Optimal photosynthetic nitrogen partitioning in cucumber leaves for maximizing canopy photosynthesis

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Introduction

In response to considerable variation in light intensity within the canopy, the partitioning of nitrogen (N) to various photosynthetic functions should vary to achieve efficient utilization of light. Here, photosynthetic N partitioning (PNP) is defined as optimum when the whole canopy photosynthesis is maximized. The objective of this work is to identify the optimal PNP in cucumber leaves as dependent on light conditions, and to determine the discrepancy between actual and optimum at both leaf and canopy level.

Materials and Methods

Cucumber cv. 'Aramon' was grown hydroponically in a growth chamber to determine the empirical PNP (ENP). Twenty-four leaves, which had been positioned perpendicularly to constant light intensities ranging from 5-40 mol m^{-2} d^{-1} daily photon irradiance (DPI). The PNP of these leaves was determined based on Niinemets and Tenhunen (1997) and Buckley et al., (2013). PNP fractions for carboxylation (f_v) and electron transport (f_j) were calculated from their maximum rates, V_{cmax} and J_{max}, respectively. The fraction in light harvesting (f_c) was calculated from leaf chlorophyll content. f_v and f_j were described depending on DPI using monomolecular functions with three parameters, $f_{x,max}$, d_x and a_x:

$$f_x = f_{x,max}[1 - d_x \times exp(-a_x \times I_d)] \quad (1)$$

f_c was calculated as:

$$f_c = 1 - f_v - f_j \quad (2)$$

To test the optimal PNP, a multi-layer model representing a canopy with 25 layers was constructed to simulate daily canopy CO_2 assimilation (DCA) depending on PNP in each layer and DPI above the canopy. Each layer was different in leaf area, specific leaf area, N content, local light intensity (I_d) and PNP, which is used to determine the photosynthetic variables, V_{cmax}, J_{max} and chlorophyll content, in the layer. Layer structural characteristics and total N content were determined by a greenhouse experiment. PNP was calculated by Eqn 1 and 2 depending on I_d, which was simulated for each layer in the canopy using Lambert-Beer law. The diurnal irradiance above the canopy was simulated by a simple cosine bell function (Kimball and Bellamy, 1986).

Using this model, the dependency of DCA on DPI above the canopy (5-50 mol m^{-2} d^{-1}) was simulated and compared between ENP, the theoretically optimal PNP (TNP) proposed by Buckley et al., (2013), and several different optimal PNP patterns. These optimal PNP patterns were derived from ENP by changing the three parameters in Eqn 1 by which maximum DCA was obtained under a given DPI above the canopy. The variation of the parameters were constrained between 0 and two-fold of the original values in ENP functions.

Results and Discussion

DCA simulated with TNP is up to 16 % higher than ENP under various DPI above the canopy. This suggests that developmental acclimation of PNP to light intensity in cucumber cv. 'Aramon' is not optimal. f_v of ENP is higher and f_j of ENP is lower than those of TNP throughout the whole range of I_d, suggesting that N might be over-invested in carboxylation and under-invested in electron transport .

With the optimal PNP patterns derived from ENP, up to 20 % DCA can be theoretically increased over the typical light regimes in the greenhouse. To improve PNP in cucumber leaves, a higher proportion of photosynthetic N should be invested into electron transport instead of into carboxylation under low I_d, while under high I_d, more photosynthetic N should be partitioned into electron transport instead of into light harvesting function. In the actual canopy, chlorophyll content is higher than optimum throughout the canopy. V_{cmax} exceeds optimum below middle layers, while V_{cmax} and J_{max} are both considerably lower than optimum in the upper layer.

Conclusions

20 % higher DCA could be obtained with optimal PNP. At leaf level, a higher proportion of photosynthetic N should be partitioned into electron transport from carboxylation and light harvesting functions. At canopy level, photosynthetic variables are not optimal. In the upper canopy, a higher proportion of photosynthetic N should be partitioned from light harvesting to carboxylation and electron transport. Below middle canopy, a higher proportion of photosynthetic N should be partitioned from light harvesting and carboxylation to electron transport.

Acknowledgements

Many thanks to Ilona Napp, Marlies Lehmann, and Dr. Dany Pascal Moualeu.

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