Effects of Growing Temperature on Translocation of ^{14}C-photosynthates in Cucumber Seedlings

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In growing fruit-vegetables under structures*, not only high initial yields, but also high yields maintained for a long period are required. It has been known by cultural experiments[1,5,6] or by farmer's experiences that such a high productivity can be attained by adequate temperature management in the structures.

Toki[6] examined effects of day- and night-temperatures in cucumber cultivation, and reported that, in view of the behavior of photosynthates, it was more desirable to maintain a higher temperature in the period before midnight combined with a lower temperature after midnight than to maintain a constant night-temperature even though the accumulated night-temperature is same each other. Otsuka and Inayama[5] studied the designing of night-temperature, and reported that the number of lateral branches, which is an yield component, was increased by a low night-temperature, and that the gradual change from day-temperature to the prescribed lowest night-temperature was more effective in increasing yields than the sudden change from day-temperature to the prescribed night-temperature which was kept constant over-night.

In relation to such temperature effects, the authors carried out two experiments using ^{14}C-tracer to examine the relationship between temperature for raising cucumber seedlings and translocation of photosynthates. At first, the uptake of $^{14}CO_2$ and translocation of photosynthates were examined with cucumber seedlings grown under various combinations of day-temperature and night-temperature for the purpose of making clear the optimal temperature range for raising seedlings. The result showed that with the gradient temperature control system in which pre-determined day- and night-temperatures lasted for 4 hr, respectively, the seedlings grown at day-temperature 25°C with night-temperature 14°C (hereafter referred to as D25°–N14°) showed the highest activity of photosynthesis and translocation[3]. Secondly, the seedlings which had grown at D25°–N14° were exposed to $^{14}CO_2$, and after the uptake of $^{14}CO_2$ by the seedlings, they were grown in two plots, i.e., high or low night temperature with the same day-temperature, to examine the effect of night temperature on the fate of photosynthates. The result showed more accumulation of photosynthates under the low night-temperature[4]. Details of these experiments will be presented in this paper.

* Growing horticultural crops under glasshouses or plastic houses.

Effects of growing temperature on $^{14}CO_2$-uptake and translocation[3]

1) Preparation of plant material

Cucumber (CV: Natsu-sairaku No. 3) was sown on 16 January, transplanted to pots (diameter: 12 cm) at the rate of 1 seedling per pot at the cotyledon-expanding stage, and grown for 1 month in phytotrons under different temperature treatments by the gradient temperature control method (Fig. 1). The prescribed day- and night-temperatures are

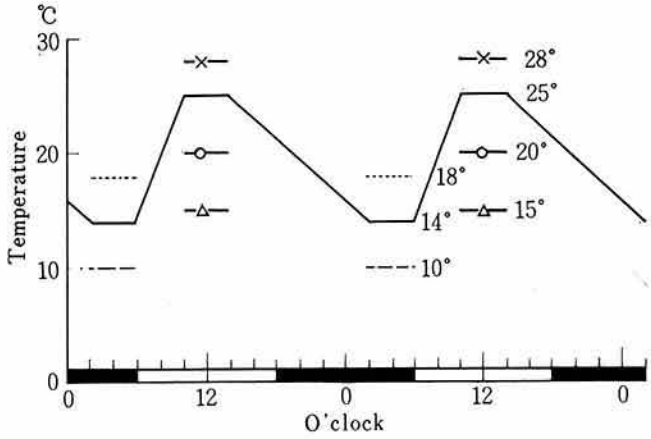

Fig. 1. The gradient temperature control system designed for the present study

given during a 4-hr period of AM10–PM2 and AM2–AM6, respectively. During the intervals between these periods, temperature was changed gradually. To examine the effect of day-temperature, 28°, 25°, 20° and 15°C were adopted for day-temperature combined with 14°C of night-temperature. On the other hand, to examine the effect of night-temperature, 18°, 14°, and 10°C of night-temperature combined with 25°C of day-temperature were adopted. The standard plot, D25°–N14°, was the control for both cases. Growth of seedlings as effected by the temperature treatments is shown in Table 1.

