Effects of Root-Zone Heating in Early Morning on Celery Growth and Electricity Cost

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Abstract

We investigated the effects of root-zone heating in early morning to improve the growth of celery and reduce the cost of electricity for root-zone heating during winter in a hilly and mountainous area of Japan. Celery plants were transplanted to a soilless culture system in a sloped greenhouse. Polyethylene bags (30 x 90 cm) filled with bark composts were used as a substrate in the system. We used a heating wire and a thermostat for the root-zone heating. Four heating treatments were set after transplanting: 24h constant heating; CH, early morning (03:00-09:00) heating; MH, daytime (09:00-15:00) heating; DH, and non-heating; NH. The treatments were continued after transplanting through harvesting. The thermostat for root-zone heating was set at 15°C during the heating time. In CH and MH, the fresh weights of plants and the marketable part weights were larger than NH significantly. There were no significant difference in marketable part weights in CH and MH. We thought that MH was more effective in celery growth than other treatments, because the ratio of the difference in marketable part weights (dW) from NH to the diifference in root-zone temperature (dT) from NH was significantly larger than CH and DH. We also thought that maintaining favourable root-zone temperature from the morning to the evening was effective, and that at night was a little effective, in celery growth. The electricity consumption for the root-zone heating in DH was the lowest. However, the electricity cost was the lowest in MH, thanks to the dual fee system for electricity. We consequently concluded that root-zone heating in early-morning was more effective to improve celery growth in winter than constant heating the whole day.

INTRODUCTION

Root-zone heating in hydroponics may improve crop growth in winter. Cost and energy use of root-zone heating may be lower than whole greenhouse heating (Moss, 1983; Moss and Dalgleish, 1984; Hurd and Graves, 1985; Shedlosky and White, 1987). In many reports on root-zone heating, the root temperatures were kept constant in all day. There are a few reports on effects of diurnal change in root-zone temperature on crop growth in hydroponics (Ali et al., 1994; Gent and Ma, 1998; Gent and Ma, 2000). But, these reports were on growth and yield of tomato. The effects of diurnal change in root-zone temperature on other crops were hardly clarified.

We had developed and installed a sloped greenhouse and a soilless culture system for sloping land in hilly and mountainous areas of Japan (Nagasaki et al., 2001; Higashide et al., 2005a, b). In summer-fall season, the period of tomato harvesting was extended and an increased yield of tomato was achieved by installing them in those areas (Higashide et al., 2005a,b, 2007). To use the greenhouse and the system all year round, some crops should be introduced during winter. Then, we tried to install celery cultivation after tomato harvesting. It is difficult to grow celery without heating the greenhouse in winter. However, there is a need to save the energy in spite of heating, because of cost of heating and global warming.

In the control of greenhouse temperature, variable set-points during the day are common to improve crop growth and yield (Toki, 1970, 1975; Calvert and Slack, 1980; Nagaoka and Takahashi, 1983). Early morning heating is applied because the temperature is important for photosynthesis in the morning. However, root-zone heating rather than heating the whole greenhouse might be as efficient for celery growth and save energy because root-zone volume is small and in early morning root-zone temperature is usually the lowest, and also important for photosynthesis. Particularly in early morning there is an additional advantage because in Japan (and other countries as well) the electricity fee from the midnight to the early morning is lower than that in the other time of the day. If root-zone heating in the early morning is effective in plant growth, it should be possible to save both energy and cost of heating. In this report, we investigated the effects of root-zone heating in early morning on celery growth, electricity consumption and cost.

MATERIALS AND METHODS

Seeds of celery plants (*Apium graveolens* 'Cornell 619') were sown in 288-holes plug trays filled with commercial growing medium (Metro mix #350, Sun-Gro, USA) on September 2, 2005 and potted in 7.5cm rock wool cubes on October 11, 2005. Seedlings were transplanted to a soilless culture system for sloping land (Higashide et al., 2005a,b) in a sloped greenhouse (284 m^2; about 300 m above sea level) 108 days after sowing, on December 19, 2005. Polyethylene bags (30 x 90 cm) filled with bark composts were used as a substrate in the system. "Otsuka-A" nutrient solution (Otsuka Chemical Co., Ltd., Osaka, Japan) which was adjusted to an electrical conductivity 2.0~3.0 dS m^{-1} was given to the plants. The plants were harvested 98 days after transplanting, on March 27, 2006. The root-zone heating system in the experiment is shown in Figure 1. A heating wire (Vinyl-Onshosen, Nishiden Sangyo, Tokyo, Japan) and thermostat (Green Ace, Nishiden Sangyo, Tokyo, Japan) were used for heating the root-zone. The heating wire was folded by polyester clothes and set on insulation.

