Efficiency of Light Energy Used by Leaves Situated in Different Levels of a Sweet Pepper Canopy

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Abstract

In order to make the most use of the available light in glasshouse crops, measurements of light penetration, leaf photosynthesis, respiration and transpiration were performed at five levels in a sweet paper canopy at two commercial farms, from July to November 2004. Light response curves of leaf photosynthesis showed that photosynthesis, transpiration respiration decreased from top to bottom in the canopy. These reductions in gas exchange lower in the canopy likely result from adaptation to lower ambient light conditions as well as leaf aging. At a low light intensity of 50 µmol m^{-2} s^{-1} above the canopy, the net photosynthesis in the top 25% of the leaves (2 m^2 m^{-2}) was positive, while at a higher light irradiance, 200 µmol m^{-2} s^{-1}, the top 50% (4 m^2 m^{-2}) was positive. From the middle of August onwards, the net photosynthesis of the lower half of the crop was negative. Based on these measurements, the contribution of each leaf level to the net crop photosynthesis and transpiration was calculated. On an annual basis, the lower half of the crop made a 0.5% negative contribution to net photosynthesis, while making a 10% positive contribution to crop transpiration. Thus, removal of leaves from the lower levels might increase the efficiency of energy utilization. In this contribution, participation of leaves from different part of the canopy in crop photosynthesis and transpiration were quantified and discussed in relation to growth, production and energy utilization.

INTRODUCTION

Sweet pepper crops are characterized by a large leaf area which increases continuously throughout the growing season and can result in a large leaf area index (up to LAI 8). Leaves in the upper canopy layer contribute the most to net photosynthesis. Lower leaf levels are less able to contribute to crop photosynthesis due to limited light penetration. If the stomata still remain open transpiration may well continue, even in reduced light conditions, increasing the humidity in the glasshouse. Excessive humidity is often regulated through ventilation. Thus optimizing the aerial environment regulates the cost of energy. In order to conserve energy in glasshouse crops, additional means of realizing reductions in crop transpiration and thus air humidity are also being examined. One possibility may be to reduce a portion of the leaf biomass in the crop (Adams et al., 2002) and the challenge is to achieve this without the loss of production or an increase in disease, and while maintaining fruit quality.

It is plausible that because leaves in the lower canopy levels are thought to have a low rate of assimilation, but possibly with a relatively high rate of transpiration, the removal of some the lower leaves might result in the conservation of energy. Whether or not crop production can also be maintained remains to be seen. Leaf removal might reduce photosynthesis and growth and thus lead to loss of production, but may also lead to increased production as a result of decreased maintenance respiration (Wolk et al., 1983).

In an attempt to assess the contribution of the various leaf layers in a sweet pepper crop to production and possibly energy conservation, measurements of photosynthesis and transpiration were performed at two sweet pepper farms. The contribution of the different leaf layers in the canopy to crop photosynthesis and transpiration were quantified and discussed in relation to growth, production and energy utilization.

MATERIALS AND METHODS

Measurements on light penetration, photosynthesis and transpiration were performed at two farms growing sweet pepper (cv Ferrari) located in the vicinity of each other. Both pepper crops were started in December 2003 and measurements were performed in July and September 2004.

Light penetration measurements at five levels in the crop were performed at each farm during a two-day period with a SunScan canopy analysis system (Delta-T). The amount of photosynthetically active radiation (PAR) measured at the four lower levels was compared to the PAR at the top of the canopy. The LAI was assumed to be evenly distributed in a vertical direction in the crop. Each leaf level at which photosynthesis and transpiration measurements were performed represents a portion of the total leaf area as indicated in Table 1.

The photosynthesis and transpiration measurements at each farm performed in July and September 2004, took place during a three-day period with a portable LCpro ADC. Light-response measurements at each of the five crop levels were performed at seven light levels varying from 0 to 330 W m^{-2} (0 to1500 µmol m^{-2} s^{-1}) at about 22 °C, 400 ppm CO_2 and 60% to 80% RH in the leaf cuvet.

