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A new paradigm in leaf-level photosynthesis: direct and diffuse lights are not equal

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Introduction

- Various climate-change models have predicted future increases in diffuse light due to elevated atmospheric water vapour due to increased cloud cover.
- Plants usually experience wide variation in the directional quality of incident light in their natural environment.
- Direct and diffuse light affect photosynthetic processes differently from the leaf to landscape.

Introduction

- To the best of our knowledge no information is available about the relative ability of individual leaves to utilize direct versus diffuse light for photosynthesis.
- Previous research describing anatomical features adapted for direct light, suggest that different leaf-level photosynthetic responses to direct and diffuse light may exist.
- Here we present results that suggest that to leaves, direct and diffuse light are not equal.

Materials and Methods

- Greenhouse growth conditions

C_3

C_4

One group of plants was grown with supplemental lighting (400 W HPS lamps) and a second group was grown without supplemental lighting.

Materials and Methods

- Gas-change measurements

➢ Six different light-response curves were measured for plants in each group, using a different plant for each measurement, under both direct and diffuse light using an LI-6400 portable photosynthesis system.

➢ These irradiances were then corrected for the amount of light actually absorbed by the leaf, as measured using an integrating sphere system to determine the reflectance and transmittance of direct and diffuse light as described in Brodersen & Vogelmann (2007).

Materials and Methods

- Direct and diffuse lighting for gas-exchange measurements

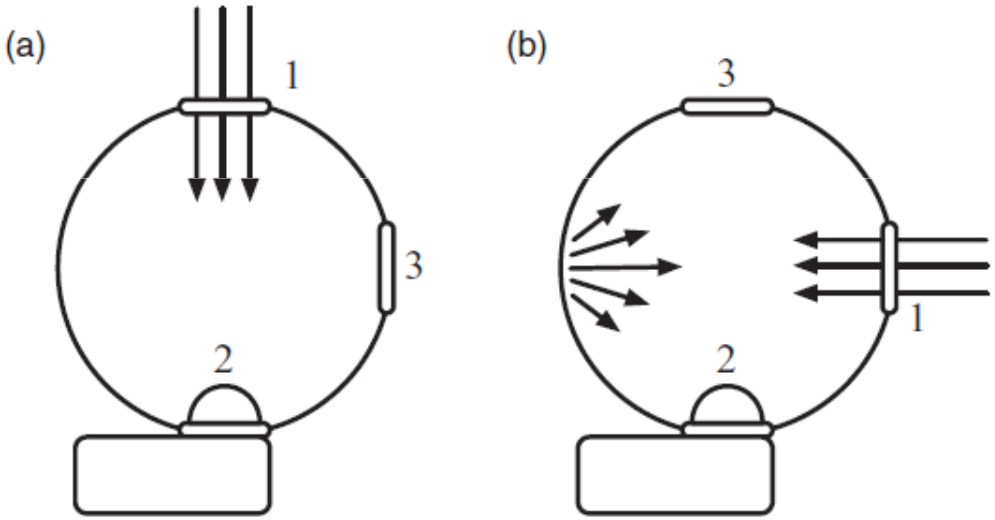


Figure 1. Configuration of light source and an integrating sphere to irradiate leaves with direct or diffuse light for photosynthesis. (a) Direct light consisted of a collimated beam that entered an integrating sphere through an open port (1) and passed directly through the sphere to chamber head (2) of a LI-6400 where a leaf was mounted perpendicular to the beam. (b) Diffuse light was created by directing collimated light through a port (1) on the equator of the sphere where it struck the interior wall and then was multiply scattered within the sphere to create a diffuse radiation field on a leaf in the LI-6400 chamber (2). Ports (3) were closed with reflective covers when not in use.

Materials and Methods

- Direct and diffuse lighting for gas-exchange measurements

➢ They used a single optical fibre glued into the eye of a needle that was mounted on-axis at the end of a metal rod attached to the centre of a calibrated rotation stage.

➢ They recorded the signal every 5 degrees as we rotated the fibre through 180 degrees, from horizontal, through vertical, and back to horizontal. They repeated the measurements with the fibre oriented perpendicular to its original orientation, again rotating it from horizontal, through vertical, and back to horizontal.

Materials and Methods

- Microscopy

➢ Leaf anatomical measurements were made from images of three cross sections taken from three leaves from each plant using image-analysis software.

Results

- Characterization of light sources

➢ During plant growth, the direct: diffuse ratios as measured with the BF3 sensor for the high-light and low-light treatments were 0.31 and 0.21 (at 1030 h) and 1.03 and 0.40 (at 1600 h).

➢ Measurements made with an optical fibre indicated that angle of the cone of light striking the leaf surface from the direct light source was 22° at half maximum intensity; the corresponding angle for the diffuse light from the integrating sphere was 105°.

