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Growth of Bedding Plants in Response to Root-zone Heating and Night Temperature Regimes

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Abstract. **Nine bedding plant vegetable and flower cultivars were grown in each of 10 night air and root media temperature regimes. Generally, fresh and dry weights were greater at 16°C than at 7° night air temperature when root-zone (RZ) heating was not used. Soil warming increased fresh and dry weights of all cultivars grown at 16° night air temperatures. When air temperatures were below 16°, soil warming maintained fresh and dry weights equivalent to or better than plants grown at 16° without soil warming. Two split-night (SN) air temperature regimes were as effective as a constant 16° night temperature, ranking first and 3rd in fresh and dry weight per unit of energy consumption. All soil warming treatments had higher energy productivity than the 16° air temperature treatment with no RZ heating.**

Energy conservation practices should reduce energy consumption per unit of fresh or dry weight while maintaining or increasing plant quality. Reduced air temperatures for part of the night (SN heating), and soil warming (RZ heating) can reduce energy consumption (2, 4, 7, 9, 14, 16). Studies have examined whole-plant growth responses to RZ temperatures (3, 8, 10), but few have considered the seedling growth period separately.

The objectives of this study were to examine the effects of selected combinations of night air temperature regimes and RZ heating on seedling growth of five vegetable and four flower bedding plant crops and to determine energy productivity (EP) associated with each temperature combination.

Materials and Methods

Treatments. An entire greenhouse was maintained at 7° ± 1°C during the night by heating or venting as necessary and at a minimum of 16° ± 2° during the day by heating. Ventilation began when the day temperature rose to 21°.

Ten night temperature treatments were maintained by covering or not covering individual benches with thermal blankets and by supplying or not supplying RZ heating for 24 hr per day (Table 1).

Two treatments were selected as experimental controls. The cold control (CC) bench area was maintained at 7°C during the night. This temperature also was the level maintained in the greenhouse at night outside of the thermal blankets. No thermal blankets were pulled over this treatment area during the 14-hr dark period. The warm control (WC) was a 16° night air temperature, which was selected to simulate growing under a more traditional night air temperature. Thermal blankets and electric resistance heaters placed under the benches were used to maintain air temperature in the WC bench area above the surrounding 7° greenhouse air temperature. No soil heating was used for either of the control treatments. Soil temperatures were called ambient, with a minimum of 7° or 16°, since they responded to air temperature.

Two treatments with a SN air temperature regime were at 16°C for the first part of the night, and at 7° for the 2nd part of the night. The temperature was maintained at 16° for 8 hr in the split-night long (SPL) and at 16° for 4 hr in the split night short (SPS) treatment; the 14-hr night began at 1800 HR. Like the controls, the soil was not heated in these treatments. Consequently, soil temperature responded to the air temperature of the treatment and to incoming solar radiation. During the late afternoon (1430–1530 HR) soil temperatures were 16° in each treatment and dropped to 15° during the (16° temperature portion) night, and then dropped rapidly during the 7° portion. By 0800 HR, the 16° (8 hr)/7° (6 hr) treatment had a 10° ± 1° soil temperature, while the 16° (4 hr)/7° (10 hr) treatment had a 8° ± 1° soil temperature.

Two treatments (16/16, 16/21), which employed both soil heating and warm air temperature, were 16° air temperature at two different levels of soil warming (16° and 21°, respectively). Soil heating was supplied by an electric hot water heater so that watt hour meters could be used to monitor energy consumption in each treatment area. Warm water was pumped through 13 mm (i.d.) black polyethylene pipe buried 13 cm deep in sand in an insulated concrete v-bottom bench.

The two soil heating treatments were 16° and 21°C (Am/16, Am/21) soil temperature combined with night air temperatures that were influenced by the soil heating systems of these treatments. This heating was accomplished by pulling thermal blankets over these treatment areas at night. The net result was to modify air temperatures in the crop zone so that they would be warmer than the 7° air temperature of the greenhouse section. Actual air temperatures under the blankets varied between 10° and 14°, depending on how rapidly an overall 7° greenhouse temperature was achieved during the dark period.

