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Greenhouse Rose Production with Split Night Temperatures

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Abstract. **The reduction of the minimum temperature during the latter part of the dark period as a means of energy conservation was studied for 3 consecutive years with greenhouse roses. A warm temperature during the early part of the dark period was more promotive of growth than at subsequent or continuing portions of the dark period. The most rapid bloom development in the first and 3rd years' trials was at the continuous warm night temperature of 17°C. During the 2nd year, the greatest production of blooms was also at the continuous minimum night temperature of 17°, but, in the 3rd year, a reduction in the minimum night temperature to 9° from 0100 to 0800 HR did not reduce production below that at a continuous 17° minimum. Split night temperatures did not affect the quality of cut roses when compared to a continuous minimum of 17°.**

Loefstedt (4) reported that a reduction of 6–10°C in greenhouse night temperature during the latter half of the dark period would save energy required to heat a greenhouse but might not appreciably retard growth and development of crops. Trials at the Connecticut Agricultural Experiment Station confirmed this response for several crops, notably Easter lily, marigold, and petunia (5). Further work indicated that there was little effect of a split night (SN) temperature on lily, but that there was a slight reduction in fruit production by tomato and reduced growth of tobacco (1). The rate of photosynthesis at sunup rose as rapidly following a SN temperature as after a constant warm night temperature, and sugars accumulated equally in both sets of plants. The SN temperature regimes accelerated translocation and metabolism of carbohydrate before the cool part of the night (relative to controls), and starch depletion in leaves was reduced during the cool period for SN plants. The SN temperature did not inhibit flowering, promote fruit abortion, nor affect the growth rate of fruit in tomato.

Hanan (2) found shoot development promoted by SN temperatures on greenhouse rose plants. Flowering was reduced, and Hanan concluded that split temperature for roses as a means of energy conservation did not appear to be a viable practice.

Materials and Methods

General. The study reported herein was done at College Park, Md, during the 3 consecutive winters from Oct. 1978 to Apr. 1981 in greenhouse sections in which thermostat settings were lowered during the latter part of the night. Temperatures were increased at about the time of winter sunup to increase the savings further. Only the minimum temperatures were subject to adjustment.

Glass-partitioned sections of detached greenhouses were equipped with clock-controlled dual thermostats, and recording thermographs were used in each section to monitor minimum night temperatures and make thermostat adjustments as necessary. Each section also was provided with continuously operating fans for vertical air circulation as well as with thermostatically controlled ridge ventilators. All sections had a minimum daytime temperature of 17°C with the ridge ventilators

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opening on sunny days as the greenhouse temperature reached 24°.

Plants of greenhouse roses ('Forever Yours' and 'Pink Sensation'), which had been in a greenhouse bed for 4 years, were replanted in containers for the 1978–1979 trials. These, in addition to newly received plants of 'White Satin' and 'Volare', were used for the 1979–1980 and 1980–1981 trials. All were planted in 20-liter black plastic containers with a root medium of 1 soil : 1 peat moss : 1 perlite (by volume), which then was limed to pH 6.5 and supplemented with fritted trace elements. Fertilizer was applied at bi-weekly intervals in aqueous solution at 600 ppm N, 100 ppm P, and 200 ppm K. Irrigation was done by hand, and pesticides were applied for insect and disease control as required.

Plants were grown outdoors in full sun from June through August, and 12 plants of each cultivar (selected for uniformity) were placed in comparable positions in each experimental section at a spacing of 35 × 45 cm. Plants were pruned in early June of each year and again in the greenhouse to avoid excessive height. Blooms were harvested by cutting just above the second 5-leaflet leaf when the first one or 2 petals diverged from the bud and the calyx reflexed. Undercutting below the point of shoot origin was practiced on long shoots, in which case the stem was re-cut at the point of origin for weighing and measurement from the cut to the tip of the flower bud.

From early November to early March, ambient temperatures permitted the greenhouse temperature to fall consistently to the programmed temperature minimum at some point during the night. Major emphasis during the first year was on the bloom development time (BDT—the number of days from the time an axillary bud became dominant following the harvest of a bloom to the harvest of the next flower), on flower production during the 2nd year, and on both production and BDT during the 3rd year. Each year's trial was conducted as a separate experiment.

