Tomato Plant Photosynthetic Activity as Related to Canopy Age and Tomato Development

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Abstract. Tomato plants (Lycopersicon esculentum Mill. cv. Laura), pruned to a single-flower truss, were exposed to 90 μmol·s⁻¹·m⁻² supplemental photosynthetic lighting (0400 to 2200 hr) during the developmental period: a) anthesis to initial fruit set, b) anthesis to mature-green fruit, or c) anthesis to red-ripe fruit. The yield response was compared to plants receiving d) no supplemental photosynthetic lighting after incipient anthesis. The greatest increase in average fruit weight was produced with continued supplemental lighting during the developmental-period initial fruit set to the mature-green stage. Net photosynthetic activity, μmol CO₂/min per dm², was the greatest in the canopy during early anthesis and then steadily declined as the canopy aged. Net whole plant photosynthetic activity, μmol CO₂/min per plant, increased steadily after the early anthesis stage of development to a peak rate during the rapid fruit development stage. Net whole plant photosynthetic activity then declined as the plant approached the mature-green and then finally the red-ripe stage of fruit development.

Greenhouse tomato yields increase significantly in response to supplemental lighting when naturally available radiation is limiting (1, 16, 19). Different cropping strategies, representing various combinations of plant density and truss number, will produce similar yields when supplemental lighting is used (17). Commercial production of tomato fruit from single-truss plants, in the greenhouse (15, 17), allows one to judiciously apply supplemental light at precise stages of crop development to produce a specific growth response (14).

Fruit yield from the single-truss tomato plant is strongly correlated with total leaf dry weight (4) and is typically limited by the size and photosynthetic activity of the canopy in a cropping situation (5). The level of hexoses and starch in the leaves (9) and the distribution of carbohydrate throughout a fruiting tomato plant (7, 11, 12, 23) respond to both artificial manipulation and natural developmental changes in the plant. Thus, crop productivity is directly influenced by the carbon fixed during photosynthesis (10) and the subsequent partitioning of the photosynthesize (3, 6, 8).

In industry, techniques for improving photosynthetic efficiency and modifying the translocation pattern are only employed on a limited basis. Increasing canopy photosynthesis with the use of supplemental lighting is possible, but requires a large initial capital investment in addition to a continuing operating budget. If supplemental lighting is used, it must be done as efficiently as possible. That is, the light input must be connected to weight gain of the salable product rather than to increased vegetative growth. For example, a high light environment during flowering and pod set in soybean will result in a 30% increase in seed weight per plant (21). Thus, identifying the precise stage of crop development during which supplemental light will most effectively increase yield is an important consideration for the efficient management of the lighting resource.

An experiment was designed to investigate the effect of total available photosynthetic photon flux (PPF) on tomato yield at various stages of development from incipient anthesis through final harvest. These data were considered in relation to the changes in canopy photosynthetic activity and net whole plant carbon fixation during fruit development.

Materials and Methods

'Laura' tomato seedlings were grown in 10-cm pots (0.5 liter) containing a 40 peatmoss : 40 vermiculite : 20 perlite mix (percent by volume), amended with (all in kg·m⁻³) 4.82 dolomitic lime, 1.06 super phosphate (20%), 0.6 KNO₃, 0.6 MgSO₄, 1.65 gypsum, 0.053 fritted trace elements, 0.026 B, and 0.04 Fe. Plants were fertilized with 200 mg N/liter (15N-6.6P-12.5K) with each watering. Two weeks before anthesis, the plants were fertilized with 100 mg N/liter (13N-0P-36.5K) and 240 mg Ca/

Table 1. Average yield response of tomatoes to supplemental HPS lighting from anthesis to initial fruit set (15 days), supplemental HPS lighting from anthesis to the mature-green fruit stage (45 days), HPS lighting during the entire production cycle (65 days), and natural light conditions (0 days).

<table>
<thead>
<tr>
<th>Duration of light supplement (days)</th>
<th>Total PPF (mol·m⁻²)</th>
<th>Yield variable</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>710</td>
<td>Total fruit yield (g)</td>
<td>b₀ = 417.9, b₁ = 2.2, b₂ = -0.0007</td>
</tr>
<tr>
<td>15</td>
<td>800</td>
<td>Average fruit wt (g)</td>
<td>b⁰ = 139.3, b₁ = -1.14, b₂ = 0.07</td>
</tr>
<tr>
<td>45</td>
<td>942</td>
<td>No. fruit</td>
<td>b₀ = 2.98, b₁ = 0.04, b₂ = 0.0002</td>
</tr>
<tr>
<td>65</td>
<td>1083</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Response**

L = a linear response to total PPF; C = a cubic response to the duration of supplemental light, whereby; Y(ield variable) = b₀ + b₁ (days) + b₂ (days)³ + b₃ (days)⁴.