The last two treatments (7/16, 7/21) each employed one of the two levels of soil heating used in the other soil heating treatments. However, in these treatments, the crops were grown at the 7° air temperature at which the greenhouse section was run during the night. No thermal blankets were pulled over these two treatment areas during the night.

Three individual crop cycles or experimental replications in time were conducted during the course of the research project. The first replication began on 18 Dec. with transplanting into bedding plant flats and ended on 17 Jan.; the 2nd began 22 Jan.

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Table 1. Temperature treatments and energy consumption.

Treatment code	Treatment description	Air temp (°C)	Soil temp (°C)	Thermal blanket	Energy consumption (kwh/0.09 m^2)
CC	7/ambient	7	6–13	No	0.00
WC	16/ambient	16	15–20	Yes	0.28
SNL	16 (8 hr)/ambient 7 (6 hr)	16 7	10–16	Yes	0.14
SNS	16 (4 hr)/ambient 7 (10 hr)	16 7	8–15	Yes	0.06
16/16	16/16	16	16	Yes	0.30
16/21	16/21	16	21	Yes	0.39
Am/16	ambient/16	10–13	16	Yes	0.12
Am/21	ambient/21	11–15	21	Yes	0.23
7/16	7/16	7	16	No	0.18
7/21	7/21	7	21	No	0.31

All air temperatures (°C) were for the 14-hr night period, which commenced at 1800 HR and ended at 0800 HR the next day, except as noted for SNL and SNS. The minimum day temperature was 16°, which was maintained from 0800 HR until the beginning of the next dark period. Soil temperatures (°C) were maintained 24 hr per day.

Table 2. Effects of night air and soil temperatures on mean fresh weight and mean dry weight yields of five vegetable cultivars.

Treatment temp		Crop and cultivar									
		Cabbage (Emerald Cross)		Eggplant (Blacknight)		Pepper (California Wonder)		Lettuce (Buttercrunch)		Tomato (Big Boy)	
Air (°C)	Soil (°C)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)
7	Ambient	32.7 c	2.5 b	11.3 d	1.4 e	8.2 d	1.1 e	36.6 c	2.4 b	14.8 e	1.3 c
16	Ambient	41.3 b	3.0 ab	22.8 c	2.0 bcd	15.5 c	1.6 d	52.3 b	2.8 ab	27.3 cd	1.9 ab
16 (8 hr) 7 (6 hr)	Ambient	44.3 ab	3.3 a	22.5 c	2.0 bcd	20.4 b	2.2 ab	54.2 ab	3.0 ab	28.0 bcd	2.0 ab
16 (4 hr) 7 (10 hr)	Ambient	44.2 ab	3.2 a	23.3 c	2.1 bcd	16.9 bc	1.9 bcd	53.7 ab	3.0 ab	23.5 d	1.8 b
16	16	44.5 ab	3.1 a	32.7 ab	2.3 ab	20.6 b	2.0 bcd	60.4 ab	3.1 a	34.9 ab	2.2 a
16	21	47.5 a	3.2 a	38.8 a	2.5 a	25.8 a	2.4 a	64.1 a	3.4 a	37.3 a	2.2 a
Ambient	16	45.6 ab	3.2 a	23.3 c	1.7 d	17.5 bc	1.9 bcd	58.7 ab	3.1 a	29.8 bcd	2.0 ab
Ambient	21	46.0 ab	3.2 a	31.2 b	2.2 abc	19.7 bc	2.0 bcd	62.0 ab	3.2 ab	31.4 abc	2.0 ab
7	16	45.5 ab	3.4 a	22.3 c	1.9 cd	17.0 bc	1.8 cd	58.4 ab	3.2 a	23.8 d	1.7 b
7	21	46.2 ab	3.4 a	21.8 c	1.8 cd	19.1 bc	2.0 bcd	61.9 ab	3.4 a	30.2 abcd	2.1 ab
Crop mean		43.8	3.2	25.0	2.0	18.1	1.9	56.2	3.1	28.1	1.9
SE		3.7	0.3	2.8	0.2	1.9	0.2	6.0	0.3	3.4	0.2

[z]Mean separation by Waller and Duncan's (Bayesian) least significant difference test, k = 100.

and ended 20 Feb.; and the final replication was started 26 Feb. and terminated 26 Mar.