Table 1. Mean number of days required for bloom development for roses ('Forever Yours' and 'Pink Sensation') growing at split night and constant night temperature regimes (low temperature 12°C, first year).

Period of 17°C minimum	Mean no. of days: Month of original cut				
	Oct.	Nov.	Dec.	Jan.	Feb.
0800–1700 HR (0)[z]	64.6 c[y]	72.7 c[y]	77.9 d[y]	70.1 c[y]	56.7 c[y]
0800–2000 HR (3)	52.5 ab	59.2 ab	62.2 b	58.8 b	52.6 b
0800–2300 HR (6)	55.5 b	60.8 b	66.8 c	61.4 b	50.9 b
0800–0200 HR (9)	54.0 ab	58.9 ab	60.7 b	58.9 b	51.6 b
At all times (15)	50.5 a	55.4 a	53.9 a	51.6 a	46.0 a

[z]Figures in parentheses indicate number of hours between 1700 and 0800 HR at 17°C minimum.
[y]Mean separation within columns by Student–Newman–Kuel test, P = 5%.

First year. The following minimum temperature regimes were maintained in 5 greenhouse sections: 17°C 0800–1700 HR, then 12°; 17° 0800–2000 HR, then 12°; 17° 0800–2300 HR, then 12°; 17° 0800–0200 HR, then 12°; and 17° at all times.

Plants were pruned to 45 cm on 27 Aug. 1978 and placed in the experimental sections in early October. As flower buds on new shoots reached 0.75 cm in diameter, the shoots were removed by cutting just above the second 5-leaflet leaf from the bottom and tagged with the date of cut (25 Oct.; 8, 20, or 30 Nov.). Blooms originating from these cuts were harvested and the harvest date recorded. This tagging procedure was repeated for subsequent flowering, and records were maintained through Apr. 1979. BDT data were grouped according to the month in which the cut placing the developing bud in an apical position was made.

Second year. The warm temperature in the 5 greenhouse sections remained at 17°C, but 10° was used as the low sequence thermostat setting. Plants were returned to the greenhouse sections on 21 Sept., pruned to 50 cm on 5 Oct., and first blooms were harvested in December. Each flowering stem was measured and weighed at harvest. Data were grouped into 3 periods by the dates of harvest as follows: 1) 1 Dec.–10 Jan., 2) 18 Feb.–25 Mar., and 3) 26 Mar.–30 Apr.

Third year. Seven greenhouse sections were used to provide the following temperature minimums: 17°C 0800–1700 HR, then 9°; 17° 0800–2100 HR, then 9°; 17° 0800–0100 HR, then 9°; 17° 0800–1700 HR, then 12°; 17° 0800–2100 HR, then 12°; 17° 0800–0100 HR, then 12°; and 17° at all times.

Plants were pruned to 55 cm in late August and placed in the greenhouse sections by mid-September. The 3 harvest periods established were 13 Oct.–7 Dec., 8 Dec.–8 Feb., and 9 Feb.–3 May. Stem length was recorded as follows (grade and inclusive lengths, respectively): 1, 10–20 cm; 2, 21–30 cm; 3, 31–40 cm; 4, 41–50 cm; 5, 51–60 cm; and 6 >60 cm. The midpoint of each grade was multiplied by the number of blooms in that grade in calculating the total stem length. A dated tag was attached as each bloom was harvested for the recording of the BDT.

Design and analysis. A finite number of greenhouse sections and daily harvesting over a long period of time dictated a simplified experimental design, and a large number of plants was used to reduce the effect of plant variation, rather than randomization and individual plant records. The blocks of plants were placed in comparable locations and in the same pattern in each

Table 2. Mean number of blooms per plant produced by 4 rose cultivars for 3 harvest periods and the total number and total stem length of blooms at split night and constant night temperature regimes (low temperature 10°C, 2nd year).

