THESIS

SUBSTRATE TEMPERATURE AND CARNATION GROWTH

Submitted by

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Horticulture Department

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall, 1978

COLORADO STATE UNIVERSITY

Fall 1978

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY Shannen Olsen Ferry

ENTITLED Substrate Temperature and Carnation Growth

BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF Master of Science

Committee on Graduate Work

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ABSTRACT OF THESIS

SUBSTRATE TEMPERATURE AND CARNATION GROWTH

Carnation (Dianthus caryophyllus L.) cultivar 'CSU White' was grown in raised greenhouse benches in soil and in gravel. Soil temperatures were controlled at 7.2 to 10.0, 15.6 to 18.3, and 22.8 to 25.6°C. Gravel temperatures were controlled at 7.2 to 10.0 and 15.6 to 18.3°C. Some plots in both soil and gravel were left to fluctuate with the air temperature.

Warming was accomplished with electrical heating tapes buried 7.6 cm below the substrate surface. Cooling was maintained by cold water circulation through pipes buried at the same depth. The use of 6.1°C irrigation water had little effect on plot temperatures.

The substrate temperature treatments had no significant effect on the production, quality, weight, length, or internode length of the flowers. Timing was not significantly affected during the duration of the experiment. Manipulation of soil temperatures over the range studied had no beneficial or detrimental effect on the growth and production of carnations.

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INTRODUCTION

Since the 1950's, carnations have been the most important cut flower crop in Colorado. The environment of Colorado is highly conducive to carnation growth, with the high light intensity that carnations require for optimum growth.

Environmental requirements for carnations have been widely studied. Air temperature requirements and their importance in quality production and timing is known. One thing that is not widely known is the effect of substrate temperatures on the growth and production of carnations in Colorado. Some work in this area has been done, but little of it had been done in Colorado. Colorado-based research on soil heating with carnations has had contradictory results. One study began in January and did not subject the plants to experimental temperatures throughout the entire life of the plant (15). The results found no difference in timing, but no flower quality data were taken. Another experiment claimed some differences in timing but had a small sample size upon which to base conclusions (11).

Increasing concern and awareness of energy conservation has prompted a resurgence in substrate heating studies. It is therefore the purpose of this experiment to: investigate the effect of root substrate temperatures on the growth and production of *Dianthus caryophyllus* L.

Gravel culture of carnations is an alternative growing media in Colorado. Since little is known about root temperatures and gravel culture, this is considered to be an important aspect of this study.

It is such research as this that will provide the foundation for future studies of carnation root temperature control in conjunction with air temperature manipulation.

REVIEW OF THE LITERATURE

Plant growth is greatly influenced by temperatures (12, 14, 25). The root temperatures to which a plant is subjected largely determine its natural habitat (12). This review is intended to provide an overview of important horticultural and agronomic crop responses to various soil temperatures. A brief discussion of soil warming techniques and their feasibility is also included.

Basic Physiology

In an excellent compilation of literature, Hagan (12) reviewed the relation of soil temperature to plant processes and growth. Many researchers feel that low temperatures restrict water absorption and transpiration (3, 5, 9, 12, 20, 23, 24, 25, 29). Kramer (23) reviewed the literature and theorized that low soil temperatures caused decreased water absorption in roots due to increased root resistance and increasing viscosity of water. In a later investigation, Kramer (24) found that there was less water uptake at low soil temperatures by plants grown in warm soil or climates as compared to those plants grown in cooler soils. Levitt (25) recognized this reduced water uptake to be important in winter injury.

In young 'Valencia' orange trees, Cameron (5) observed that a reduction in soil temperatures from 32.2 to 7.2^{o}C reduced the rate of transpiration quite noticeably with definite signs of wilting being produced. It was found that both field grown and growth chamber grown trees, with low soil temperatures, showed a much higher leaf water deficit.

In 1972, Rutland and Pallas (29) experimented with snapdragon variety 'Panama,' and found that plant wilting and the subsequent stomatal closure was perhaps the most marked effect of low soil temperatures. In the greenhouse, a low soil temperature in late spring and early fall, when cool nights are followed by warm, sunny days, could be detrimental to many greenhouse crops (12, 29).