Nine bedding plant cultivars were grown in each temperature treatment. Vegetables included *Brassica oleracea* Group Capitata 'Emerald Cross', *Capsicum annuum* 'California Wonder', *Solanum Melongena* 'Blacknite', *Lactuca sativa* 'Buttercrunch', and *Lycopersicon esculentum* 'Big Boy'. Flowers included *Antirrhinum majus* 'World's Fair White', *Petunia* x *hybrida* 'White Cascade', *Viola* x *Wittrockiana* 'Imperial Blue', and *Tagetes patula* 'Orange Jubilee'. Crops were selected to include species requiring cool, moderate, and warm temperatures within each commodity group.

Crop culture. For each of three crop cycles the seeds of each species were germinated in a growth room at a constant 21° ± 2°C air temperature with 16 hr of cool-white fluorescent light plus 20% of total wattage as incandescent light. Irradiance was 200 ± 50 $\mu mol \cdot s^{-1} \cdot m^{-2}$.

Seeds were germinated in Seedling model 001A Todd planter flats. Each flat had 595 cavities (1.3 cm square by 2.5 cm deep). Plants grown in individual cavities permitted uniform transplant selection, increased transplanting efficiency, and reduced transplant shock.

Seedlings were transplanted when the first true leaves expanded and touched the leaves of adjacent plants. Time from seed sowing to transplant differed for each species and was determined prior to the beginning of the experiment so that each species could be timed to meet the preselected transplanting dates.

For each species and for each replication, 960 seedlings were transplanted into commercial bedding plant flats 54.5 cm long × 28 cm wide × 6 cm deep. Each flat contained a removable plastic insert with 32 individual 6-cm-square by 5.5-cm-deep compartments. The compartments were arranged in the flat four across by eight lengthwise.

A growing medium consisting of a mixture of 1 sphagnum peat : 1 coarse vermiculite : 1 coarse perlite : 1 mushroom casing soil (by volume) (15) was used to fill each flat. Plants were irrigated as needed with 15N–7P–14K (Peter's 15–16–17) solution at 200 ppm N.

Table 3. Effects of night air and soil temperature on mean fresh weight and mean dry weight yields of four flower cultivars.

Treatment temp		Crop and cultivar							
		Marigold (Orange Jubilee)		Pansy (Imperial Blue)		Petunia (White Cascade)		Snapdragon (World's Fair White)	
Air (°C)	Soil (°C)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)	Fresh wt (g)	Dry wt (g)
7	Ambient	6.2 d	0.6 b	17.2 c	2.4 c	48.4 d	3.1 d	18.2 d	2.1 c
16	Ambient	13.1 abc	1.1 a	22.6 b	2.7 bc	66.0 c	3.7 cd	27.1 c	2.5 b
16 (8 hr) 7 (6 hr)	Ambient	13.2 abc	1.2 a	25.5 ab	3.0 abc	73.0 bc	4.1 abc	26.2 c	2.5 b
16 (4 hr) 7 (10 hr)	Ambient	10.9 bc	1.0 a	25.7 ab	3.0 abc	67.3 c	3.9 bcd	27.0 c	2.7 ab
16	16	15.0 a	1.2 a	27.2 ab	3.1 ab	85.9 ab	4.6 ab	32.5 a	2.9 a
16	21	14.7 a	1.2 a	26.0 ab	3.0 abc	93.7 a	4.5 ab	31.4 ab	2.9 ab
Ambient	16	11.4 bc	1.0 a	26.0 ab	3.0 abc	90.0 a	4.6 ab	29.1 abc	2.7 ab
Ambient	21	14.1 ab	1.2 a	28.5 a	3.3 ab	99.0 a	4.9 a	32.2 a	3.0 a
7	16	10.4 c	0.9 ab	23.2 b	2.9 abc	73.8 bc	4.0 bc	27.9 bc	2.8 ab
7	21	10.8 c	1.0 a	27.2 ab	3.4 a	90.0 a	4.6 ab	28.7 abc	2.9 a
Crop mean		12.0	1.2	25.0	3.0	78.7	7.6	28.0	2.1
SE		1.0	0.1	2.9	0.3	4.2	0.5	2.7	0.2

