Japan. Jour. Crop Sci. 58 (4) : 689—694 (1989)

# Effects of Light Quality, Daylength and Periodic Temperature Variation on the Growth of Lettuce and Radish Plants*

Katsumi INADA** and Yoichi YABUMOTO***
(***Sand Dune Research Institute, Tottori University, Hamasaka, Tottori 680, Japan* ;
*** *Development Center, Iwasaki Electric Co. Ltd., Gyoda, Saitama 361, Japan*)
Received April 26, 1989

**Abstract** : Effects of light qualities under continuous lighting, daylengths at a constant temperature, and periodic temperature variations under continuous lighting on the vegetative growth of lettuce and radish plants were studied to find the suitable environmental conditions for plant production in controlled environment rooms.

Among the four light qualities, most growth parameters increased with increasing photon flux of the red component and the red/blue ratio in the light spectra, except when the red/farred ratio was extremely high. The plant growth was promoted with the increase of daylength up to 24 h, whereas the lighting efficiency in terms of dry-matter production per lighting duration was greatest in 20 h daylength. Daily periodic temperature variations showed some effects on the plant growth and the greatest effect was found in temperature regimes of 16H/8L for lettuce and 20H/4L or 16H/8L for radish. The increased dry matter was distributed to both the top and roots in lettuce, but exclusively to the storage root in radish.
**Key words** : Daylength, Lettuce, Light quality, Radish, R/B ratio, R/F ratio, Thermoperiodicity, Vegetative growth.

**レタスおよびハツカダイコンの生長に及ぼす光質，日長ならびに変温の影響**：稲田勝美・藪本陽一*** (鳥取大学農学部附属砂丘利用研究施設・***岩崎電機株式会社開発センター)

**要　旨**：制御環境下での植物生産に好適な環境条件を明らかにするため，連続照明下での光質，恒温下での日長，および連続照明下での変温の影響を調べた．

光質については，赤色光/遠赤色光 (R/F) 比が著しく高い場合を除けば，赤色光の光量子量が多いほど，また赤色光/青色光 (R/B) 比が大きいほど生長は促進された．日長は長いほど生長は旺盛となり 24 h 日長 (連続照明) で最大となったが，乾物生産に対する照明効率は 20 h 日長で最も高かった．連続照明下で，日平均 20°C，高低差 5°C とした変温を与えると，恒温下に比べて生長は促進され，レタスでは 21.7°C，16 h と 16.7°C，8 h (16 H/8 L)，ハツカダイコンでは 20.8°C，20 h と 15.8°C，4 h (20 H/4 L) または 16 H/8 L の変温下で最も効率が高かった．ハツカダイコンでは，変温によって増大した乾物はもっぱら貯蔵根に分配された．

本研究から，R/B 比 10 またはそれ以上，R/F 比 1～2 の光質をもつランプで日長を 20 h 前後とし，これに変温を組合せた条件が植物の栄養生長の促進に有効であろうと結論した．
**キーワード**：栄養生長，温周性，光質，赤色光/遠赤色光比，赤色光/青色光比，日長，ハツカダイコン，レタス．

Light conditions—spectral quality, intensity and duration—strongly affect the growth and development of plants. As for the light quality, radiation energy of red component[2,11] and the ratio of red/blue component[7,10,12] are known to be very important to the growth, photosynthesis and/or dry-matter production. The ratio of red/farred component also regulates the growth of plants[12,17]. Effects of daylength on the vegetative stage of plants grown in controlled environment chambers have been studied using tomato[3,6], lettuce[4,8,14], turnip[9], etc. and revealed that the growth and dry-matter production generally increased with the daylength up to 24 h. On the other hand, the effect of alternate variation in temperature during day and night on the growth and development has been known as thermoperiodicity[18]. However, there is no information about the thermoperiodic effect under continuous lighting.

The present study was made to know the suitable light and temperature conditons to accelerate the vegetative growth of plants in controlled environment rooms.

* This study was carried out at the National Institute of Agrobiological Resources, Tsukuba, Ibaraki 305, Japan, and the outline was presented in the 184th meeting of the Crop Science Society of Japan, October, 1987.