2) $^{14}CO_2$-feeding

On 25 February, seedlings representing characteristics of each temperature treatment were selected and exposed to $^{14}CO_2$. As a set of two different samples was used for the $^{14}CO_2$-feeding under an artificial light with two-repetition, the values of $^{14}CO_2$-uptake obtained can not directly be compared among different treatments, so that relative values to the standard are used for comparisons. $^{14}CO_2$ was generated by adding lactic acid to $Ba^{14}CO_3$ (1 m Ci) and fed to seedlings for 60 min in the cabinet at about 15°C. Then plant samples were taken immediately after the $^{14}CO_2$-feeding (sample group 1), and 1 day after the seedlings were returned to each temperature treatment (sample group 2).

3) Seedling-raising temperature and growth

Dry weight, number of leaves, and leaf area of the sample group 1 are given in Table 2. There is no difference between D28° and D25°, but D20° and D15° are inferior to the standard D25°. On the other hand, these values and plant height (Table 1) are extremely great in N18°. Dry weight per unit leaf area is the smallest for high night-temperature (D25°–N18°), followed by high day-temperature (D28°–N14°).

4) Amount of assimilated $^{14}CO_2$

Total amount of assimilated $^{14}CO_2$ and ^{14}C-specific activity (cpm of ^{14}C/mg of dry matter) expressed by relative values to the standard plot, are given in Fig. 2, which shows that the total assimilated $^{14}CO_2$ is almost proportional to total dry weight, and specific activity to leaf dry weight per unit leaf area.

5) Distribution of assimilated ^{14}C in plant

^{14}C-specific activity of different leaves in the sample group 1 shows that it is highest in the leaf at the middle part of plants in all plots (Fig. 3), suggesting that this leaf is the center of physiological activity of leaves.

Table 1. Effect of seedling-raising temperature* on growth of cucumber seedlings (average of 3 seedlings)

Treatment	Day-temperature treatment				Night-temperature treatment		
Temperature °C (day-night)*	28°–14°	25°–14°	20°–14°	15°–14°	25°–18°	25°–14°	25°–10°
Height of plant (cm)	25.4	15.4	11.6	7.8	58.8	15.4	17.4
Relative value**	1.65	1.00	0.75	0.51	3.82	1.00	1.13
Number of unfolded leaf	7.3	6.0	5.3	5.0	9.3	6.0	6.3
Relative value**	1.22	1.00	0.88	0.83	1.55	1.00	1.05
Length of hypocotyl (cm)	8.9	8.0	6.7	8.6	9.1	8.0	7.8
Relative value**	1.11	1.00	0.84	1.08	1.14	1.00	0.98
Node bearing the 1st female flower***	2.3	1.3	—	1.7	3.0	1.3	2.7

* The day-temperature was set from 10:00 a.m. to 2:00 p.m. and the night one from 2:00 a.m. to 6:00 a.m.
The shift between day and night-temperatures was made as moderate as possible.
** Values relative to the control (D25°–N14°).
*** Node-order counted from the base of plant.

Table 2. Effect of seedling-raising temperature on growth of cucumber seedlings Sampled immediately after $^{14}CO_2$-feeding

Treatment		Day-temperature treatment				Night-temperature treatment		
Temperature °C (day-night)		28°–14°	25°–14°	20°–14°	15°–14°	25°–18°	25°–14°	25°–10°
Dry wt.	leaf blade	1.00	1.00	0.81	0.73	1.77	1.00	0.89
	stem*	1.06	1.00	0.73	0.52	3.33	1.00	0.87
	total top	1.01	1.00	0.78	0.67	2.20	1.00	0.89
Leaf area		1.12	1.00	0.85	0.61	2.18	1.00	0.89
Number of unfolded leaf		1.14	1.00	0.86	0.71	1.43	1.00	0.86
Dry wt. (mg) of leaf per unit leaf area (cm^2)		0.89	1.00	0.95	1.19	0.81	1.00	1.01

Relative values are shown in this Table.
* Stem including hypocotyl, cotyledons, petioles, flowers, buds, folded leaves and shoot apices.

This leaf is located 2 nodes above the leaf with the greatest dry weight. In the sample group 2, movement of ^{14}C-photosynthates to upper leaves was observed in all plots. However, in the high night-temperature plot (D25°–N18°), specific activity in leaves around the center of physiological activity was decreased markedly, and that in the uppermost leaf was also low. This may be explained by the exhaustion of photosynthates due to increased respiration at high night-temperature, although respiration was not measured. Translocation of ^{14}C was slower in D15°–N14° and D25°–N10°, presumably due to lowered receptive function of sink for photosynthates.