[z]Mean separation by Waller and Duncan's (Bayesian) least significant difference test, k = 100.

Table 4. Energy productivity of mean total fresh weight (g) and dry weight (g) per 0.09 m^2 of growing area compared to the mean nightly (14-hr) energy consumption (kwh/0.09 m^2) for five vegetable cultivars.

Treatment temp		Crop and cultivar									
		Cabbage (Emerald Cross)		Eggplant (Blacknite)		Pepper (California Wonder)		Lettuce (Buttercrunch)		Tomato (Big Boy)	
Air (°C)	Soil (°C)	Fresh wt EP[z]	Dry wt EP	Fresh wt EP	Dry wt EP	Fresh wt EP	Dry wt EP	Fresh wt EP	Dry wt EP	Fresh wt EP	Dry wt EP
7	Ambient	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	Ambient	61.9	3.7	82.8	4.6	52.3	3.6	113.2	3.4	90.3	4.1
16 (8 hr) 7 (6 hr)	Ambient	170.3	11.1	164.6	9.2	179.1	14.9	257.5	9.6	194.2	9.3
16 (4 hr) 7 (10 hr)	Ambient	425.2	23.1	438.3	27.7	320.5	29.7	630.9	23.3	324.1	16.0
16	16	79.5	3.9	144.6	6.1	83.7	6.0	160.8	4.8	135.6	5.5
16	21	76.2	3.7	142.1	6.1	90.4	6.3	142.1	5.1	116.1	4.6
Ambient	16	214.4	10.7	199.3	6.8	153.9	11.8	367.4	11.3	248.7	11.3
Ambient	21	118.1	5.8	175.8	8.3	101.6	7.3	225.2	6.9	147.0	5.7
7	16	146.4	10.1	125.6	5.9	99.9	7.5	249.4	9.5	103.0	4.6
7	21	88.3	5.7	68.3	3.0	70.9	5.7	164.8	6.9	101.0	4.8

[z]Energy productivity (EP): Δ FW/Δ energy, e.g., fresh weight of cabbage $41.3-32.7/0.28 \times 2 = 61.4$ g/kwh per 0.09 m^2. The difference in the table value of 61.9 and the example value of 61.4 is due to rounding-off errors in the example.

Thirty flats were then randomly arranged on the bench space of each treatment area. The flats were positioned three rows across the bench with 10 flats in each row, with the long axis of the flat parallel to the long axis of the bench. Randomization of the flats was not complete in that each of the crop species was designed to be located in each of three rows on an individual bench. The three flats nearest the center of the bench for each treatment area served as buffers. No data were taken from these three flats.

Seedling transplants were established 4 days before any temperature treatments were begun. During this time, night air temperature was 16° ± 2°C and soil warming was not used. All species underwent the 4-day adjustment with the exception of cabbage, lettuce, and marigolds, which were transplanted on the day temperature treatments were begun because of the logistics of harvesting and maintaining the schedules of the following replications.

Root-zone temperatures. Root-zone temperatures were measured with thermocouples in each treatment before irrigating. Those treatments having the coldest RZ temperatures were irrigated first. The water temperature was then increased, with a heat exchanger to the RZ temperature of the next warmer soil treatments before they were irrigated.