## Materials and Methods

*1. Plant materials*

Lettuce (*Lactuca sativa* L., cv. "Okayama Saradana") and radish (*Raphanus sativus* L., cv. "Comet") seeds were sown in plastic cases [10×10×8 (H) cm] filled with vermiculite and cultured with Otsuka House fertilizer solutions. The seed rate was 10 per case and 8 cases were used for each plot. Seedlings were thinned out for spacing and unify as they grew up.

Lettuce seedlings were grown in a growth chamber up to the stage with 2-to 5-unfolded leaves depending on the experiments, under continuous lighting at a constant temperature of 23°C and a relative humidity of about 70%. Metalhalide lamps (Mitsubishi MLRBOC-400-FUM, reflected type) were used as the light source and the intensity was 240 $\mu$mol $m^{-2}$ $s^{-1}$ in photosynthetic photon flux (PPF) at plant level. Radish seedlings were grown in a natural light-growth chamber up to the stage with 2-unfolded leaves under the conditions of day/night temperature, 25/18°C and about 70% relative humidity.

After the precultivation the plant cases were transferred into growth chambers (Koito HNL-35) and treated for 2 weeks. Growth parameters were measured for each 10 plants per treatment at the start, 7th and 14th day of treatment for all the experiments. Details of the treatments are as follows.

*2. Experiment on light quality*

Two types of metalhalide lamps, Mitsubishi MLRBOC-400-FUM (M1) and Iwasaki MHR 400D (M2), and two types of high-pressure sodium lamps, Iwasaki NHR 360L (N1) and Iwasaki NHR 400DX (N2) were used as the sources of different light qualities. Spectral photon distributions of these lamps were measured with a LICOR spectroradiometer, LI-1800 and given in Fig. 1. Spectral photon ratios of red (600—700nm) to blue (400—500 nm), (R/B) and red to farred (700—800 nm), (R/F) were calculated from the curves. The R/B and R/F ratios widely varied among the lamps in the ranges 1.34—14.2 and 1.28—6.11, respectively (Fig. 1).

The experiment was made under continuous lighting at two PPF levels of 200 and 320 $\mu$mol $m^{-2}$ $s^{-1}$, determined with a Quantum Sensor, LI-190S and an Integrating Light Meter, LI-188 (LICOR) and adjusted with cheese clothes at the plant level. Daily air temperature was varied periodically as 21.7°C for 16 h and 16.7°C for 8 h (daily average 20°C).

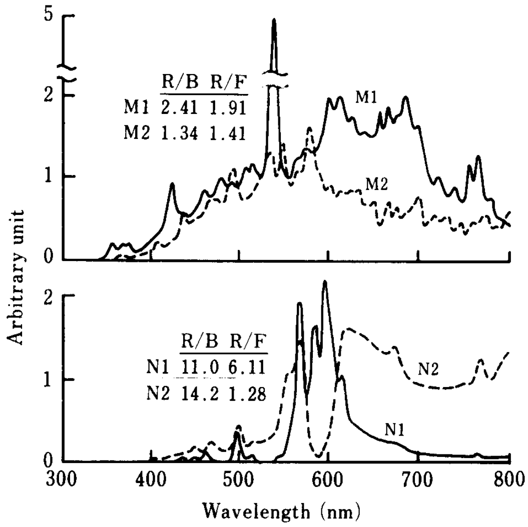


Fig. 1. Spectral photon flux distribution curves of lamps under the experimental conditions.

*3. Experiment on daylength*

The plants were grown under M1 lamps at PPF 320 $\mu$mol $m^{-2}$ $s^{-1}$ and 20°C constant, and the effects of daylengths 12, 16, 20 and 24 h were investigated.

*4. Experiment on thermoperiodicity*

Different durations of high (H) and low (L) temperatures were alternately given everyday, providing that the daily average 20°C and the difference 5°C, under continuous lighting by M1 lamps at PPF 320 $\mu$mol $m^{-2}$ $s^{-1}$. The temperature regimes were as follows: 20°C constant (Constant); 20.8°C, 20 h and 15.8°C, 4 h (20H/4L); 21.7°C, 16 h and 16.7°C, 8 h (16H/8L); and 22.5°C, 12 h and 17.5°C, 12 h (12H/12L).

*5. Chlorophyll assay*

Leaf pieces of 3—5cm² from full-grown leaf blades were extracted with 10 ml of 80% acetone solution. Chlorophyll (a+b) content in the extract was analyzed with a spectrophotometer (Hitachi, model 100-60) and calculated according to Arnon equation[1].