**Coefficients for regression equations.**

*Each datum is the mean of 40 plants.*
Fig. 1. Net photosynthetic activity (μmol CO₂/min per dm²) at various photon flux densities (PFD) ranging from light compensation to light saturation of photosynthesis. Data were obtained at: (A) initial anthesis, 5 days after transplanting into the production house (LAI 1.8); (B) early fruit sizing, 24 days after transplanting into the production house (LAI 4.8); (C) the mature-green fruit stage, 40 days after transplanting into the production house (LAI 4.6); or (D) the 90% red-ripe stage of fruit development, 54 days after transplanting into the production house (LAI 5.6) (LAI = leaf area index).
Fig. 2. Net whole plant CO$_2$ fixation ($\mu$mol/min per plant) at various photon flux densities (PFD) ranging from light compensation to light saturation of photosynthesis. Data were obtained at: (A) initial anthesis, 5 days after transplanting into the production house (LAI 1.8); (B) early fruit sizing, 24 days after transplanting into the production house (LAI 4.8); (C) the mature-green fruit stage, 40 days after transplanting into the production house (LAI 4.6); (D) the 90% red-ripe stage of fruit development, 54 days after transplanting into the production house (LAI 5.6) (LAI = leaf area index).
for 14 days at 75°C and dry weights were determined. The experiment was repeated during four separate cropping cycles with similar results.

Results and Discussion

The total PPF, available at the canopy level of the four light treatments, and the total fresh weight fruit yield increased linearly as the length of the supplemental light application period increased (Table 1). Total fresh weight fruit yield is determined by the number of fruit produced and the weight of the fruit produced. The data indicate that a curvilinear relationship exists between the supplemental light treatments used in this study and both the number of fruit produced and the average fruit weight (Table 1). Providing supplemental light during the period of initial anthesis to early fruit set (15 days) increased the number of fruit produced. Continued lighting after this period did not increase the number of fruit produced. Supplementing light during anthesis and initial fruit set only did not increase the average fruit weight. The control treatment (receiving no supplemental PPF) resulted in fruit with an average weight similar to the treatment receiving a supplemental PPF for the first 15 days. Additional PPF, continued during the period of rapid fruit development, increased the average fruit weight. Additional PPF, continued after the mature-green stage of fruit development, did not further increase the average fruit weight, as the 45-day and 65-day treatments produced fruit of similar weights.

The total PPF during final flower development and initial anthesis is one factor that determines sink size in the tomato (13, 20). The single-truss plant used in this study was a very simple source-sink system. Upon initiation of the experimental treatments, the apical meristem and the axillary shoots were removed, leaving the root system and the fruiting truss to compete for available assimilates. Both the 15-day and 45-day treatment received additional PPF during anthesis and initial fruit set. These treatments produced a similar number of fruit, but produced different average fruit weights. Thus, the most likely reason for the observed differences in the average fruit weight was an increase in source strength at a critical stage of fruit development rather than any differences in sink strength. Yield can be increased by increasing photosynthetic efficiency and by increasing canopy photosynthesis (8). Canopy photosynthesis can be increased by changes in the LAI, the photosynthetic duration, and by a more rapid canopy closure. Both the final LAI and canopy closure were fully effected by the end of the 15-day treatment. Photosynthetic duration, as well as total PPF, was increased by the 45- and 65-day treatments during the critical rapid fruit development stage.

Net photosynthetic rate (μmol CO₂/min per dm² at light saturation) was the highest when leaf expansion was still occurring; i.e., when 40% of the final size, as indicated by the LAI, had been reached and the crop was at the early anthesis stage of development (Fig. 1A). Similar data have been reported (2, 18). Once the canopy fully expanded and the fruit rapidly began to size, the net CO₂ fixation rate per unit leaf area decreased (Fig. 1B). This decrease in net photosynthetic activity continued as the fruit approached the mature-green stage (Fig. 1C), and ultimately the red-ripe stage of development (Fig. 1D). With no significant change in the LAI, the net photosynthetic rate dropped from 70% of the peak rate during early fruit sizing to 40% of the peak rate as fruit approached the mature-green fruit stage (Fig. 1B and C, respectively). The net CO₂ fixation rate declined to 20% of the peak rate when the fruit reached the red-ripe stage of development (Fig. 1D).