6) Conclusion

From the above results, it was made clear that D20°–28° combined with N14° gives better $^{14}CO_2$ assimilation, and temperatures above D20° and N14° are required for better translocation of photosynthates. N18° results in large seedlings, but of poor quality with low photosynthetic activity. D28° seems to be too high as it promoted senescence of lower leaves, and D20° gives less dry matter production than D28° and D25°. In the gradient

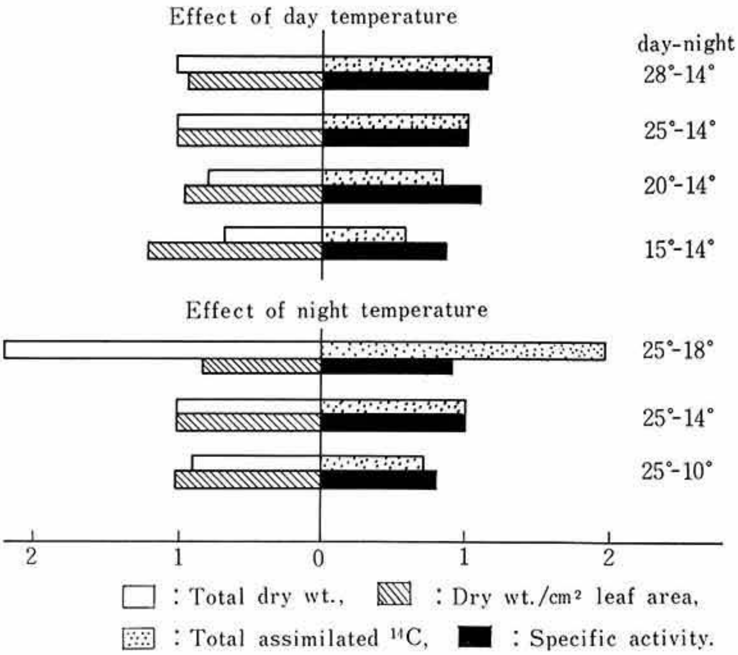

Fig. 2. Effects of temperature for raising seedlings on total assimilated ^{14}C, ^{14}C-specific activity, total dry weight of top, and dry weight per cm^2 leaf area measured immediately after $^{14}CO_2$ feeding

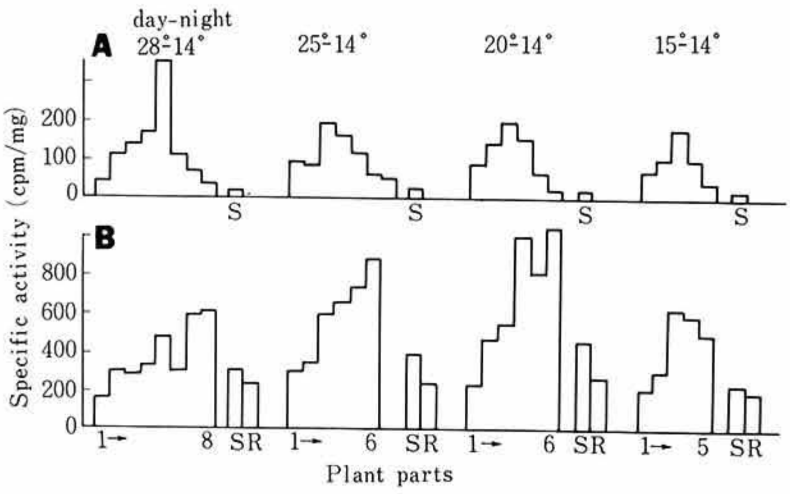

Fig. 3-1. Effect of day temperature on assimilation and distribution of ^{14}C

Note: A: Immediately after $^{14}CO_2$ feeding
B: 1 day after $^{14}CO_2$ feeding
1→: Leaf order from the base
S : Stem including hypocotyl, cotyledon, petioles, flowers, buds, folded leaves and shoot apices
R : Roots