## Results and Discussion

*1. Growth responses to different light qualities*

Data of the growth parameters are shown in Table 1. Among the light qualities, the leaf

Table 1. Growth responses of lettuce and radish plants to four different light qualities at two PPF levels.

| PPF | Lamp | Leaf No.[2)] | Leaf length[3)] (cm) | Leaf area ($cm^2$) | Fresh weight (g) | Dry weight (g) | T/R ratio | Chl. content ($mg\ dm^{-2}$) |
|---|---|---|---|---|---|---|---|---|
| Lettuce | | | | | | | | |
| 200 | BT[1)] | 2.0 | 2.1 | 3 | 0.1 | 0.01 | | |
| | M1 | 11.4[a] | 14.0[b] | 483[a] | 15.0[ab] | 1.08[ab] | 7.2 | 3.56[a] |
| | M2 | 11.4[a] | 13.7[b] | 444[b] | 14.2[bc] | 1.00[bc] | 7.4 | 2.86[b] |
| | N1 | 10.8[a] | 11.8[c] | 332[c] | 11.7[c] | 0.85[c] | 6.7 | 3.84[a] |
| | N2 | 11.6[a] | 18.0[a] | 542[a] | 16.8[a] | 1.18[a] | 8.2 | 2.97[b] |
| 320 | BT | 5.3 | 6.0 | 44 | 1.3 | 0.12 | | |
| | M1 | 15.2[a] | 19.3[ab] | 1,339[b] | 63.3[a] | 4.34[a] | 6.0 | 3.84[a] |
| | M2 | 15.5[a] | 19.0[ab] | 1,275[b] | 61.5[a] | 3.97[ab] | 6.4 | 3.46[ab] |
| | N1 | 16.5[a] | 16.5[b] | 1,133[c] | 51.9[b] | 3.42[b] | 7.3 | 3.87[a] |
| | N2 | 16.5[a] | 21.5[a] | 1,598[a] | 68.6[a] | 4.37[a] | 7.4 | 3.17[b] |
| Radish | | | | | | | | |
| 200 | BT | 2.0 | 3.3 | 8 | 0.5 | 0.04 | | |
| | M1 | 6.1[a] | 18.4[b] | 179[ab] | 22.7[b] | 1.42[b] | 0.75 | 4.80[a] |
| | M2 | 5.9[a] | 19.6[ab] | 159[ab] | 19.4[c] | 1.20[bc] | 0.79 | 4.09[b] |
| | N1 | 6.0[a] | 18.6[b] | 149[b] | 20.0[bc] | 1.19[c] | 0.70 | 5.29[a] |
| | N2 | 6.5[a] | 23.1[a] | 198[a] | 26.4[a] | 1.69[a] | 0.80 | 4.45[ab] |
| 320 | BT | 2.0 | 4.0 | 12 | 0.5 | 0.04 | | |
| | M1 | 7.0[a] | 17.1[b] | 183[ab] | 27.4[b] | 1.81[ab] | 0.63 | 4.88[a] |
| | M2 | 6.2[b] | 17.2[b] | 144[c] | 22.5[b] | 1.50[b] | 0.67 | 3.63[b] |
| | N1 | 5.9[b] | 16.7[b] | 149[bc] | 24.0[b] | 1.53[b] | 0.61 | 4.40[ab] |
| | N2 | 6.9[a] | 22.8[a] | 230[a] | 34.6[a] | 2.30[a] | 0.77 | 3.95[b] |

1) BT, beginning of treatment. 2) Unfolded leaves. 3) Length of the largest leaf. Figures followed by the same letter within a column are not significantly different at the 5% level.

length, leaf area, fresh and dry weights and T/R ratio were highest in N2 plot and generally lowest in N1 plot, regardless of the species and PPF levels. Chlorophyll content per unit leaf area was, however, highest in N1 plot, lower in M1, and lowest in M2 or N2, for the all cases.

Similar results have been roported[13)] for lettuce which grown under A, B and C lamps resembled in the light qualities to the N1, N2 and M2 lamps, respectively.