Harvesting. The duration of time from the start of each replication to the time a particular species was harvested for data collection was dependent on certain prescribed criteria. Primary consideration was given to the status of the plants growing under the 16°C night air temperature control treatment. If the majority of a particular plant species on this treatment were of marketable size, then all treatments of that species were harvested. If plants in the 16° treatments were not further advanced, then plants in the other treatments were examined, particularly those in the 16° or a 21° soil warming regime. If the development of plants was at a stage where it appeared that competition for light among

Table 5. Energy productivity of mean total fresh weight (g) and dry weight (g) per 0.09 m^2 of growing area compared to the mean nightly (14-hr) energy consumption (kwh/0.09 m^2) for four flower cultivars.

Treatment temp		Crop and cultivar							
		Marigold (Orange Jubilee)		Pansy (Imperial Blue)		Petunia (White Cascade)		Snapdragon (World's Fair White)	
Air (°C)	Soil (°C)	Fresh wt EP[z]	Dry wt EP	Fresh wt EP	Dry wt EP	Fresh wt EP	Dry wt EP	Fresh wt EP	Dry wt EP
7	Ambient	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	Ambient	49.9	3.7	38.9	2.0	126.7	4.0	64.5	3.0
16 (8 hr) 7 (6 hr)	Ambient	102.9	7.6	120.8	8.6	360.3	14.2	117.4	5.9
16 (4 hr) 7 (10 hr)	Ambient	175.2	12.3	312.4	23.6	695.4	27.4	324.1	21.5
16	16	59.5	4.0	70.8	4.9	252.2	10.0	96.6	5.3
16	21	44.3	3.0	45.2	2.8	233.5	7.3	68.3	4.0
Ambient	16	87.7	6.0	148.9	10.5	690.0	25.1	182.4	10.0
Ambient	21	70.6	5.0	100.0	7.7	447.5	15.4	124.3	7.6
7	16	47.9	3.3	67.8	5.7	288.8	9.7	111.3	7.7
7	21	30.2	2.5	65.3	6.6	271.1	9.6	68.8	5.4

[z]Energy productivity (EP): Δ FW/Δ energy, e.g., fresh weight of of marigold $13.1-6.2/0.28 \times 2 = 49.3$ g/kwh per 0.09 m^2. The difference in the table value of 49.9 and the example value of 49.3 is due to rounding-off errors in the example.

Table 6. Mean energy productivity (EP) of the mean total fresh weight (g) and dry weight (g) growth of all crop species per 0.09 m^2 of growing area compared to the mean nightly (14-hr) energy consumption (kwh/0.09 m^2).

Treatment temp					
Air (°C)	Soil (°C)	Fresh wt EP	Dry wt EP	Mean EP[z]	Rank[y]
7	Ambient	0.0	0.0	0.0	10
16	Ambient	75.6	3.6	39.6	9
16 (8 hr) 7 (6 hr)	Ambient	185.2	10.1	97.6	3
16 (4 hr) 7 (10 hr)	Ambient	405.1	22.7	213.9	1
16	16	120.4	5.6	63.0	6
16	21	106.5	4.8	55.6	7
Ambient	16	254.7	11.5	133.1	2
Ambient	21	167.8	7.6	87.7	4
7	16	137.8	7.1	72.4	5
7	21	103.2	5.6	54.4	8

[z]Energy productivity (EP): Δ FW/Δ energy, e.g., fresh weight of cabbage $41.3-32.7/0.28 \times 2 = 61.4$ g/kwh/0.09 m^2. Mean EP is the mean of fresh and dry weight EPs.

[y]Numerical ranking based on values from the column of mean EPs. Treatments are ranked from most efficient to least.

the plants in individual flats would soon begin, these species were harvested. Finally, all plants had to be harvested before the date of transplanting for the next crop replication. Starting no more than 10 days before the next transplant date, one species per day was harvested using the previous guidelines to determine the order of harvest.