Four heating treatments were set after transplanting; 24h constant heating: CH; early morning (03:00-09:00) heating: MH; daytime (09:00-15:00) heating: DH; and non-heating: NH. The treatments were continued from transplanting through harvest. The thermostat for root-zone heating was set at 15°C during the heating time. To prevent freezing injury in night time, the greenhouse was heated to maintain higher than 3°C air-temperature by a greenhouse heater, and ventilating temperature was 25°C.

Fresh weights of plants and marketable part weights of 15 plants were measured at harvesting. The root-zone temperature was measured every 60 minutes at 3 points in each treatment. Electricity consumption for root-zone heating was also measured.

RESULTS AND DISCUSSION

Figure 2 shows the diurnal change in root-zone temperatures. Root-zone temperatures in NH were the highest in the evening and lowest in the morning, and always lower than in the heating treatments. The temperatures in CH were almost the same as those from the morning to the afternoon in MH and those in the afternoon in DH. The temperatures at night in MH and those from the night to the morning in DH were lower than those in CH. The mean root-zone temperature during the experimental period was the highest in CH and the lowest in NH significantly (Table 1). There were no significance between MH and DH.

Table 2 shows the effects of root-zone heating period on the fresh weights of plants and the marketable part weights. In CH and MH, the fresh weights of plants and the marketable part weights were significantly larger than NH. There were no significant difference in marketable part weights in CH and MH.

Table 3 shows that difference in root-zone temperature (dT) and marketable part weights (dW) from NH, and ratio of dW to dT. The ratio (dW/dT) means the efficiency of root-zone heating on marketable part weights. In MH, it was significantly larger than CH and DH. Therefore, it was considered that MH was more effective in celery growth than the other treatments. A favourable root-zone temperature for celery growth was reported to be between 13 and 23°C (Hori et al., 1970). Therefore, 15°C as set in this experiment should be a favourable root-zone temperature. Ali et al. (1994) reported that the growth of tomato was better when the root-zone temperature was higher in daytime than night compared to constant root-zone temperature all the day in the same average temperature conditions. Therefore, maintaining high root-zone temperature from morning to evening should be effective on the growth of tomato. In our results, root-zone was kept in the favourable temperature region from the morning to the evening in MH. Therefore, it may be considered that maintaining the favourable root-zone temperature from the morning to the evening was also effective, and that night-time root-zone temperature had little effect on celery growth.

The electricity consumption and the electricity cost for the root-zone heating are shown in table 4. The electricity consumption in DH was the lowest; 54% of that in CH. However, the electricity cost was the lowest in MH; 42% of that in CH, when we selected the electricity billing system which is cheaper from late night to early morning in Japan. Therefore, heating root-zone in early-morning could cut the cost of heating substantially.

We consequently concluded that root-zone heating in early morning in winter was more effective than constant heating the whole day, not only in improving celery growth but also in saving energy and cost for heating.

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Tables

Table 1. Average root-zone temperature in the whole experiment period in each heating treatment.

Heating time of the day	Average root-zone temperature (°C)
24h constant (CH)	15.3a[z]
Early morning (MH)	13.4b
Daytime (DH)	12.6b
Non-heating (NH)	9.3c

[z] Means separation at 5% level by Tukey's multiple comparison test, n=3.

Table 2. Effects of root-zone heating time of the day on fresh weights of plants and marketable part weights.

Heating time of the day	Fresh weight of plants (g)	Marketable part weights (g)
24h constant (CH)	2760 a[z]	1613 ab
Early morning (MH)	3015 a	1783 a
Daytime (DH)	2576 ab	1460 b
Non-heating (NH)	2095 b	1229 c

[z] Means separation at 5% level by Tukey's multiple comparison test, n=15.

Table 3. Difference in root-zone temperature (dT) and marketable part weights (dW) from NH, and the ratio of dW to dT.