Relative growth rate (RGR) was the greatest under N2 lamps and the smallest under N1 lanps in most cases. Dry-matter production and RGR during the treatment were increased with the absolute value of photon flux of red component, regardless of the species and PPF levels, except those under N1 lamps having an extremely high R/F ratio (6. 11), which they were largely dropped from the increasing curves with the photon flux of red component. The effect of photon flux of the red component on RGR normalized to N2 plot was greater in radish than in lettuce (Fig. 2). A similar relationship was found between RGR and logarithmic R/B ratio as shown in Fig. 3. RGR in N1 plot was also disconnected from the increasing tendency with R/B ratio in all cases.

The present results coincide with the facts that the red light intensity in the visible spectrum was very effective to dry-matter production in radish[2,7)], cucumber and spanish-paprika plants[7)], and that the supplemental farred irradiation to a fluorescent light remarkably promoted the growth of lettuce[15)].

2. *Growth response to daylength under constant temperature*

In either species, all of the leaf length, leaf area, fresh and dry weights, chlorophyll content (Table 2), RGR and net-assimilation rate (NAR) (Fig. 4) were generally increased with increasing the daylength, though their differences were not significant between 20 h and 24 h.

These responses agree well with those reported for lettuce[4,8,14)], turnip[6)] and tomato[3)], demonstrating that the plant growth can be accelerated by the increase of daylength within a certain period of vegetative growth.

On the other hand, the lighting efficiency in terms of dry-matter production per lighting duration was highest in 20 h, lower in 16 h and 24 h, and lowest in 12 h. In young tomato, it has been described that the efficiency of dry-matter production was reduced by increasing the daylength from 16 h to 24 h[3], whereas in lettuce, it was reported that the efficiency was not much affected by daylength[4] and that of fresh-weight increment was decreased with the increase of daylength[4,14]. The discrepancy on the lighting efficiency may be due to the differences of plant materials and other environmental conditions during the treatment.

*3. Thermoperiodic effect under continuous lighting*

The leaf number, leaf area and fresh and dry weights were increased by thermoperiodic treatments in either species, even if the

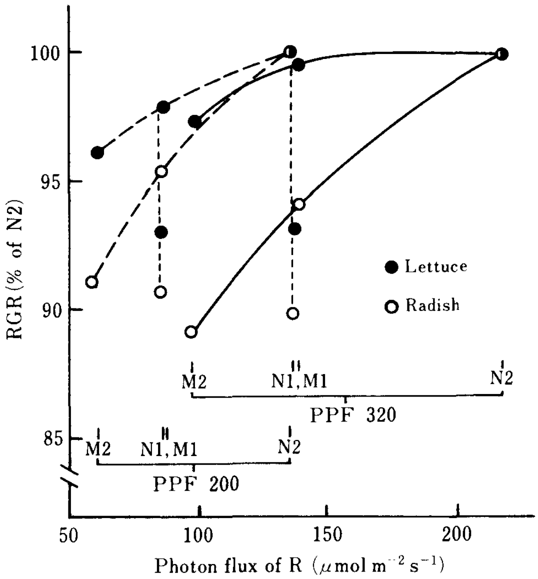


Fig. 2. RGR of lettuce and radish plants in relation to photon flux of red component in the light spectrum.

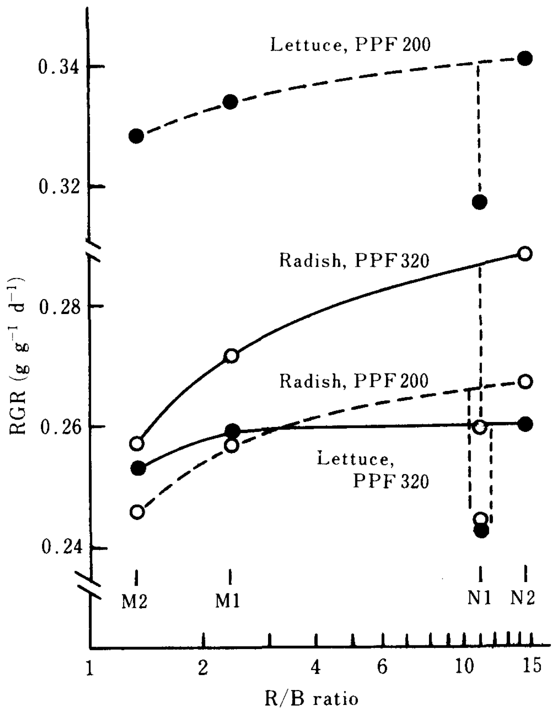


Fig. 3. RGR of lettuce and radish plants in relation to logarithmic R/B ratio in the light spectrum.

