Leaf Injury and Dry Mass Production in Eggplant and Pepper Plant as Affected by Overnight Supplemental Lighting

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Effect of overnight supplemental lighting at different light intensities following natural day length on growth and leaf injury of eggplant and pepper plant was investigated. Leaf chlorosis was observed with over 35 μmol m⁻² s⁻¹ PPFD and there was no correlation between light intensity and dry matter production in eggplant. On the other hand, pepper plants grew vigorously without any injurious symptoms even at 200 μmol m⁻² s⁻¹ PPFD. Total dry weight in pepper plant increased linearly with increase in light intensity. For instance, when supplemental light intensity was 100 μmol m⁻² s⁻¹, dry weight increase was 1.57 g/plant at 3 weeks after the initiation of light treatment, which was about 2 times higher than that in natural dark control (=0.71 g/plant). When light intensity was 200 μmol m⁻² s⁻¹, the increase rate of total dry weight was 3 times higher than that in natural dark control. Increase rate of root dry weight was 4 times, but root length in the longest root was not different between the two treatments, suggesting that the lateral root growth was promoted by supplemental lighting. When sunlight intensity was reduced by 50%, the dry weight increase rate was 1.6, 1.5 and 2.0 times for leaf, stem and root, respectively, against 1.3, 1.2, 1.3 times in non-shaded plants. These results indicate that the enhancement of dry mass production in pepper plants by overnight supplemental lighting is more profound when the daytime solar radiation is low.

Keywords: Capsicum annuum, daytime solar radiation, dry weight, light intensity, Solanum melongena

INTRODUCTION

In Solanaceae family, continuous light inhibits plant growth whereby leaf chlorosis has been reported in tomato (Withrow and Withrow, 1949; Bradley and Janes, 1985; Doraí et al., 1995) and potato (Wheeler and Tibbits, 1985; Tibbits et al., 1990). Young eggplant is extremely sensitive to continuous light, exhibiting severe leaf necrosis within 1 week from the beginning of light treatment (Murage et al., 1996). However, pepper plants grow vigorously without any symptoms of leaf injury, and subsequent flowering and fruit setting occur successfully (Masuda and Murage, 1998; Masuda et al., 2000). High power artificial lighting system consumes much energy in the cooling of the heat generated from lamps. For fruit production, it is therefore, necessary to enhance the total light energy by prolonging the light period. The longest light period is ultimately continuous. Lettuce plant has been well known to grow vigorously under continuous light (Craker and
Seibert, 1983; Koontz and Prince, 1986). It has produced highest dry weight under continuous light at an intensity of around 250 μmol m⁻² s⁻¹ (Oda et al., 1989). Knight and Mitchell (1983) reported that the dry weight was 2 times higher under continuous light at an intensity of 455 μmol m⁻² s⁻¹ than that at 250 μmol m⁻² s⁻¹, but at 900 μmol m⁻² s⁻¹ the dry weight was only a half of that at 455 μmol m⁻² s⁻¹. These results suggest that too high light intensity leads to decrease in dry mass production under continuous light.

In natural conditions accompanied with high sunlight intensity, there is no evidence of overnight supplemental lighting effects at different light intensities following natural day length on dry weight and leaf injury in eggplant and pepper plant. Therefore, a greenhouse experiment was conducted to examine the plant response to light intensity by using metal halide lamp as a light source for supplemental lighting.

MATERIALS AND METHODS

Effect of overnight supplemental lighting on leaf injury and dry mass production in eggplant and pepper

Eggplant (Solanum melongena L.), cv. Senryo and pepper (Capsicum annum L.) cv. Kyo-midori were used. Seeds were sown in vermiculite in 10 April, 2000, and when the 2nd true leaves unfolded, the seedlings were transplanted to 12 cm-diameter pots filled with a mixture of soil and peat moss (3 : 1 ratio) and then subjected to supplemental lighting from 25 April, 2000. As a source of light, one metal halide (MH) lamp was set up 1.5 m above the plant canopy. Supplemental lighting time was 12 h from 5:00 pm to 5:00 am. Different light intensities on the plant canopy were achieved by varying the distance of the plants from the lamp. The minimum night temperature in the greenhouse was maintained at 16°C. The plants were fertigated once a day with half-strength of Enshi-formulated solution containing N03-N: 112, NH4-N: 9, P: 20.5, Ca: 80, Mg: 14, Fe: 3, B: 0.5, Cu: 0.02, Mo: 0.01 mg l⁻¹ (pH: 6.4, EC: 1.4 dS m⁻¹). During the light treatment for 3 weeks, visible leaf chlorosis was recorded, and at last day leaves and stems were harvested and dried at 80°C for 3 days for dry weight evaluation.

Effect of overnight supplemental light intensity on dry mass production of pepper plant

The seedlings of pepper cv. Kyo-midori and Shishito were sown in 20 October, 2000 and when the 2nd true leaves unfolded, they were transferred to conditions with different light intensities modified by varying the distance from the MH lamp as described above. Supplemental lighting was used for 1 month from 15 November to 15 December, during this period minimum night temperature in the greenhouse was maintained at 16°C.