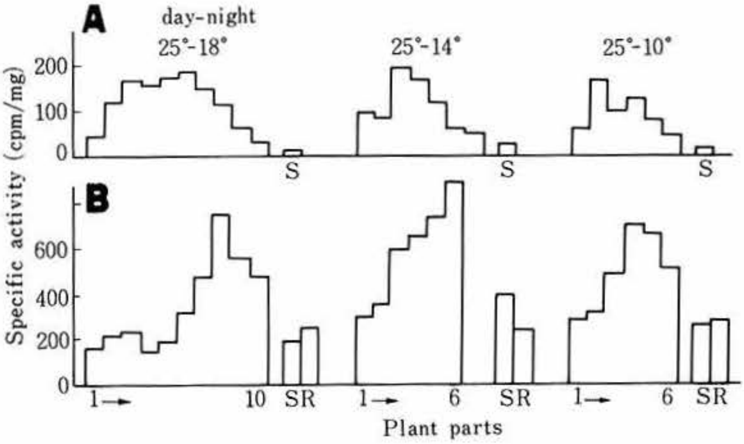

Fig. 3-2. Effect of night temperature on assimilation and distribution of ^{14}C
Note: A,B,1→,S, and R: Same as shown in Fig. 3-1

temperature management with 4 hr period for day and night-temperature each, it can be concluded that D25°–N14° is the optimum temperature condition for raising seedlings of summer-type cucumber.

Effects of night-temperature after $^{14}CO_2$-feeding of fate of ^{14}C-photosynthates[4)]

1) Preparation of plant material and $^{14}CO_2$-feeding

Seedlings (same cultivar as above, sown on 17 and transplanted on 21 April) were raised at D25°–N14°, which was found to be optimal in the above experiment, for 39 days, and exposed to $^{14}CO_2$. After the $^{14}CO_2$-feeding, the seedlings were subjected to two different night-temperature treatments: N20° and N14°, both with D25°. In this case, both day- and night-temperatures lasted for 12 hr, respectively. Fate of the photosynthates was traced for 2–3 days after the $^{14}CO_2$-feeding.

The $^{14}CO_2$-feeding was carried out in a large acryl chamber, containing 15 uniformly grown plants, under natural light (average 23 klux) at 28°C.

2) Night-temperature and percent dry matter

Dry weight of plant parts immediately after the $^{14}CO_2$-feeding and name of plant parts are shown in Fig. 4 and Table 3, respectively. The leaf with the highest dry weight is the 3rd leaf counted from the base of plant. Percent dry matter (Fig. 5) was high in young elongating leaves, the lowest in adult leaves, and slightly high in old leaves.

The percent dry matter observed immediately after the $^{14}CO_2$-feeding was kept almost unchanged after 2–3 days at the low night-temperature, but it was markedly reduced at the high night-temperature in all plant parts. This result can be regarded that the high night-temperature caused an imbalance between accumulation and consumption of dry matter, i.e. consumption exceeding accumulation.

3) Translocation of ^{14}C-photosynthates as effected by night-temperature

Immediately after the $^{14}CO_2$-feeding, specific activity of ^{14}C was low in both old leaves and adult leaves, and the highest in young leaves centering the 10th leaf. When the plants were kept at the high night-temperature, the specific activity decreased markedly

Table 3. Plant parts sampled for measurements

Plant parts		Days after expansion	Abbreviation
Leaf blade (L)	1*	31	Old-leaves (Lo)
	2	24	
	3	20	
	4		Adult-leaves (La)
	5		
	6		
	7		
	8	7	
	9		Young-leaves (Ly)
	10		
	11		
	12		
	T**	0	
Stem***			(S)
Root***			(R)

* Leaf order from the base
** Folded leaves in the stem apex
*** Including cotyledons, petioles, flowers, buds, fruits and lateral shoots
**** Including hypocotyls

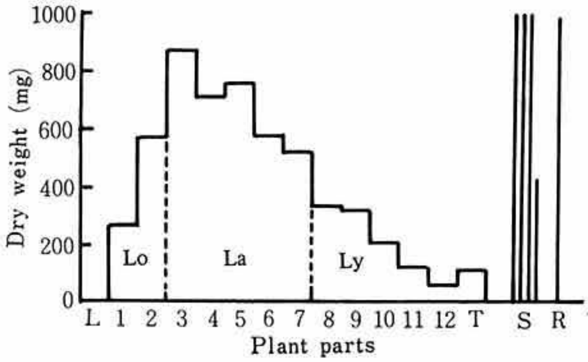

Fig. 4. Dry weight content in each of plant parts sampled immediately after $^{14}CO_2$ feeding
Note: Abbreviation refer to Table 3

