 4).

Fig. 2. Photosynthetic rate ($P_n$) (A), stomatal conductance ($g_s$) (B), instantaneous CO$_2$ quantum efficiency ($\Phi_{CO2}$) (C), and instantaneous carboxylation efficiency ($k$) (D) in leaves +1 and +4 of thirteen sugarcane genotypes under high light [index ‘H’, Q = 2,000 μmol(photon) m$^{-2}$ s$^{-1}$]. * indicates a difference between leaves +1 and +4 (BF$_{10}$ > 3, n = 4).
values measured in SP80-3280 and the lowest ones found in S. spontaneum, IACCTC06-8126, and CTC4 (Fig. 4A,D). Regarding gs+4L:+4H, only RB83-5486 differed from S. officinarum and IACSP94-2094 (BF10 = 3.31 and 6.84, respectively), as shown in Fig. 4B. Under natural conditions, leaves +4 receive less light than leaves +1 and we decided to compare the measurements taken considering such assumption (Figs. 3S, 4S, supplement). Pn+4L:+4H and ΦCO2+4L:+4H varied (BF10 = 6.7 × 103 and 6.1 × 103, respectively) among genotypes, with SP80-3280 presenting the highest mean values and S. spontaneum the lowest ones (Fig. 4A,C). IACSP01-5503 exhibited higher gs+4L:+1H than S. officinarum and RB83-5486 (Fig. 4B). IACSP94-2094 showed higher k+4L:+4H than S. spontaneum, IACCTC06-8126, and CTC4 (Fig. 4S).

Correlations: Pn+1H was correlated with Pn+4H (r = 0.62), gs+1H (r = 0.68), and ΦCO2+1H (r = 0.96). Pn+4H was positively correlated with gs+4H (r = 0.87), ΦCO2+4H (r = 0.99), k+4H (r = 0.76), and LAI (r = 0.65) (Fig. 5). Significant correlation was also observed between k+4H and ΦCO2+4H (r = 0.72), LAI (r = 0.59), and sky ratio (r = −0.60), as shown in Fig. 5. Positive correlations were noticed for Pn+4L:+4H vs. sky ratio (r = 0.60) and MTA

Fig. 3. Ratio of photosynthesis between leaves +4 and +1 (Pn+4H:+1H) of thirteen sugarcane genotypes under high light [index ‘H’, Q = 2,000 μmol(photon) m−2 s−1]. Different letters indicate statistical differences between genotypes (BF10 > 3, n = 4).

Fig. 4. Ratios of photosynthesis (Pn+4L:+4H), stomatal conductance (gs+4L:+4H), instantaneous CO2 quantum efficiency (ΦCO2+4L:+4H), and instantaneous carboxylation efficiency (k+4L:+4H) in leaf +4 of thirteen sugarcane genotypes under low [index ‘L’, Q = 200 μmol(photon) m−2 s−1] and high [index ‘H’, Q = 2,000 μmol(photon) m−2 s−1] light. Different letters indicate statistical differences between genotypes (BF10 > 3, n = 4).
Tillering correlated negatively \( (r = -0.65) \) with the mean tilt angle of the foliage (Fig. 5).

**Discussion**

We found a high genotypic variation of photosynthesis through the sugarcane canopies, with \( P_{N+1H} \) varying from 32 to 44 \( \mu \text{mol(CO}_2\text{)} \text{m}^{-2} \text{s}^{-1} \), and \( P_{N+4H} \) from 22 to 41 \( \mu \text{mol(CO}_2\text{)} \text{m}^{-2} \text{s}^{-1} \) \( (\text{Fig. 2A}) \). Such photosynthetic variability was already reported and ascribed to differences in leaf anatomy and morphology, stomatal conductance, leaf nitrogen content, and phosphoenoypyruvate carboxylase (PEPC) and Rubisco abundances and activities \( (\text{Irvine 1967, 1975, 1983; Marchiori et al. 2010, 2014; Jackson et al. 2016, Li et al. 2017, Almeida et al. 2021}) \).

As a novelty, our data revealed that some sugarcane canopies have similar \( P_N \) in leaves +1 and +4 \( (\text{IACCTC06-8126, IACSP95-5000, IAC87-3396, SP70-1143, IACSP94-2094, CTC4, and IAC48-65}) \) while others have leaf +1 with higher \( P_N \) than that of leaf +4 \( (\text{S. spontaneum, S. robustum, S. officinarum, SP80-3280, IACSP01-5503, and RB83-5486}) \) under high light \( (\text{Fig. 2A}) \). \( P_N \) was similar in leaves +1 and +4 in sugarcane canopies with high leaf area index and a high fraction of the sky blocked by the foliage, with planophile-like leaves \( (\text{Figs. 1A,C, 2A, 5, and 2S}) \). Such similar photosynthetic performance between shaded (leaf +4) and light-exposed leaves (+1) would be a consequence of increasing photosynthetic nitrogen-use efficiency, instantaneous CO\(_2\) quantum efficiency \( (\text{as shown herein, Fig. 2C}) \), and the maintenance of Rubisco activity \( (\text{Marchiori et al. 2014}) \) in leaves +4.