The response pattern observed for the carbon fixation rate, on a whole-plant basis (Fig. 2 A-D), was markedly different than the observed photosynthetic activity per unit leaf area. The rate of net carbon fixed per plant was at a maximum value with a closed canopy during rapid fruit sizing (Fig. 2B). This rate was >50% higher than the whole-plant rate observed during the expanding canopy stage at anthesis (Fig. 2A). The whole-plant CO₂ fixation rate dropped to the expanding canopy level as the crop reached the mature-green fruit stage (Fig. 2C). The rate dropped to a low value of ~45% of the peak rate at the red-ripe fruit stage (Fig. 2D).

The peak rates of net whole-plant carbon fixation, reflected in these data, coincided with the period of fruit development when supplemental PPF produced the greatest increase in average fruit weight. However, the observed changes in net photosynthetic activity per unit of leaf area more closely reflected changes in the age and stage of development of the canopy. A direct relationship exists between carbon fixed by source leaves and carbon exported from these leaves when the PFD is above the light-compensation point (10). The supplemental PFD used in this experiment was above the compensation point when natural light was not available. In addition, the number of hours in a day when the total PFD exceeded the light saturation point due to the supplemental PFD increment would be expected to be low during the light-limited months of the year (17, 19). Thus, an increase in the photosynthetic efficiency would be expected whenever supplemental light resulted in a linear increase in the carbon fixation rate.

The application of supplemental light during rapid fruit sizing was found to be most effective for increasing the average fruit weight. Providing supplemental light at an intensity exceeding the compensation point during naturally dark hours and naturally light hours when the total PFD does not surpass the light saturation point constitutes the most judicious use of this resource during light-limiting times of the year.

Literature Cited

Leucostoma persoonii Tolerance and Cold Hardiness among Diverse Peach Genotypes

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Abstract. Open-pollinated progeny from 15 peach (Prunus persica) cultivars, two peach x P. kansasensis hybrids, and one peach almond (P. amygdalus) hybrid were evaluated for their cold hardiness and for tolerance to Leucostoma canker following artificial inoculation with Leucostoma persoonii. Winter hardiness was negatively correlated with canker necrotic length (r = -0.26**) and positively correlated with canker rating (r = 0.26**), as indicated by qualitative ratings. The half-sib families differed for canker necrotic length following fall inoculation, indicating that individuals with increased tolerance to L. persoonii canker could be selected from the population. Progeny from the cultivar Yennoh exhibited the shortest canker necrotic length following fall inoculation, and all the inoculated branches were visually healthy. ‘Yennoh’, a plant introduction from Russia, may have a higher tolerance to Leucostoma than has previously been found in U.S. germplasm.

Cytospora canker, caused by Leucostoma persoonii Fr. (Nits.) Hohn. and Leucostoma cincta (Pers. ex Fr.) Hohn., is the most serious disease reducing peach tree life in Michigan, New York, New Jersey, and Colorado (7). Symptoms include cankering of the trunk and branches, branch dieback, progressive weakening, and, ultimately, death of the tree. Leucostoma is a pathogen that enters through dead and damaged tissues. Pruning cuts that do not callus properly are ideal Leucostoma entry sites. Winter injury that results in dead and damaged tissue predisposes the tree to Leucostoma invasion (1). Usually the combined influence of low temperature stress and Cytospora canker is greater than the effect of either acting alone.

There has been no large-scale effort to identify genetic resistance or tolerance to Leucostoma in a broad-based population of peach (4). Cultivars do, however, differ in their level of tolerance to Leucostoma, but no highly tolerant selections have been identified (2, 6). Various inoculation techniques have been investigated for screening peach for Leucostoma tolerance, but these techniques have not been used to screen a diverse peach germplasm collection (5, 8).

Because cold injury predisposes peach trees to Leucostoma infection, it is important to determine the hardiness of the trees inoculated in a screening program. Well-acclimated, hardy cultivars not only should have reduced infection, but also increased capacity to combat disease progression. The objectives of this study were to evaluate a broad collection of peach germplasm for L. persoonii disease development following inoculation and for cold hardiness in the Michigan climate to identify useful genetic material to breed for L. persoonii tolerance.

Materials and Methods

In Spring 1984, open-pollinated peach seedlings from 15 peach clones of diverse background, two peach x P. kansasensis hybrids, and one peach almond (P. amygdalus) hybrid (Table 1) were planted in a completely randomized design at the Horticultural Research Center, East Lansing, Mich. Open-pollinated

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