In another experiment for determining the effect of continuous light on root growth promotion, seedlings were transferred to a condition supplemented with light at an intensity of 200 μmol m⁻² s⁻¹ (PPFD) and compared with a control of darkness. In this experiment, a slight loss of root was unavoidable when they were taken from soil and rinsed with tap water. Therefore, to determine the variance of root dry mass, 5 seedlings were placed. After the supplemental lighting for 1 month, dry weight of leaves, stems and roots was measured separately.

Association between daytime solar radiation and supplemental light effects on dry mass production of pepper plant

The seeds of pepper plant ‘kyo-midori’ were sown in vermiculite in 10 April, 2000. These seedlings were grown under natural day length until the 4th true leaves unfolded. At this stage, uniform 24 seedlings were selected and transferred to three experimental blocks namely, 1) natural condition, 2) overnight supplemental light at an intensity of 150 μmol m⁻² s⁻¹ and 3) with black cheesecloth 50 cm above the lamp and in this case the sunlight intensity was reduced by 50%. Two weeks after the treatment, the latter two blocks were used for analyzing photosynthetic capacity on the 4th true leaves using assimilation leaf chamber apparatus (Shimadzu LAC-3) and leaf area
using meter (Hayashi Denko AAM-8). Dry weight of leaves, stems, and root was measured separately as mentioned above.

RESULTS

Effect of overnight supplemental lighting on leaf injury and dry mass production in eggplant and pepper

Severe leaf chlorosis on the 3rd true leaves of eggplants occurred after 13 days of continuous light treatment with an intensity range of 150 μmol m⁻² s⁻¹ (just below lamp) to 60 μmol m⁻² s⁻¹ PPFD. A few days later, a slightly leaf chlorosis was found at 35 μmol m⁻² s⁻¹. No more observable symptoms were found at lower than 25 μmol m⁻² s⁻¹. On the other hand, pepper plants grew vigorously without any injurious symptoms. The relationship between dry weight (Y) and light intensity (X) was, $Y = 0.13 \times 10^{-2} X + 0.24$ ($r=0.25$) for eggplant, and $Y = 0.86 \times 10^{-2} X + 0.71$ ($r=0.98$) for pepper plant (Fig. 1). Therefore, we found eggplants not to be responsive to light intensity but pepper plants were highly responsive, and the regression coefficient was six times higher in pepper plant than in eggplants. For example in pepper plants, when supplemental light intensity, X, was 100 μmol m⁻² s⁻¹, dry weight increase, Y, was 1.57 g plant⁻¹, which was about two times that of natural dark control (=0.71 g plant⁻¹).

Effect of overnight supplemental light intensity on dry mass production of pepper plant

Since there was no correlation between light and dry matter production in eggplant, in this experiment only pepper was used. Dry mass production in pepper plant was affected by supplemental light intensity in greenhouse conditions. Plant height, stem diameter and number of expanded leaves in ‘Kyo-midori’ increased linearly with increased light intensity; the correlation coefficient factor were 0.65, 0.84 and 0.75, respectively. Similar values were obtained in cv. Shishito (Fig. 2). For these plants, the shoot and root dry mass also increased linearly, with a high correlation coef-

![Fig. 1](image1.png)  
Fig. 1 Dry mass production and leaf injury in eggplants and pepper plants as affected by overnight supplemental lighting. Arrows indicate the incidence of chlorosis.

![Fig. 2](image2.png)  
Fig. 2 Growth of pepper plants as affected by overnight supplemental lighting.
icient factor, being 0.93 and 0.88 for ‘Kyo-midori’ and 0.97 and 0.89 for cv. Shishito, respectively. When light intensity was 200 \( \mu \text{mol m}^{-2} \text{s}^{-1} \), dry weight increase rate was 3 times higher than dark control (Fig. 3). Figure 4 shows that root dry weight was 3 times higher at continuous lighting for cv. Kyo-midori and 4 times for cv. Shishito with a small standard error. However, there was no difference in length of the longest root between the treatments (Fig. 5), beside that the growth of lateral roots was promoted by supplemental lighting.

*Enhanced dry mass production of pepper plant by supplemental lighting is associated with daytime solar radiation*

Leaf area and dry weight of individual parts of the plants were measured 3 weeks after the treatment. Shading caused to decrease leaf area and dry weight of leaf and root, but had no effect on stem dry weight. Supplemented lighting significantly increased the leaf area and dry weight of all parts in both shaded and non-shaded plants in daytime (Table 1). The rate of increase of leaf, stem and root dry weight with supplemental lighting was 1.6, 1.5 and 2.0 with shading and 1.3, 1.2, 1.3 without shading, respectively. On the other hand, that of leaf area was similar, being 1.4 times, in both cases. The difference of dry mass production between shaded and non-shaded plants was induced by light intensity in daytime, and the enhancement of dry mass production by supplemental lighting at night was more profound when the daytime solar radiation was weak. Photosynthetic

![Fig. 3](image-url)  
**Fig. 3** Dry mass production of pepper plants promoted by overnight supplemental lighting.