In order to estimate canopy photosynthesis and transpiration, the following methology was used: (1) the development of the LAI in the course of the growing season was taken from earlier representative measurements for sweet pepper, reaching a maximum of LAI 8; (2) the hourly light levels (global radiation) at the top of the canopy from July through October were taken from an average year, and (3) the theoretical curve for light interception according to Lambert-Beer was used for the expected LAI mentioned above. These three points were combined to calculate the light levels in each of five crop levels throughout the growing season. The light-response curves measured at each level in the crop in July and September (average of both farms), together with the amount of light penetrating to each level and the leaf area, were used to calculate the hourly net photosynthesis and transpiration for each of the five levels in the crop. These were summed to daily (24 hour) values.

RESULTS AND DISCUSSION

Some degree of difference in light interception existed between the two crops only at 75% crop height in July (Fig. 1), implying that light in one of the crops penetrated deeper into the canopy. The difference at the other heights in the crops in July, and at all heights in September were very small. Most of the light (90%) was intercepted at 50% crop height in July, but in September 90% of the light had already been intercepted at 60% crop height, due to an increased LAI. Light interception curves in sweet pepper at both farms are very similar to the theoretical curve (exponential reduction), the solid line in Fig. 1 according to the Lambert-Beer Law (Monsi and Saeki, 1953) with an extinction coefficient (k) of 0.75.

The results of the net photosynthesis and transpiration measurements at both sweet pepper farms were similar, and the results of one of the crops for July and September, 2004 are given in Fig. 2. In July, the light response curves for net photosynthesis measured in the highest canopy level (levels 4 and 5), were as expected. The contribution of the lower levels to photosynthesis, however, was significantly reduced; leaf levels 1 to 3 yielding only 2-4 µmol CO_2 m^{-2} s^{-1} even at the highest light intensity. In September, with a barely positive balance, photosynthesis in leaf level 4 was also strongly reduced, while in leaf levels 1 to 3 a negative net photosynthesis (reduced respiration) was observed. No measurements were performed in September at light levels above 50 W m^{-2} because these light intensities were not measured in the lower levels of either crop.

In contrast to the net photosynthesis, transpiration in the lower levels of the sweet pepper crops did not decrease in the course of the growing season. The transpiration in September was reduced compared to the July measurements, but even at lower light intensities, the lower leaf layers yielded a considerable amount of the total crop transpiration. This indicates that the stomata remain open and that the reduction in net photosynthesis is not caused by stomata closure, but some other internal regulation.

Based on the measured net photosynthesis and transpiration in July and September in combination with the global radiation taken from an average year and the estimated LAI, the net photosynthesis and transpiration was estimated for the months July through October. The contribution of each of the leaf levels to crop net photosynthesis and transpiration was thus calculated and is shown in Fig. 3.

The net photosynthesis at each leaf level was well related to the light reaching it, and decreased (especially in the top leaf level) with naturally decreasing light intensity in the course of the growing season. The net photosynthesis in the highest leaf level started at almost 800 mmol CO_2 m^{-2} leaf area day^{-1} and decreased to 300 mmol CO_2 in October. Photosynthesis in the fourth leaf layer began just below 200 mmol CO_2 m^{-2} leaf area day^{-1} and decreased until middle of September when almost no net assimilation took place. These observations are supported by Acock et al. (1978), who found that the uppermost third of a tomato canopy accounted for 23% of the total leaf area and assimilated 66% of the net CO_2 fixed by the canopy. The lowest three leaf levels contributed very little to crop photosynthesis, less than 50 mmol CO_2 m^{-2} leaf area day^{-1} and even became negative from early September onwards. Calculated for the months August to October, the lower half of the crop had a 2% negative contribution on crop photosynthesis and on an annual basis 0.5%.

Like photosynthesis, crop transpiration was highest in the upper leaf layer, varying from 160 to 110 mmol water m^{-2} leaves day^{-1} during July through October (Fig. 3). Averaged over the months August to October, this leaf level contributed by 34% to the total crop transpiration (Table 2). While the lower leaf levels transpired significantly less water, transpiration declined only slightly from July through October. This also resulted in a considerable amount of water transpired; averaged over the last three months the lower three leaf levels contributed 36% of the crop transpiration. On an annual basis, these leaf levels contributed 10% of the crop transpiration.

