Using leaflet heliotropic movements and 3D virtual soybean plants to simulate daily photosynthesis

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Abstract
The leaf area index (LAI) and the characteristics of leaf arrangement through the plant canopy, such as inclination, azimuth, orientation and spatial distribution, strongly affect light interception and photosynthesis. Some species also show complex daily heliotropic adjustments of leaf angles. The ecophysiological significance of heliotropism is related to plant and canopy processes, such as leaf energy balance, transpiration, photosynthetic carbon gain, photoinhibition, and UVB effects mitigation. Paraheliotropism (avoiding direct sunlight) can reduce transpiration losses by diminishing light interception. Diaheliotropism (solar tracking) can increase diurnal carbon gain in low LAI canopies, and reduce carbon gain in high LAI canopies. The aim of this study was to relate the heliotropic movements of two soybean cultivars (BR 16 and Embrapa 48) to photosynthesis (A) on a daily scale through 3D simulations. The soybean cultivars were grown in field under two water regimes. Leaflet movements and physiological parameters were measured in three stages: V4-V6 (low LAI), V7-V10 (mid LAI) and R5 (high LAI) on central leaflets of upper trifoliates of 40 plants. The plants were codified and reconstructed in VPlants. The MTG's were decomposed in three scales (plants, stems and internodes) and were written to recognize the length and angles of stems and petioles, and the length/width/inclination of central and lateral leaflets. The phyllotaxy of 180° was attributed to distichous leaves and of 121.25° to spirally arranged trifoliates. Various scenarios of the upper trifoliate leaflet angles (elevation and rotation to x-axis), dark respiration, maximum rate of carboxylation (V_{cmax}) and potential rate of electron transport (J_{max}) were performed to correct simulations of midday leaf A (computed in VegeSTAR) to measured values. Successful scenarios were used for subsequent plant and canopy simulations of daily photosynthesis. Compared to BR 16, higher paraheliotropic activity of Embrapa 48 led to whole season lower leaf area, and lower leaf A especially under low LAI, but to a more efficient A in high LAI, even under water stress.

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INTRODUCTION AND AIMS

The leaf area index (LAI) and the characteristics of leaf arrangement through the plant canopy, such as inclination, azimuth, orientation and spatial distribution, strongly affect light interception and photosynthesis (Ross *et al.*, 1999). Some species also show the complex daily heliotropic adjustments of leaf angles. The ecophysiological significance of heliotropism is related to the plant and canopy functioning, as leaf energy balance, transpiration, photosynthetic carbon gain, photoinhibition (Kao and Tsai, 1998), or mitigation of UVB effects (Bawhey *et al.*, 2003). Paraheliotropism (*avoiding direct sunlight*) can reduce transpiration losses by diminishing light interception. Diaheliotropism (solar *tracking*) can increase diurnal carbon gain in low LAI canopies, and reduce carbon gain in high LAI canopies.

The aim of this study was to relate the heliotropic movements of two soybean cultivars (BR 16 and Embrapa 48) to photosynthesis (*A*) on a daily scale through 3D simulations.

MATERIAL AND METHODS

- Cv. 'BR 16' and cv. 'Embrapa 48', with and without **irrigation**;
- leaflet movements (cosine of the angle of incidence) and ecophysiological parameters were measured in three **stages**:
  - V4-V6 (low LAI, 0.52-1.06),
  - V7-V10 (mid LAI, 2.59-4.72) and
  - R5 (high LAI, 4.65-7.28)

  on central leaflets of upper trifoliates.
- 40 plants codified and reconstructed in **VPlants**;
- MTG's were written to recognize the length and angles of stems and petioles, and the length/width/inclination of central and lateral leaflets;
- Phyllotaxy of 180° was attributed to *distichous* leaves and of 121.25° to spirally arranged trifoliates;
- Leaf **photosynthesis** (*A*) measured on central leaflets of upper trifoliates (~midday - 10h15-11h15.);
- **VegeSTAR** – estimations of leaf and plant photosynthesis.

RESULTS AND DISCUSSION

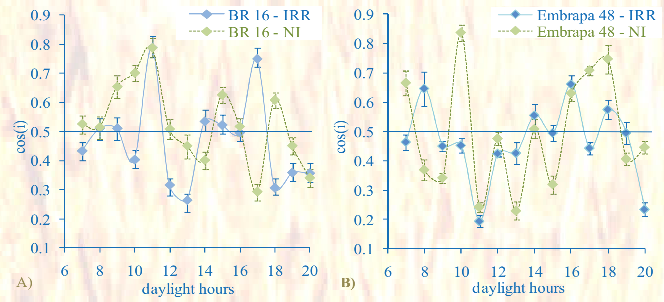

Figure 1. Example of diurnal courses of cosine of the angle of incidence - cos(i) of central leaflets in upper leaves of two soybean cultivars: A) 'BR 16' and B) 'Embrapa 48', grown under irrigation (IRR) and without irrigation (NI) measured at stage R5. The line for cosine = 0.5, as a division between paraheliotropic and diaheliotropic responses, is indicated.

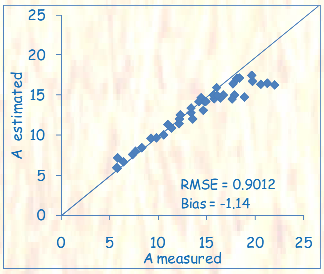

Figure 3. Comparison of leaf photosynthesis (A) between measured and estimated values of central leaflets of upper trifoliates for R5. The bias, root mean square error (RMSE) values and 1:1 line are indicated.

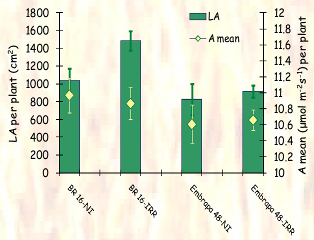

Figure 4. Plant leaf area (*LA* - cm^{-2}) and average photosynthesis of all plant leaves (*A mean* - µmolCO_2 $m^{-2}s^{-1}$) for R5.

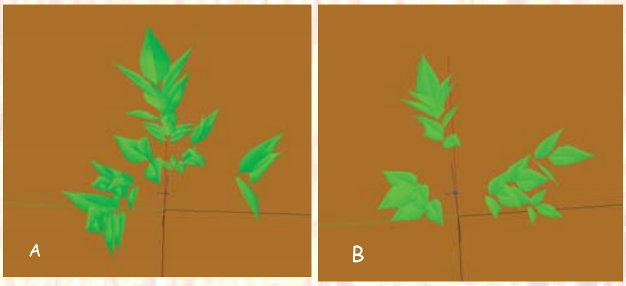

Figure 2. Reconstructions (PlantGLViewer) of the midday leaflet positions of two soybean cultivars: A) 'Embrapa 48' grown without irrigation and B) 'BR 16' grown under irrigation. The example for R5.

Various scenarios of the upper trifoliate leaflet angles, and whole plant angulations (elevation and rotation to x-axis) were created (Figure 2). They were used to estimate the midday *A* (computed in VegeSTAR). The dark respiration was computed according to Thomas and Griffin (1994). The maximum rate of carboxylation (V_{cmax}) and the potential rate of electron transport (J_{max}) were computed according to Wohlfahrt *et al.* (1999).

The comparison of measured and estimated values for R5 are shown in Figure 3. The average *A* estimated on central leaflet was slightly underestimated. Compared to BR 16, higher paraheliotropic activity of Embrapa 48 (Figure 1) led to whole season lower leaf area, and lower *A*, but to a more efficient carbon gain in high LAI, even under water stress (Figure 4).

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