Period at 17°C minimum	No. of blooms (mean)				Total length (cm)
	1 Dec.–10 Jan.	18 Feb.–25 Mar.	26 Mar.–30 Apr.	Total	
0800–1700 HR (0)[z]	4.3	2.7	9.9	16.9 b[y]	657 b[y]
0800–2000 HR (3)	6.7	4.2	7.5	18.4 b	815 ab
0800–2300 HR (6)	6.7	4.1	8.9	19.7 ab	781 ab
0800–0200 HR (9)	6.5	4.7	7.9	19.2 ab	810 ab
At all times (15)	7.1	7.0	9.5	23.8 a	1097 a

[z]Figures in parentheses indicate number of hours between 1700 and 0800 HR at 17°C minimum.
[y]Mean separation within columns by Duncan's multiple range test, P = 5%.

Table 3. Mean length and weight of blooms of 4 cultivars of roses for 3 harvest periods growing at split-night and constant night temperature regimes (low temperature 10°C, 2nd year).

	Wt and length for 3 harvest periods					
	1 Dec.–10 Jan.		18 Feb.–25 Mar.		26 Mar.–30 Apr.	
Period at 17°C minimum	Length (cm)	Weight (g)	Length (cm)	Weight (g)	Length (cm)	Weight (g)
0800–1700 HR (0)[z]	38 b[y]	16 ab[y]	36 a[y]	22 a[y]	40 b[y]	22 b[y]
0800–2000 HR (3)	42 ab	17 a	43 a	24 a	45 a	27 a
0800–2300 HR (6)	40 b	15 ab	42 a	24 a	44 ab	25 ab
0800–0200 HR (9)	45 a	15 ab	45 a	22 a	43 ab	22 b
At all times (15)	42 ab	14 b	43 a	21 a	46 a	23 ab

[z]Figures in parentheses indicate number of hours between 1700 and 0800 HR at 17°C minimum.
[y]Mean separation within columns by Duncan's multiple range test, $P = 5\%$.

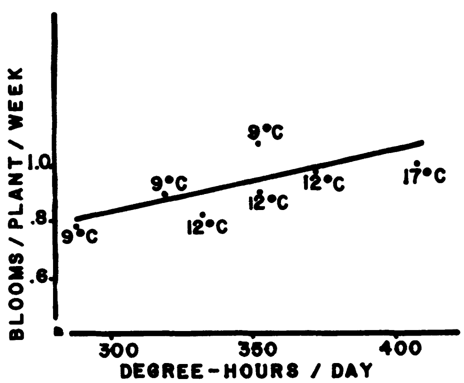

Fig. 1. Regression of average number of blooms per plant per week on estimated degree–hours per day. y = 0.024x + 2.82*. Minimum temperatures as indicated from left to right: 1700–0800 HR; 2100–0800 HR; 0100–0800 HR; 17°C continuous.

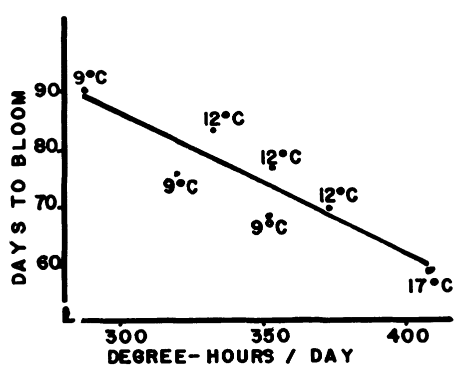

Fig. 2. Regression of bloom development time in days on estimated degree–hours per day represented by each treatment. y = −0.241x + 158.4**. Minimum temperatures as indicated from left to right: 1700–0800 HR; 2100–0800 HR; 0100–0800 HR; 17°C continuous.

greenhouse section. Greenhouse sections (temperature regimes) were main plots with harvest periods as sub-plots. Cultivars were used as replicates except in obtaining a cultivar interaction (Table 4), where sub-plots and replicates were reversed. Mean separation was accomplished at the 5% level for the Student–Newman–Kuel test, Duncan's new multiple range test, or by LSD as indicated in each table.