Table 2. Growth responses of lettuce and radish plants to different daylengths under the constant temperature.

| Day-length (h) | Leaf No.[2] | Leaf length[3] (cm) | Leaf area ($cm^2$) | Fresh weight (g) | Dry weight (g) | T/R ratio | Chl. content (mg $dm^{-2}$) | Lighting efficiency (mg⊿W/h) |
|---|---|---|---|---|---|---|---|---|
| Lettuce | | | | | | | | |
| BT[1] | 5.8 | 4.3 | 34 | 1.1 | 0.13 | | | |
| 12 | 12.6[a] | 12.3[ab] | 550[b] | 21.7[c] | 1.23[c] | 6.3 | 2.39[c] | 6.55 |
| 16 | 12.7[a] | 10.9[b] | 627[b] | 29.4[b] | 1.78[b] | 5.8 | 2.93[c] | 7.37 |
| 20 | 13.6[a] | 12.2[a] | 898[a] | 44.0[a] | 2.77[a] | 6.1 | 3.74[b] | 9.43 |
| 24 | 13.3[a] | 13.2[a] | 831[a] | 43.4[a] | 2.86[a] | 7.1 | 4.51[a] | 8.13 |
| Radish | | | | | | | | |
| BT | 2.2 | 6.7 | 21 | 1.0 | 0.08 | | | |
| 12 | 5.8[a] | 15.3[b] | 156[b] | 19.3[c] | 1.07[c] | 0.69 | 3.72[b] | 5.89 |
| 16 | 6.1[a] | 14.9[b] | 167[ab] | 25.2[b] | 1.46[b] | 0.63 | 4.59[ab] | 6.16 |
| 20 | 6.7[a] | 16.3[ab] | 205[ab] | 34.1[a] | 2.12[a] | 0.60 | 5.00[a] | 7.29 |
| 24 | 6.7[a] | 18.0[a] | 201[a] | 32.4[a] | 2.16[a] | 0.67 | 5.52[a] | 6.19 |

Refer to Table 1 for 1), 2), 3) and figures.

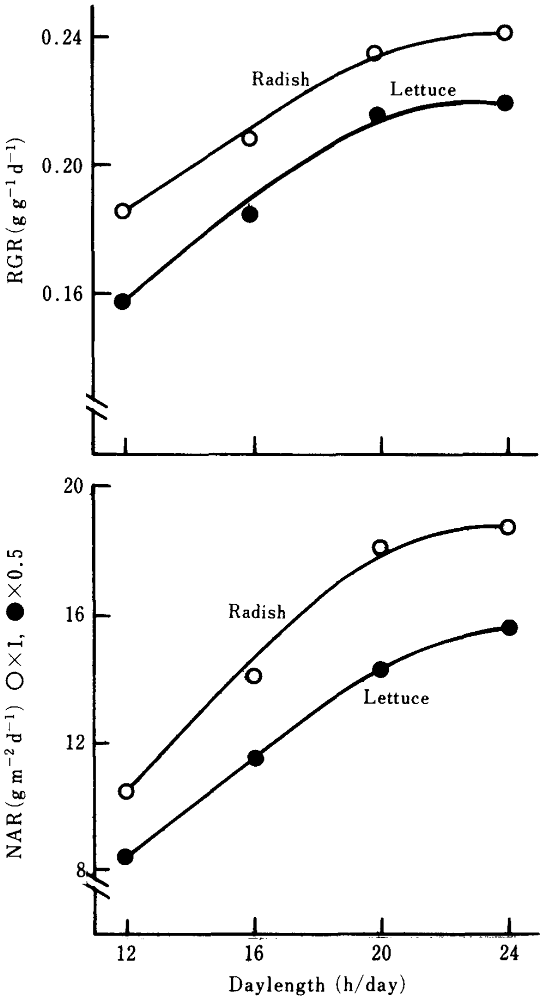


Fig. 4. RGR and NAR of lettuce and radish plants in relation to daylength under the constant temperature.