Measurements and calculations. Night air and RZ temperatures were sampled every 12 min for each treatment using a strip chart recorder and copper-constantan (T-type) thermocouple probes. Air temperatures were monitored at the aspirated thermostat, and soil temperatures were measured 5 mm from the bottom of the growing container at 10 locations on each treatment. The soil temperature data were converted to an average value of the 10 locations by making a parallel connection between all of the thermocouple probe wires. Recorded temperature data were examined on a daily basis to ensure that treatment temperatures were within ± 1°C of the desired set point, and adjustments were made if needed.

Kilowatt-hour demand readings for electric heating were recorded daily at 0830 and 1630 HR for air heating and soil warming with hot water systems for all applicable treatments during each experimental replication.

At harvest, fresh and dry weight data were recorded for the center two rows in each of three flats. Each row of eight plants was treated as a single observation, giving a total of six observations per crop species for each treatment.

Fresh weight, dry weight, and energy usage data were compiled for replications of each of the first nine treatments. The CC treatment, which required no energy input, was considered the base line above which nightly average energy consumption of the other treatments was calculated in kilowatt hours per 0.09 square meters of growing area.

The data then were used to establish energy productivity (Δ fw/Δ energy) for the remaining nine experimental treatments. These values represented a treatment's average net increase in yield per 0.09 m^2 of growing area over the CC divided by the average nightly kilowatt hour consumption per 0.09 m^2 of growing area needed to maintain the air and soil temperatures above those of the CC treatment. The EPs were calculated for the respective fresh and dry weight yields of each crop, e.g. fresh weight of cabbage $41.3 - 32.7/0.28 \times 2 = 61$ g/kwh per 0.09 m^2.

The EPs were used to rank each treatment's relative efficiency in converting additional energy input into fresh and dry weight yields. These values should be interpreted cautiously, since the ratio of surface area of thermal blanket to volume of heated air beneath it was much greater than it would have been if the entire greenhouse section were covered with a single thermal blanket. An eave-to-eave thermal blanket would be much more efficient than the bench enclosures used in this experiment.

Results and Discussion

General. Fresh and dry weights generally were greater at 16°C night air temperature than at 7° night air temperature when soil heating was not used. However, dry weights were not significantly greater at a 16° than at a 7° air with cabbage, lettuce, pansy, and petunia (Tables 2 and 3).

Soil warming. Soil warming was beneficial for all crop species compared to the CC. At a 16°C night air temperature, soil warming produced larger fresh and dry weight yields for all crop species than 16° night air temperature without soil heating. The fresh weights for eggplant, pepper, tomato, petunia, and snapdragon and dry weights for petunia and snapdragon were significantly greater when soil heat (16° and 21°) was used in conjunction with 16° night air temperature than when it was not (Tables 4 and 5). For the majority of crops, at least one of the two levels of soil heating produced dry weights that were significantly better than the 16° night air temperature without soil heat.

In treatments where air temperatures were below 16°C, soil warming maintained fresh and dry weights that were not statistically different from those of the 16° night air temperature regime without soil heating. Petunia fresh and dry weights were significantly greater with 7/21 than with WC. Similar results for dry weight occurred with pansy and snapdragon. When grown with 7/16 or 7/21, all cultivars, with the exception of eggplant,marigold, and tomato, had fresh and dry weights that were heavier than those with WC. These differences, however, were not always significant.

The soil warming treatments, which had thermal blankets to help maintain air temperatures above 7°C but below 16°, also had fresh and dry weights that generally were equivalent to growing the crop at 16° with no soil heating. Fresh and dry weights of petunias grown at 16° and 21° soil heating using thermal blankets to trap bench heat significantly exceeded the 16° night air temperature treatment with no soil heat. Likewise, increased fresh weight of snapdragon, pansy, and eggplant, and dry weights of snapdragon, demonstrated the significant benefits of 21° soil temperature.

The EP for all crops for all six soil heating treatments were higher than the EP for WC (Table 6). Am/16 was the most-efficient soil heating regime for all crops. Am/21 was the next most-efficient soil heating treatment. However, this treatment was only slightly better than 7/16. The EPs also were related to the reduction in time to marketable size; e.g., with a small amount of additional daily energy use the same-size plant might be produced in fewer days. The youngest stages of seedling development appear to be the most responsive and therefore the most efficient in using increased energy inputs.