Results and Discussion

First year. Axillary buds becoming dominant in October and November flowered as rapidly at SN temperatures lowered at

Table 4. Mean bloom development time of 4 cultivars of greenhouse roses at split night and constant temperature regimes (3rd year).

		Mean bloom development time (days)			
Period at 17°C	Low temp (°C)	Pink sensation	Forever yours	White satin	Volave
0800–1700 HR (0)[z]	9	87.3 a[y]	80.0 ab[y]	95.5 a[z]	92.6 a[z]
0800–2100 HR (4)	9	72.2 bc	66.6 c	84.9 b	76.1 c
0800–0100 HR (8)	9	73.5 b	58.2 d	74.2 c	65.8 d
0800–1700 HR (0)	12	77.7 b	84.4 a	85.3 b	85.8 b
0800–2100 HR (4)	12	74.1 b	74.6 b	82.4 b	75.2 c
0800–0100 HR (8)	12	64.4 c	66.3 c	75.5 c	72.7 c
At all times (15)	17	56.1 d	60.3 cd	62.3 d	58.1 e

[z]Figures in parentheses indicate number of hours between 1700 and 0800 HR at 17°C minimum.
[y]Mean separation within columns by Duncan's multiple range test, $P = 5\%$.

2000 or 0200 HR as at the constant 17°C minimum, but from December to February the BDT was most rapid at the constant 17° temperature (Table 1). The BDT for all periods (heating to 2300 HR for cuts made in December was an exception) was the same for all SN temperature regimes. The most efficient time for heating to 17° at night was the 3-hr period 1700–2000 HR (Table 1), as the first increment of dark period heating (to 2000 HR) reduced the BDT 11 days (from 68 to 57 days) while the additional 12 hr to 0800 HR reduced the BDT 6 days (from 57 to 51 days) (mean data for all 5 monthly periods not shown).

Second year. The mean number of blooms of plants when maintained at 17°C minimum temperature until 2300 or 0200 HR was not different from that at the 17° constant minimum temperature, and the total length of stems at any of the split night temperatures was similar to that at the 17° minimum temperature (Table 2). The data for the blooms harvested for each of the seasons (Table 2) indicate unacceptably low flower production during the period 18 Feb.–25 Mar., confirming the conclusion of Hanan (2) that SN temperatures are not practical for roses.

The mean stem length and mean weight per bloom were similar in all temperature regimes during the winter with little difference during the spring and fall except for a decline in flower weight at the 17°C minimum in the fall. Blooms tended to be heavier as the length of the reduced temperature period increased in the SN temperature regimes (Table 3).

Third year. Differences in cultivar response to SN temperatures were evident in this experiment. The BDT was shortest at the 17°C minimum for all cultivars except 'Forever Yours', in

Table 5. Mean bloom development time of greenhouse roses for 3 harvest periods at split night and constant temperature regimes (3rd year).

Period at 17°C	Low temp (°C)	Mean bloom development time (days)			
		13 Oct.–7 Dec.	8 Dec.–8 Feb.	9 Feb.–3 May	Mean
0800–1700 HR (0)[z]	9	116 a[y]	90 b[y]	61 a[y]	89 a[y]
0800–2100 HR (4)	9	81 c	86 bc	58 b	75 c
0800–0100 HR (8)	9	76 cd	75 d	52 d	68 d
0800–1700 HR (0)	12	91 b	98 a	61 a	83 b
0800–2100 HR (4)	12	84 bc	87 bc	59 ab	77 c
0800–0100 HR (8)	12	72 d	82 cd	55 c	70 d
At all times (15)	17	63 e	64 e	51 d	59 e

[z]Figures in parentheses indicate number of hours between 1700 and 0800 HR at 17°C minimum.
[y]Mean separation within columns by Duncan's multiple range test, $P = 5\%$.

Table 6. Mean number of blooms per plant produced by 4 cultivars of greenhouse roses for 3 production periods growing at split night and constant temperature regimes (3rd year).