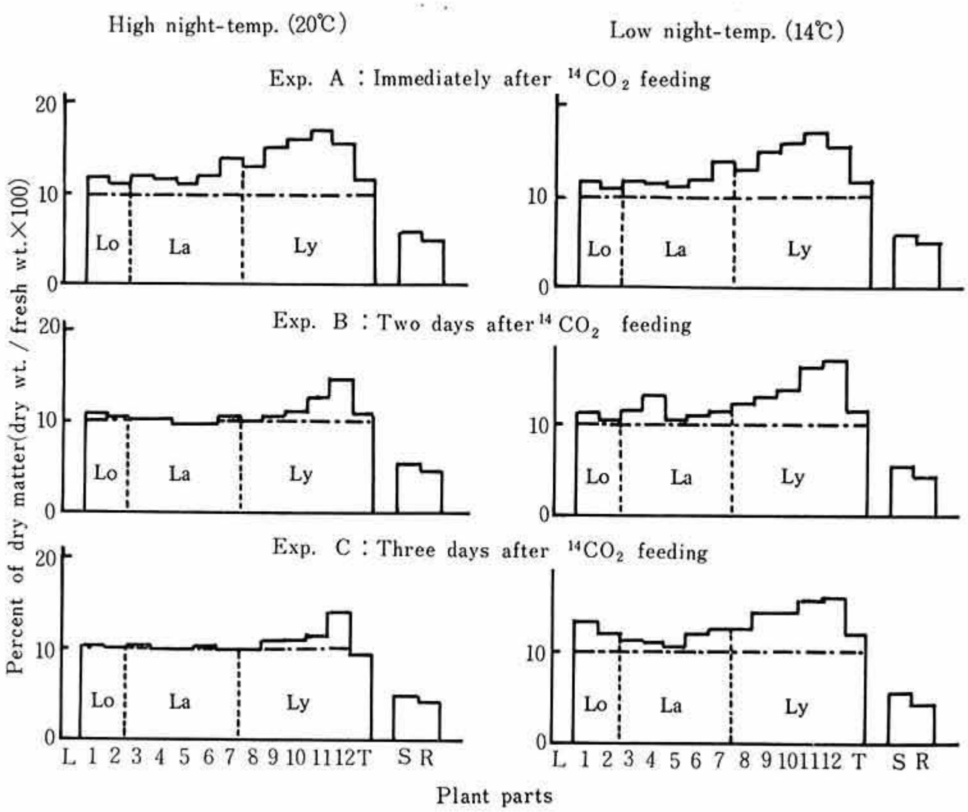

Fig. 5. Effect of night-temperature on dry matter content of plant parts
Note: —·—·—·—: Level of 10%

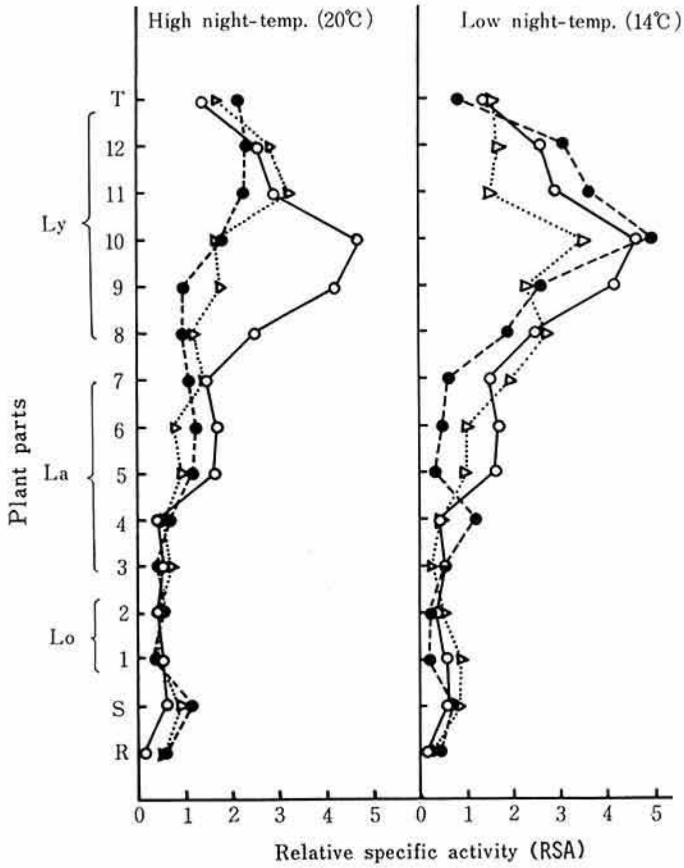

Fig. 6. Effect of night-temperature on relative specific activity of ^{14}C in plant parts
Note: RSA: Specific activity of each part/ specific activity of the whole plant
○—○ : Immediately after $^{14}CO_2$ feeding
●……● : Two days after $^{14}CO_2$ feeding
△……△ : Three days after $^{14}CO_2$ feeding