Split-night temperatures. With only one exception, both SN air temperature regimes proved to be equally effective as a constant 16°C night temperature. These observations were consistent for both fresh and dry weights with all the crop species. The fresh and dry weights of 'California Wonder' pepper were significantly heavier with SNL than with 16/16.

Despite nonsignificant growth differences between treatments, the two split-night air temperature schemes were always more efficient in their overall energy use when compared to the constant 16°C night air temperature treatment. Furthermore, the EP of the two SN treatments ranked first and 3rd among the other treatments.

Understanding the mechanisms that were responsible for the success of these SN air temperature regimes will require further investigation into their effects on other crops at various physiological stages of growth. However, the premise that the majority of growth occurs in a plant within a few hours after the beginning of the dark period (17) seems to have been demonstrated by the results of this experiment. Varying the high temperature portion of the night, which occurred at the beginning of the dark period, between 4, 8, and 14 hr did not reduce significantly the fresh or dry weights of any of the crops investigated. Therefore, it could be concluded that most growth occurred during the 4-hr period that followed the beginning of the dark phase.

These results are perhaps the most important of the entire experiment because they demonstrated that significant energy savings could be realized with the simple installation of a time-controlled multistage thermostat on an existing heating system.

Split-night temperatures vs. soil heating. A major drawback of the SN temperature treatments was that the soil temperatures on these treatments would fall below 10° during the cold (7°) temperature portion of the night. Although this decline did not appear to reduce growth, it might if crop species, physiological age, or temperature regimes were altered.

This experiment showed that all crops produced fresh and dry weights where soil heating was used that were equivalent to a 16°C night air temperature with no soil heating, irrespective of the air or soil temperatures. For several treatments, where soil treatments maintained air temperatures below 16°, growth was still significantly better than the 16° treatment with no soil heat.

By comparison, both of the SN air temperature regimes were also equivalent to the WC treatment over all crop species. Only with 'California Wonder' pepper did fresh or dry weight of SNL significantly exceed growth of WC.

Reports in the literature for other crops have confirmed the importance of soil heating with night air temperatures below 16°C (1, 4, 11, 13, 16). However, other reports have demonstrated evidence to the contrary (5, 6, 12). These published differences indicate a need for further research on crop response to night air and root temperature regimes, particularly at night air temperatures in the range of 7° to 16°. Additionally, an investigation of crop response to these regimes at various stages of growth would be helpful.

Split-night air temperature and soil heating technologies could be combined into a system that would produce greater growth and energy savings than this experiment. Preliminary work by White and Shedlosky (unpublished data) on poinsettia cultivars 'Annette Hegg Diva' and 'Annette Hegg White' indicated that such a system could be used from the beginning of short days to maturity with no delay in flowering or commercial quality. The system also demonstrated significant energy savings in terms of fuel consumption when compared to a 16°C night air temperature regime without soil heat.

The results of this experiment indicate that a greenhouse night air temperature of 16°C with no soil warming (ambient) could be replaced effectively by other less "traditional" night temperature regimes. These alternative temperature regimes not only produced equivalent or significantly better plant growth, but also saved energy.

Four treatments in this experiment were noteworthy. The first two were SN air temperature treatments without soil heating, each maintained at a 16°C air temperature for the first portion of the 14-hr dark period (4 and 8 hr, respectively), and 7° thereafter. The 2nd two were soil heating treatments that respectively had a 16° and 21° level of soil warming combined with the use of thermal blankets over the growing area to maintain an ambient air temperature of 10° to 14°. For energy efficiency, the 16° (4 hr)/7° (10 hr) SN air temperature treatment ranked first, followed by the ambient/16° soil heating treatment, the 16° (8 hr) ambient/7° (g hr) SN treatment, and by the ambient/21° soil heating treatment.

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