Results

- Characterization of light sources

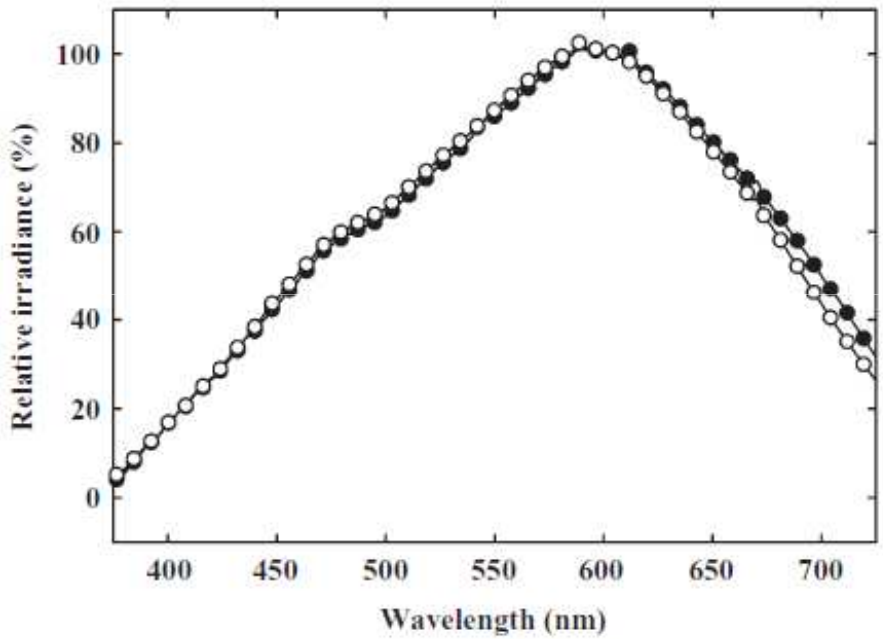
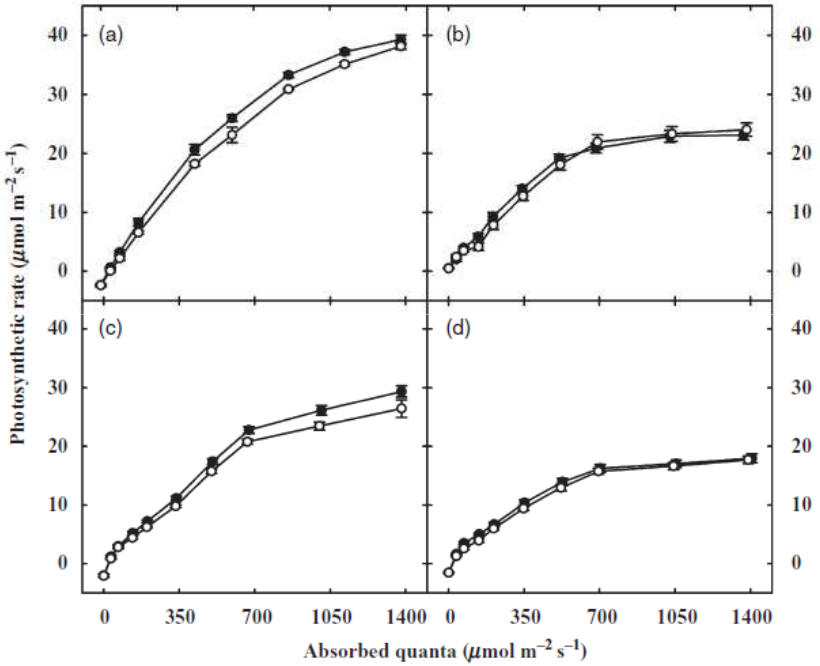


Figure 2. Spectral analysis of the direct (closed symbols) and diffuse (open symbols) light sources used in the photosynthetic light response measurements. Spectra were normalized at 605 nm.

Spectral quality analysis of the direct and diffuse light sources yielded nearly identical data from 400 to 650 nm (Fig. 2). The diffuse light source showed a slight enrichment in wavelengths beyond 650 nm.

Results

- Photosynthesis measurements



When lants were neither light-limited nor lightinhibited (500–1000 mmol m^{-2} s^{-1} PPFD), there was a clear preference for direct light (Fig. 3a,c). Plants grown in low light showed no significant difference photosynthetically when illuminated with direct or diffuse light regardless of irradiance: the differences observed in high-light plants disappeared (Fig. 3b,d).

Figure 3. Photosynthetic response to direct and diffuse light for (a) *Helianthus annuus* under direct (closed symbols) and diffuse (open symbols) light grown with supplemental lighting; (b) *H. annuus* under direct (closed symbols) and diffuse (open symbols) light grown without supplemental lighting; (c) *Amaranthus retroflexus* under direct (closed symbols) and diffuse (open symbols) light grown with supplemental lighting; (d) *A. retroflexus* under direct (closed symbols) and diffuse (open symbols) light grown without supplemental lighting.

Results

- Microscopy

➢ Palisade layers were significantly thicker in both species when grown with supplemental lighting, and high-light-grown *H. annuus* had a double palisade layer, which is typical of leaves grown in high light.

Table 1. Leaf morphology differences between plants grown with and without supplemental light

	Leaf thickness	Palisade thickness	Mesophyll thickness
Helianthus annuus +	288.2*	161.3*	112.9
H. annuus –	225.8	92.3	106.4
Amaranthus retroflexus +	206.1	52.1*	109.1*
A. retroflexus –	179.3	46.7	80.2

Discussion

- Leaves grown under supplemental high light developed sun-leaf characteristics, with thicker palisade than leaves grown under low light.
- The higher irradiance during growth, rather than a difference in the directional quality of the growth irradiance, appears to have led to the formation of leaves that were predisposed to use direct light more efficiently than diffuse light.
- Photoinhibition may also contribute to the differences in photosynthesis under direct and diffuse light.

Discussion

- There was a small enrichment of far-red light in our diffuse light source but otherwise the spectral quality was very similar to the direct light used in experiments.
- The angle at which light reaches a canopy has long been recognized as an important characteristic of light interception.
- While previous research has shown increases in productivity at the community level under diffuse light, we have shown that leaf-level photosynthetic rates can go in the opposite direction.


Thank You~