in young leaves, and only slightly increased in stems and roots. On the contrary, at the low night-temperature it decreased only slightly, and rather increased in young leaves at 2 days after the assimilation. Its increase in old leaves was also observed at 3 days after the assimilation (Fig. 6).

4) Forms of ^{14}C-photosynthates as effected by night-temperature

Hot-ethanol extract of plant samples was fractionated by ether and ion-exchange resin (Fig. 7) to identify the forms of ^{14}C-photosynthates. As given in Fig. 8, alcohol-insoluble fraction containing starch increased in leaves, stems and roots only at the low night-temperature. On the other hand, as for the alcohol-soluble, ether insoluble fraction, it was characteristic at the high night-temperature that amino acid fraction and organic acid fraction were observed to have high ^{14}C-radioactivities in roots and old leaves, respectively, as compared to those shown at the low night-temperature.

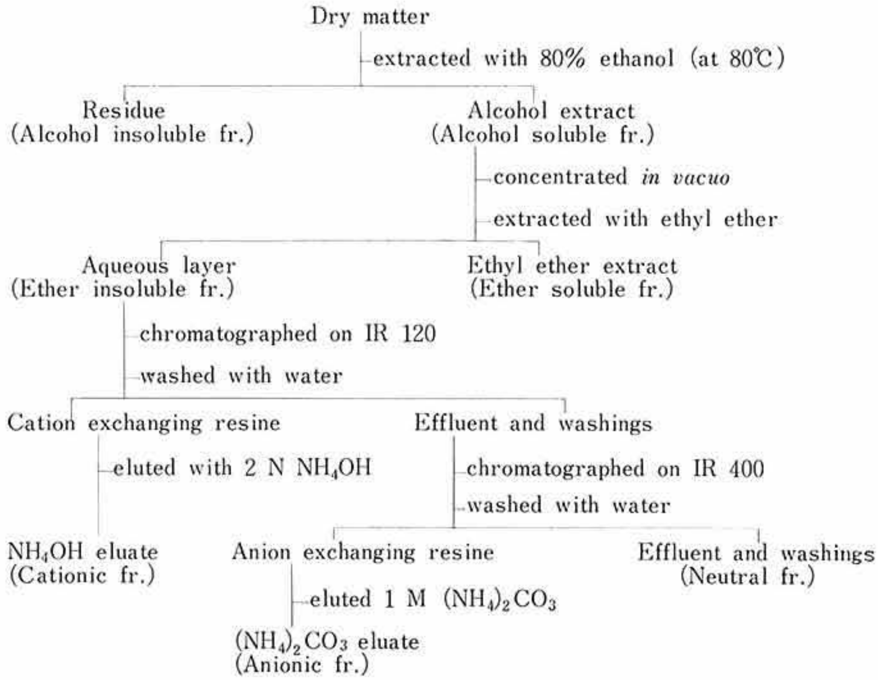

Fig. 7. Method of fractionation of photosynthates

5) Conclusion

The result of the experiment, in which the low and high night-temperature treatments, N14° and N20°, were given to seedlings after $^{14}CO_2$ feeding, indicates that N20° causes a rapid translocation, but great respiratory loss of the photosynthates, while N14° brings about somewhat delayed translocation but great final accumulation due to less exhaustion. This result offers an evidence to the merit of keeping low night-temperature during seedling-raising of cucumber, from the standpoint of photosynthate accumulation, so far as at least the comparison between N14° and N20° is concerned.

Final remarks

For the temperature management under structures, a simple method is usually employed: ventilation to avoid too high temperatures, and heating to raise temperatures to a level not lower than the minimum temperature. Recently, there is a study[6] showing that high day-temperature given from the early morning is better, and some farmers already adopt that method. However, this method seems to need further examinations from the standpoint of temperature adaptability and photosynthetic activity of plants, economy of temperature management, or energy-saving.