While upper leaves are usually exposed to direct solar radiation, those located inside the canopy intercept diffuse light or sun flecks \( (\text{short periods of direct solar radiation inside the canopy}) \), being progressively shaded by new leaves \( (\text{Bellasio and Griffiths 2014}) \). Acclimation processes to low light would increase light-use efficiency and then photosynthesis of shaded leaves or those at the bottom canopy positions, enhancing the amount of CO\(_2\) fixed by the entire canopy. Ideally, a canopy would have \((1)\) top leaves with high photosynthetic rates, \((2)\) small photosynthetic differences between top and bottom leaves under the same light intensity, and \((3)\) bottom leaves photosynthesizing close to the maximum even under low light intensity. While such an ideotype looks most hypothetical, we were able to find genotypes with interesting characteristics. Under high light, \( \text{S. spontaneum, S. robustum, S. officinarum, SP80-3280, IACSP01-5503, and RB83-5486} \) presented the highest \( P_N \) and \( \Phi_{CO2} \) in leaves +1, i.e., at the upper canopy position, as compared to leaves +4 \( (\text{Fig. 2A,C}) \). On the other hand, \( \text{IACCTC06-8126, IACSP95-5000, IAC87-3396, SP70-1143, IACSP94-2094, CTC4, and IAC48-65} \) had similar \( P_N \) and \( \Phi_{CO2} \) in leaves +1 and +4 under high light, with \( \text{IACCTC06-8126} \) presenting higher values for sky ratio, low light availability at leaf +4, and the lowest mean tilt angle \( (\text{Figs. 1C,D, 2S}) \). Among the biochemical changes underlying shade acclimation of photosynthetic apparatus in leaves +4, we would suggest increases in activity and abundance of PEPC and Rubisco, pyruvate orthophosphate dikinase, NADP-dependent malate dehydrogenase, and phosphoenolpyruvate carboxykinase \( (\text{Sales et al. 2018, Almeida et al. 2021, Jaikumar et al.}) \).
acclimation and instantaneous CO₂ studies identified a relationship between photosynthetic visible sky ratio and MTA (Fig. 5), canopy traits that was correlated positively with LAI and negatively with PA showing the lowest photosynthesis in leaves +4 (Fig. 2). During sun flecks and then canopy photosynthesis (leaves under high light would improve photosynthesis due to high gs, area. Instead, such acclimation aims to increase canopy photosynthesis, higher canopy photosynthetic capacity due to high leaf area, high photosynthetic rate of light-exposed leaves, even with light intensity commonly being less than 25% of reaching light-exposed ones. Our data highlights IACCTC06-8126 and CTC4 as those genotypes with higher canopy photosynthetic capacity due to high leaf area, high photosynthetic rate of light-exposed leaves, and high responsiveness of photosynthesis to high light in shaded leaves, contrasting with S. officinarum and SP80-3280.

While S. officinarum and SP80-3280 – genotypes showing the lowest photosynthesis in leaves +4 (Fig. 2A) – presented less responsiveness of PS, ΦCO₂, and k to light, the most light-responsive genotypes were S. spontaneum, CTC4, and IACCTC06-8126 (Fig. 4A,C,D). This reinforces that the light acclimation of photosynthesis – which means that shaded leaves can carry on photosynthesis like sun-exposed ones if the light is available – and photosynthetic responsiveness to light are linked.

The commercial cultivars developed by breeding programs are inter- or intraspecific hybrids (crosses of S. officinarum, S. spontaneum, S. robustum, and S. barberi) derived mainly from the crossing of the noble species S. officinarum (~ 70–80%) and the wild species S. spontaneum (~ 10–20%) (Moore et al. 2014). As high heritability for photosynthesis and stomatal conductance in sugarcane has been reported by Jackson et al. (2016), Li et al. (2017), and Almeida et al. (2021) and there is significant variation in photosynthesis of both light-exposed and shaded leaves reported herein, our data indicate that there is room for improving canopy photosynthesis through breeding. Sugarcane plants with erectophile-like leaves at the upper canopy layer that allows light penetration (Marchiori et al. 2014) and planophile-like leaves at bottom canopy positions (Slattery et al. 2016, Walker et al. 2018), with high photosynthetic capacity due to shading acclimation, would have a phenotype favoring higher conversion of sunlight energy into biomass.

S. officinarum stands out for the high sucrose (up to 25% on stalk fresh mass) and low fiber content in the culms. On the other hand, S. spontaneum presents a higher photosynthetic rate, lower accumulation of sucrose (~ 2% of stalk fresh mass), vigorous growth, tillering, and higher resistance to abiotic and biotic stresses, compared to S. officinarum (Irvine 1975, Moore et al. 2014). Herein, our data highlighted the superiority of S. spontaneum for tillering and photosynthesis, fixing about 13% (leaf +1) to 43% (leaf +4) more CO₂ than S. officinarum under high light (Fig. 2A). Such high photosynthetic activity would boost biomass production through breeding for the development of improved sugarcane or energy cane varieties (Cruz et al. 2021), as the heritability of photosynthetic traits is high (Jackson et al. 2016, Li et al. 2017, Almeida et al. 2021).

Conclusion: This study revealed a significant photosynthetic variation in light-exposed and shaded leaves in canopies of Saccharum complex, indicating acclimation of shaded leaves towards the maintenance of photosynthetic performance in some sugarcane cultivars and species. This way, shaded leaves are responsive to high and present photosynthetic rates similar to light-exposed leaves, even with light intensity commonly being less than 25% of reaching light-exposed ones. Our data highlights IACCTC06-8126 and CTC4 as those genotypes with higher canopy photosynthetic capacity due to high leaf area, high photosynthetic rate of light-exposed leaves, and high responsiveness of photosynthesis to high light in shaded leaves, contrasting with S. officinarum and SP80-3280.

References

Irvine J.E.: Photosynthesis in sugarcane varieties under field conditions. – Crop Sci. 7: 297-300, 1967.


© The authors. This is an open access article distributed under the terms of the Creative Commons BY-NC-ND Licence.