The functioning of the lower leaf levels may be improved by supplemental lighting situated deeper in the crop, or by increasing the distance between stems in a row (Adams et al., 2002). Another means of improving production and reducing the need for ventilation may be sought in removal of the lower leaves. Others have shown that ca. 50% of the older leaves can be removed in tomato without yield loss (Stacey, 1983; Wolk et al., 1983). Heuvelink et al. (2005) suggested that removal of young leaves in tomato might favour assimilate partitioning to fruits, thus increasing production. The results of this study indicate that leaf removal may be advantageous from August onwards. This is concurred by Adams et al. (2002), who considered that it might be detrimental to remove too many leaves in tomato early in the season (there is still sufficient light in the lower part of the canopy to contribute to photosynthesis), but later in the season could reduce water usage and thus transpiration.

ACKNOWLEDGEMENTS

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Tables

Table 1. Crop height at which measurements were performed and the thickness of each leaf layer to which the measurements apply.

	Canopy level				
	1	2	3	4	5
Measurement height	10%	30%	50%	75%	100%
Proportion of canopy	20%	20%	22.5%	25%	12.5%

Table 2. Calculated relative contribution (%) of each leaf layer to the net photosynthesis and transpiration of the whole crop. Averaged over August through October.

	Canopy level				
	1	2	3	4	5
Photosynthesis	-0.3	0.2	-2.0	12.2	89.9
Transpiration	11	9	17	29	34

Figures

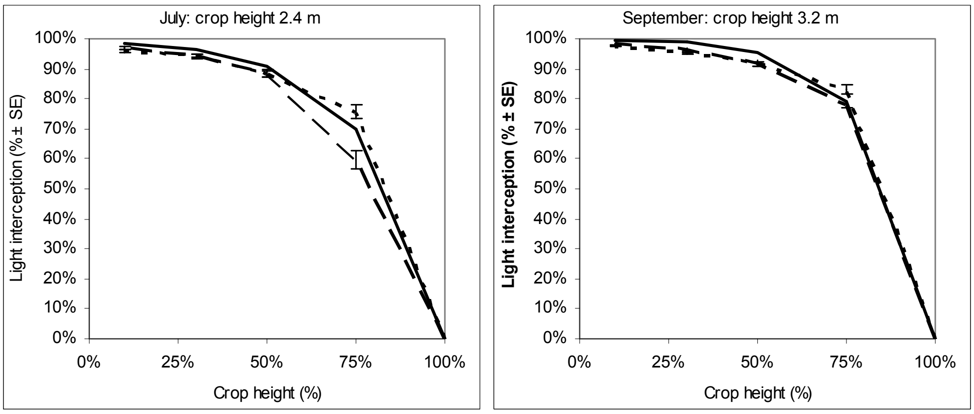

Fig.1. Measured light intensity in two sweet pepper crops (% ± SE), broken lines. The calculated light interception based on estimated LAI in July (6.23) and September (8.15) is given the solid line. n=10.