![Fig. 4](image-url)  
**Fig. 4** Root dry weight of pepper plants promoted by overnight supplemental lighting. Vertical bars indicate SE \((n=5)\).
Fig. 5 Differences in root system as affected by overnight supplemental light of 200 μmol m⁻² s⁻¹ PPFD. Photographed 1 month after the treatment.

Table 1 Dry mass production and leaf area of pepper plants as affected by combination of shading in daytime and supplemental lighting at night.

<table>
<thead>
<tr>
<th>Day with (+) or without (−) shading</th>
<th>Night with (+) or without (−) lighting</th>
<th>Dry weight (g plant⁻¹)</th>
<th>Leaf area (cm² plant⁻¹)</th>
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<tr>
<td>+</td>
<td>+ (A)</td>
<td>6.8</td>
<td>2.0</td>
</tr>
<tr>
<td>−</td>
<td>− (B)</td>
<td>4.3</td>
<td>1.3</td>
</tr>
<tr>
<td>−</td>
<td>+ (A/B)</td>
<td>1.6</td>
<td>1.5</td>
</tr>
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<td></td>
<td></td>
<td>7.5</td>
<td>1.9</td>
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<td>5.8</td>
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<td>1.3</td>
<td>1.2</td>
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<tr>
<td>Significance*</td>
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<tr>
<td>Shading</td>
<td>*</td>
<td>N.S.</td>
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<td>Lighting</td>
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<td>Interaction</td>
<td>N.S.</td>
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Seedlings were grown for 3 weeks from the unfolded 4th leaf stage.

*NS and * represent insignificant and significant, respectively, at $P \leq 0.05$ by ANOVA ($n=5$).

rate under continuous light at night was about 1.7 μmol m⁻² s⁻¹, and this rate was not different between shaded and non-shaded plants (Fig. 6).

DISCUSSION

Eggplant leaf necrosis was most severe in natural day length followed by supplemental lighting, where leaf injury was observed at light intensities above 35 μmol m⁻² s⁻¹. However, supplemental lighting did not affect the rate of dry mass production. Even this level of light intensity is considered to be excess in energy for eggplant chloroplasts. Murage et al. (1997) reported that increasing the PPFD under continuous lighting increased chlorosis into necrosis. On the other hand, pepper plants, with a high capacity to utilize the light energy responded linearly to increasing light intensity ($r=0.98$), resulting that improved plant growth and dry weight increases remarkably (Fig. 5).
The correlation between dry weight and supplemental light intensity was highly significant ($r>0.88$). This was indicated by an increase of 0.53 g and 0.65 g dry weight per 100 µmol m$^{-2}$ s$^{-1}$ PPFD, for cv. Kyo-midori and cv. Shishito, respectively (Fig. 3). The dry weight was doubled by supplemental light at a light intensity of 100 µmol m$^{-2}$ s$^{-1}$ for 1 month in cv. Shishito. This increment may be accounted for by the increase of leaf area and extra photosynthesis during supplemental lighting. Therefore, the longer the period of supplemental lighting, the more the dry weight was. Furthermore, the leaf color turned deep green within 2 days of supplemental lighting, suggesting that the extra light stimulated more chlorophyll synthesis before the initiation of dry weight increase. From these results, we concluded that overnight supplemental lighting at 100 µmol m$^{-2}$ s$^{-1}$ was a very useful method for enhancing the growth of pepper seedlings. Demers and Gosselin (1998) also reported that sweet pepper plants grown under supplemental lighting with a photoperiod of 16 and 20 h increased plant yield, but the yield was reduced by continuous light (24 h). This result indicated that natural day length associated with strong solar radiation provides excess energy for pepper plant with overnight supplemental lighting. Pepper plants grew vigorously for 10 months with excessive fruit setting and enlargement at 150 µmol m$^{-2}$ s$^{-1}$ of continuous fluorescent illumination (Masuda and Murage, 1998; Masuda et al., 2000). Furthermore, Fukuda et al. (2000) reported that leafy vegetables such as lettuce, pakchoi, tsukena, garland chrysanthemum and tomato grown for 24 days under normal photoperiod supplemented by lighting from 23:00 to 7:00 increased shoot fresh weight. A dark period of 4 h (19:00–23:00) was included in their experiment but its significance was not discussed in the report. We have previously reported that pepper plant grown under a 4-hour dark break in the growth chambers grew well as those grown under continuous light (Masuda et al., 2002b). Fierro et al. (1994) reported that supplemental light of 100 µmol m$^{-2}$ s$^{-1}$ (16 h-photoperiod) in combination with enrichment of CO$_2$ (900 µmol m$^{-2}$ s$^{-1}$) for $\approx$ 3 weeks enhanced the dry matter accumulation in shoots of pepper plant by $\approx$ 50% compared with control, while root dry weight increased by 62%. In order to promote the growth in pepper seedlings in the nursery, it seems to be useful to provide continuous light but in practice it may be more economical to include a 4-hour dark break.

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REFERENCES