The present study attempted to make clear the relationships between temperature and seedling growth under a structure, using physiological techniques. A characteristic of the temperature treatments employed in the present study is to follow the diurnal change of temperature as far as possible, because it seems to be adapted to temperature sensitivity of plants, as well as to economizing temperature management.

The results show 1) High night-temperature (D25°–N18°) caused big seedlings with poor quality, 2) Low night-temperature, N14°, combined with day temperature range, D25°～

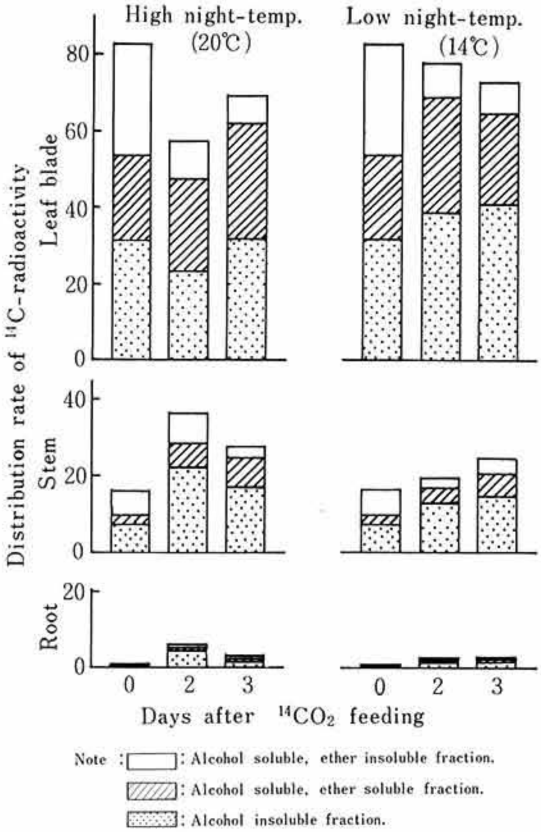

Fig. 8. Effect of night-temperature on translocation of ^{14}C-photosynthates In each plant, the total ^{14}C-radioactivity of three alcohol-extracted fractions is shown as 100

28°, exerted a good effect on CO_2 assimilation and translocation of photosynthates, 3) Photosynthates produced in the seedlings which were raised at D25°–N14° of the gradient temperature changing method showed a rapid translocation, but a great respiratory loss at the subsequent high night-temperature (N20°) while it showed more accumulation at the subsequent low night-temperature (N14°3. These results offer a theoretical basis to the fact that a low night-temperature has been recommended so far in raising seedlings.

References

1) Fujii, T., et al.: Studies on the temperature in fruit vegetable culture. (1) Effect of air and soil temperatures in raising tomato and cucumber seedlings. *Tech. Bull. Facul. Hor. Chiba Univ.*, **10**, 59–70 (1962) [In Japanese with English summary].

2) Hori, Y. et al.: Studies on the effects of root temperature and its combination with air temperature on growth and nutrition of vegetable crops. I. Cucumber, tomato, turnip and snap bean. *Bull. Hort. Res. Sta. Jap.*, Ser. **A7**, 187–214 (1968) [In Japanese with English summary].

3) Inayama, M. & Murakami, T.: Effect of temperature on the translocation of photosynthates in cucumber plants. I. Effect of raising-temperature on the assimilation and distribution of ^{14}C in cucumber seedlings. *J. Jap. Soc. Hort. Sci.*, **42**, 27–34 (1973) [In Japanese with English summary].

4) Murakami, T. & Inayama, M.: Effect of temperature on the translocation of photosynthates in cucumber plants. II. Effect of night-temperature on the translocation of ^{14}C-photosynthates in cucumber seedlings. *J. Jap. Soc. Hort. Sci.*, **44**, 43–54 (1974) [In Japanese with English summary].

5) Otsuka, S. & Inayama, M.: Ecological studies on growing of the vegetable crops under the glass- and plastic-houses. 2. Effect of night-temperature on the growth and yield of summer strain-cucumber. *Agr. Hort.*, 44, 1877–1878 (1969) [In Japanese].

6) Toki, T.: Physiological studies on optimal environment in growing of the vegetable crops under the glass- and plastic-houses. 1). Temperature analysis for growing cucumber. *Bull. Agr. Exp. Sta. Chiba Pref.*, **10**, 62–72 (1970) [In Japanese with English summary].

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