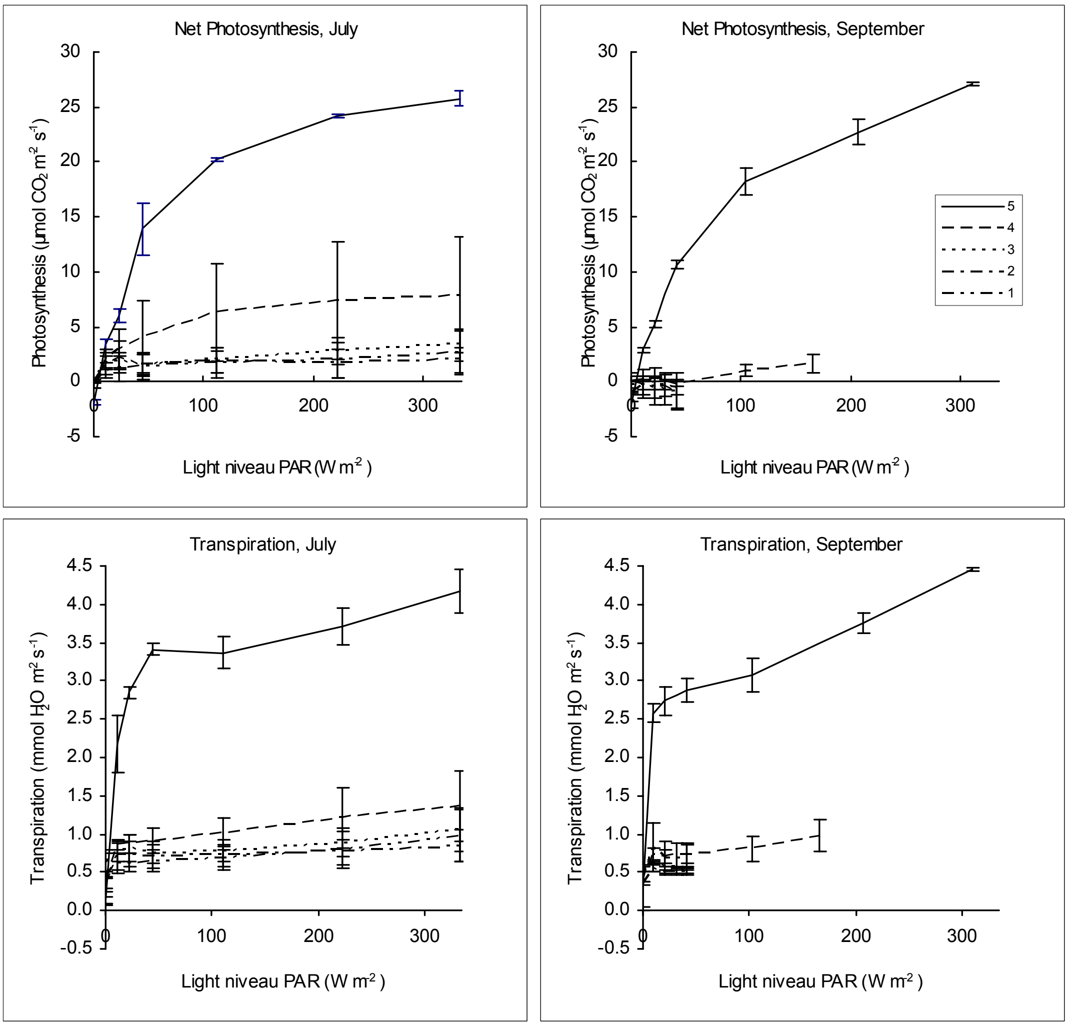

Fig. 2. Net photosynthesis (mean ± SE, above) and transpiration (mean ± SE, below) measured at 5 leaf levels in a sweet pepper crop in July and September, from the highest level (5) to the lowest level (1). n=5

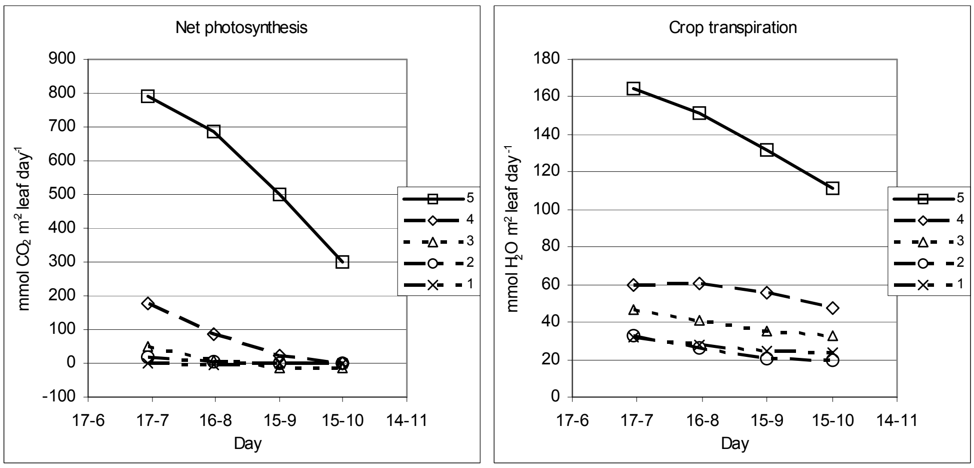

Fig. 3. Estimated course of the daily net photosynthesis and transpiration in a sweet pepper crop from July through October in each of 5 leaf levels from the highest level (5) to the lowest level (1).