Period at 17°C	Low temp (°C)	Mean no. of blooms per plant			
		13 Oct.–7 Dec.	8 Dec.–8 Feb.	9 Feb.–3 May	Total
0800–1700 HR (0)[z]	9	4.8	5.2	13.2	23.2 e[y]
0800–2100 HR (4)	9	4.9	7.3	14.1	26.4 cde
0800–0100 HR (8)	9	6.7	9.4	16.0	32.1 a
0800–1700 HR (0)	12	6.2	5.9	12.9	25.0 de
0800–2100 HR (4)	12	6.9	6.9	13.5	27.3 bcd
0800–0100 HR (8)	12	4.9	8.6	16.6	30.0 ab
At all times (15)	17	6.3	9.8	13.5	29.5 abc

[z]Figures in parentheses indicate number of hours between 1700 and 0800 HR at 17°C minimum.
[y]Mean separation within columns by LSD, $P = 5\%$.

which the BDT at the constant 17° regime was similar to BDT at the 9° minimum at 0100 HR. 'Forever Yours' had a more rapid BDT when the temperature was permitted to drop to 9° in both SN temperature regimes, as did 'Volare' when the temperature reduction was at 0100 HR. BDT was reduced with the temperature reduction to 12° at 0100 HR for 'Pink Sensation'. BDT also was shorter at a constant night temperature of 12° than at 9° for all cultivars except 'Forever Yours' (Table 4).

The BDT for all cultivars was shortest in the 13 Oct.–7 Dec. and 8 Dec.–8 Feb. harvest periods at the constant 17°C minimum temperature, but not in the 9 Feb.–3 May period when BDT was as rapid at a 9° temperature minimum from 0800–0100 HR as at the constant 17° minimum. Comparing the BDT at lowered constant night temperatures, the BDT was shorter at 12° than at 9° in the 13 Oct.–7 Dec., harvest period and shorter at 9° than at 12° in the 8 Dec.–8 Feb. harvest period, but not different in the 9 Feb.–3May harvest period. The most rapid BDT for all harvest periods, however, was at the 17° constant minimum (Table 5). As in the first year's trials, the BDT after 4 hr of heating from 1700 HR to 2100 HR (mean of 13 days) or after heating from 2100 HR to 0100 HR (mean of 11 days) was shortened more than by heating the additional 7 hr to 0800 HR (mean of 11 days) (Table 5).

The SN regimes of temperature reduction to 12°C or 9° at 0100 HR resulted in as many blooms during the experimental period as at the 17° minimum, and total production was not statistically different from the 17° minimum by reducing the temperature minimums at 2100 HR (Table 6). The mean length of roses was not different at any temperature regime, and the total stem length of roses produced in any regime was ranked in the same order as the number of blooms harvested (data not shown).

BDT and total blooms per plant were regressed on a computation of the estimated degree-hour per day (the sum of the products of the number of hours per 24-hr period × the minimum temperature for that period) (Figs. 1 and 2). The significant straight line linear relationships suggest that the total amount of heat was the most important factor in the growth and development of greenhouse roses, as suggested by Wilkins et al. (6).

Data points for the minimum temperatures of 9°C and 12° (Figs. 1 and 2) appear on different sides of the calculated regression, indicating that the minimum temperature of 9° resulted in a shorter BDT and more blooms per plant than the 12° minimum temperature. The data shown in Table 5 indicate a reduced BDT at the 9° minimum temperature, however, only in the period 9 Feb.–3 May and where the 17° temperature was maintained until 0100 HR. 'Volare' had a shorter BDT at the 9° than at the 12° minimum for the entire season where 17° was maintained until 0100 HR, while 'Forever Yours' had a shorter BDT at a 9° temperature minimum than at a 12° minimum whether the 17° was maintained to 2100 HR or 0100 HR (Table 4). It was only in the 1980–1981 trial with heating to 17° until 0100 HR that bloom production at SN temperatures was not different from that at the constant 17°, and bloom production was maintained throughout all months, particularly where the low temperature minimum was 9° (Table 6).