Heating time of the day	Difference from NH		dW/dT
	Root-zone temperature(dT) (°C)	Marketable part weights(dW) (g)	($g\ ^{\circ}C^{-1}$)
24h constant (CH)	6.0	384 b[z]	64.0 b
Early morning (MH)	4.1	554 a	135.1 a
Daytime (DH)	3.3	231 c	69.9 b

[z] Means separation at 5% level by Tukey's multiple comparison test, n=15.

Table 4. Effects of time of the day application of root-zone heating on the electricity consumption and cost of heating.

Heating time of the day	Electricity consumption[z] (kWh m^{-2})	Electricity cost[z] (Euro m^{-2})
24h constant (CH)	12.9 (100) [y]	1.61 (100) [y]
Early morning (MH)	8.0 (62)	0.68 (42)
Daytime (DH)	7.0 (54)	0.88 (54)

[z] The value per m^2 greenhouse area. The electricity cost is calculated choosing in each case the cheapest option according to the Japanese billing system: either all day constant (0.13 euro kWh^{-1}) for 24h constant heating and daytime heating; cheap at night and expensive at day (7:00-23:00: 0.16 euro kWh^{-1}; 23:00-7:00: 0.04 euro kWh^{-1}) for early morning heating. The conversion rate of 1 yen = 0.00625 euro has been applied throughout.
[y] Percentage against the value of 24h constant heating.

Figures

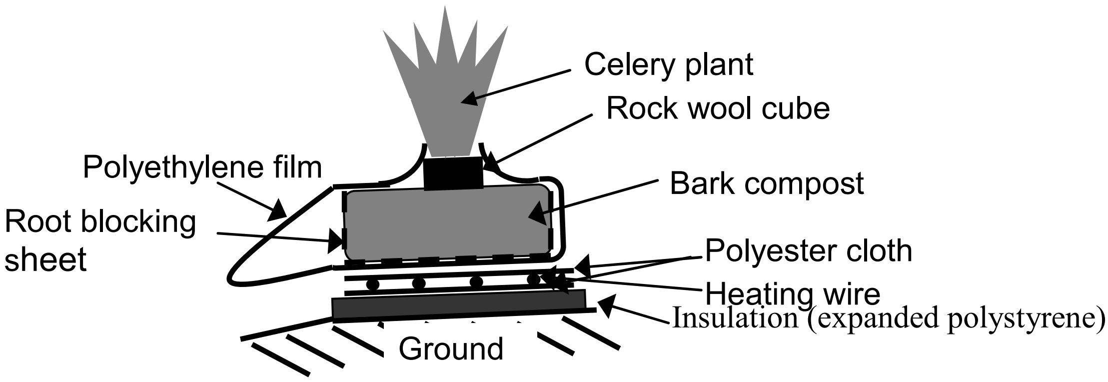

Fig. 1. Root-zone heating system in the experiment.

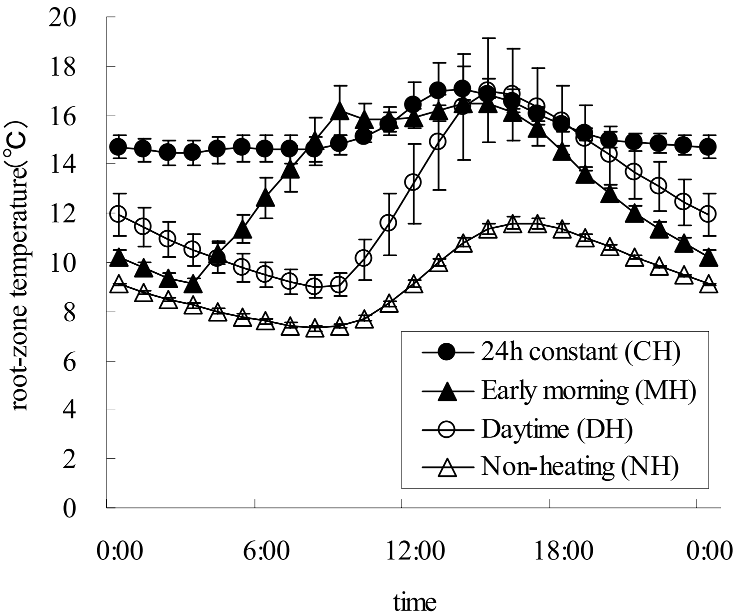

Fig. 2. Diurnal change in root-zone temperatures in different root-zone heating time of the day (Whole average in the experiment). Vertical bars show standard error (n=3).