differences were not significant in radish (Table 3). The optimum periodicity for growth was 16H/8L for lettuce, while 20H/4L or 16H/8L for radish, as indicated by means of RGR (Fig. 5). Dry matter increased by the themoperidic treatments was distributed to both the top and roots at the almost equal rate in lettuce, whereas distributed exclusively to the root in radish which possessing a large sink capacity in the storage root (Table 3). This result suggests that the periodic variation of temperature accelerates the translocation of photosynthates from leaves to storage root and/or raises the dry-matter partitioning ratio to the storage root, even under continuous

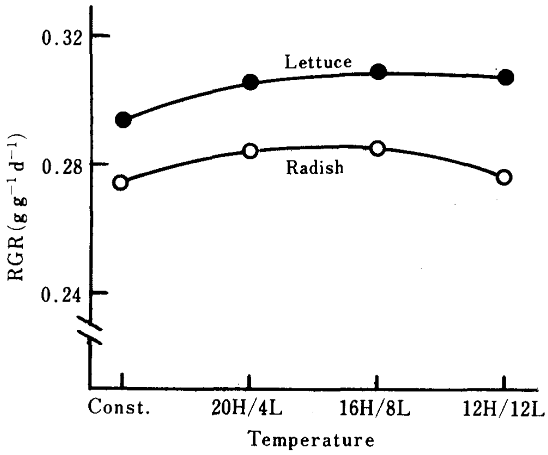


Fig. 5. RGR of lettuce and radish plants in relation to periodic temperature variation under the continuous lighting.

Table 3. Growth responses of lettuce and radish plants to different periodic temperature variations under the continuous lighting.

| Temp. regime | Leaf No.[2] | Leaf area ($cm^2$) | Fresh weight (g) | Dry weight (g) Top | Root | Total | T/R ratio | Chl. content ($mg\ cm^{-2}$) |
|---|---|---|---|---|---|---|---|---|
| Lettuce | | | | | | | | |
| BT[1] | 2.4 | | 0.2 | | | 0.02 | | |
| Constant | 12.1[a] | 411[c] | 17.5[c] | 1.07[b] | 0.19[a] | 1.26[b] | 5.6 | 2.80[a] |
| 20H/4L | 12.3[a] | 498[b] | 21.0[b] | 1.30[a] | 0.22[a] | 1.52[a] | 5.9 | 2.75[a] |
| 16H/8L | 12.9[a] | 575[a] | 24.7[a] | 1.36[a] | 0.23[a] | 1.59[a] | 5.9 | 2.94[a] |
| 12H/12L | 12.5[a] | 557[ab] | 24.3[a] | 1.33[a] | 0.23[a] | 1.56[a] | 5.8 | 3.12[a] |
| Radish | | | | | | | | |
| BT | 2.0 | | 0.6 | | | 0.04 | | |
| Constant | 6.1[a] | 173[a] | 28.1[a] | 0.81[a] | 1.10[b] | 1.91[a] | 0.74 | 3.59[a] |
| 20H/4L | 6.7[a] | 201[a] | 34.2[a] | 0.82[a] | 1.37[ab] | 2.19[a] | 0.60 | 3.67[a] |
| 16H/8L | 6.6[a] | 192[a] | 32.9[a] | 0.82[a] | 1.41[a] | 2.23[a] | 0.58 | 4.13[a] |
| 12H/12L | 6.5[a] | 166[a] | 30.3[a] | 0.67[b] | 1.29[ab] | 1.96[a] | 0.52 | 3.95[a] |

Refer to Table 1 for 1), 2) and figures.

lighting.

So far, the studies concerning the thermoperiodicity on the growth and development of plants[5,16,18] and temperature dependence of the translocation of photosynthates[19,20] were made solely by means of alternate variation in temperature between day and night. Therefore, further work will be necessary to elucidate the thermoperiodic effects on the plant growth under continuous lighting.

From the results obtained in the present study, we concluded that the daylength around 20 h using lamps having the light qualities of R/B ratios as high as 10 or more and R/F ratios 1 to 2 may be very effective in increasing the vegetative growth of plants, and that the effect of lighting regimes can be increased by combining with a suitable daily temperature variation.

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* In Japanese.

** In Japanese with English Summary.

*** Translated from Japanese by the present authors.