Hicklenton and McRae (3) reported that a controlled SN temperature of gradual reduction from 20° to 10°C beginning at 1700 HR did not delay flowering in the spring but did delay flowering in the fall and that this delay was reversed only partially by supplemental light in the fall. Our results with roses showed a more positive response to SN temperatures during the spring than in fall or winter, which could be due partly to the increased natural light and partly to the prolonged duration of warmer daytime temperatures. These long days would have increased the mean daily temperature and might have increased plant response, again in accordance with the hypothesis of Wilkins et al. (6) that the mean daily temperature and not variation in temperature was of most importance in flower production.

It is evident that results can vary from year to year as will the ambient temperature and sunshine. Both temperature and sunshine differ with geographic location. The practical significance of SN temperatures may need investigation under local situations and for different species. The data presented, particularly the results of the 3rd year's trials, suggest that the rose grower does have an option in selecting temperatures and that the rose plant does respond most efficiently to a warm temperature for the first half of the dark period.

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Defoliation, Flower Bud Cold Hardiness, and Bloom Date of Peach as Influenced by Pruning Treatments

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Abstract. **Mature 'Sunqueen' peach [*Prunus persica* (L.) Batsch] trees were dormant pruned, summer pruned, or summer topped for 4 consecutive years. Dormant-pruned trees defoliated slightly earlier than summer-pruned trees, but the onset and duration of terminal vegetative bud rest was not influenced by pruning treatment. Compared to dormant pruning, summer topping slightly reduced cold hardiness of flower buds on 2 of 4 test dates in 1982, but not in 1984. Bloom on vertical shoots in the upper canopy was advanced by summer pruning and by summer topping in both 1982 and 1983. Bloom development at other canopy positions was not influenced by pruning treatment.**

Summer pruning and summer hedging have recently received much attention as potential methods of controlling tree size and reducing pruning costs in orchard operations (20, 22, 26). Summer pruning may, however, alter tree physiological processes that are not fully understood. Summer hedging of hedgerow peach plantings hastened leaf abscission and may have increased the cold hardiness of the trees, but no data were reported (12). However, in other studies summer-pruned peach trees suffered increased injury (27) or injury (22) similar to that of dormant-pruned trees following severe winter temperatures.

Summer pruning of woody plants has resulted in altered levels of endogenous growth regulators (24) and shoot carbohydrates (23). Both of these factors may influence the cold hardiness of peach (5, 6, 8). Growth regulators also have been implicated in the acclimation process (14, 15), date of defoliation (9), and time of bloom (6). This study was conducted to compare the influence of dormant pruning, summer pruning, and summer topping on time of leaf abscission, bloom date, cold hardiness of flower buds, and the onset and duration of terminal bud rest of peach trees.

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Materials and Methods

Mature 'Sunqueen' peach trees on 'Halford' roots were subjected to 3 pruning treatments in 1981–1984. Trees were spaced 6.1×11.0 m and trained to an open center. Pruning treatments were assigned randomly to 6 single-tree replicates per treatment in a randomized, complete-block design. The following treatments were established: a) dormant pruning in March consisted of heading vertical shoots to maintain tree height at 2.2 m, and thinning cuts to improve light penetration; b) summer pruning in late July (11 weeks after bloom) was similar to dormant pruning (about half of the pruning operation was performed in July, with additional pruning during March to remove branches bearing fruit during the previous season); and c) summer topping was performed with a sicklebar mower at 2.2 m above ground in late July. Thinning cuts and watersprout removal were required in March to complete the pruning operation. A complete description of trees and treatments has been reported (20).

Prior to bloom in 1982 and 1983, previous seasons' shoots at 3 canopy positions were tagged for evaluation of flower bud development. In 1982, these consisted of 8 vertical shoots at 2.2 m above ground, 8 shoots oriented at 25° to 65° (horizontal) from horizontal at 1.5 m above ground, and 5 vertical watersprouts originating from scaffold branches. In 1983, the number of shoots per tree was increased to 12 verticals and horizontals and 7 watersprouts.

The vertical shoots at 2.2 m above ground were used in 1982 and 1983 to evaluate leaf abscission. Leaves on each shoot were