The length of time a plant is subjected to certain soil temperatures is important (6, 8, 20, 25). Kofranek (20) found that poinsettias dropped fewer leaves, and experienced less bract and cyathia abscission, after being exposed to 4.4°C soil temperature for two days, versus exposure for six days. He found no injury to the conducting tissue from plants spending up to six days in 4.4°C soil.

Greenhouse Crops

In 1954, Holley (15) regulated carnation soil temperatures at 7.2 to 10.0, 12.8 to 15.0, 15.6 to 18.3, and 18.6 to 21.1°C for the first four months of production (January 10 to May 1). He found no significant difference in production or timing, and, although no quality records were kept, there were no apparent treatment differences.

From 1952-55, studies were conducted by Seeley and Steiner (34) to determine the effects of several soil temperatures on carnation flowering peaks and total flower production. Some soils were heated to a minimum of 15.6 and 21.1°C, some were watered with 4.4, 15.6, 26.7, and 66.0°C water and some had no temperature controls at all. There were no beneficial responses observed between those heated plots and the control plots. It was also found that watering with 4.4 to 26.7°C water produced neither beneficial or detrimental results, while watering with 66.0°C water over a long period of time often provided harmful (34).

At Clemson University, Johnson and Haun (18) studied the interaction of daylength and soil temperatures on carnations. Plants were subjected to four soil temperature treatments (none, 18.0, 21.0, and 32.0°C) in combination with long (LD) or normal (ND) daylengths. The LD treatment initiated and produced flowers two to three weeks earlier than the ND treatment, with flowers opening approximately one week later in the 32°C treatment. Soil temperatures of 21 and 32°C reduced flower size in both daylengths. Long days significantly increased total flower production, with a greater percentage of top quality carnations being produced with 21 and 32°C soil heat as compared to 18°C and unheated treatments. Under ND, only 21°C gave a significant increase in top quality carnations. It was postulated (18) that, when processes such as flowering are accelerated by increased daylength, it may be necessary to compensate for reduced quality by supplying such complimentary factors as soil heating.

Until 1946, very little work had been done concerning the optimum soil temperature for roses (21, 22), and it was a common recommendation that rose growers water their plants with warm water (21, 22, 28). In 1948, Pfahl, et al., (28) reported that warm water applications to 'Better Times' rose soil did not significantly affect growth production, flower quality, nor the number of bottom breaks produced by the plants. In fact, after 17 days of watering with 32.2^{o}C water, bud breaking in young plants was inhibited.

Kohl and Weinard (22) reported on heating soil of 'Better Times,' 'Peter's Briarcliff,' and 'Pink Delight' roses to 21.1 and 26.7^{o}C. Lower soil temperatures had better production, indicating a possible inhibitory effect of high soil temperatures. In 1947-48, Kohl, et al. (21) used 'Better Times' roses and changed the temperatures to 23.9 and 29.4^{o}C. Haydite and soil were the growing media, and a constant water level culture was utilized. As before, no differences were noted in flower quality, average stem length or growth, but production decreased with an increase in soil temperature.

At Ohio State, Shanks and Laurie (35, 36) conducted rose root studies. Preliminary (35) and final (36) experiments found that optimum top growth occured at a soil temperature of 17.8°C, with progressively fewer roots produced as temperatures increased from 13.3 to 21.1°C.

In 1934, Allen (1) grew snapdragon variety 'Cheviot Maid Supreme' at soil temperatures of 11.1, 15.6, and 22.2°C. He found that with each increase in temperature there followed a greater number of flowers per plant, a decrease in stem length and flower cluster length, and an increase in the number of days to flower. These data were not analyzed for statistical significance. A slight nitrogen deficiency was also noted in the 11.1°C treatment.

Seeley (33), in 1964, reported that more saleable stems of snapdragon varieties 'Margaret' and 'Jackpot' resulted from electrically heated soil plots with a 21.1°C minimum. Also correlated with heated soil were slightly greater stem weight in a little less time than in the unheated soil. These data were not significantly different, however, so it was concluded that heated soil was neither beneficial nor detrimental to snapdragon growth and production.

A definite correlation between soil temperature and growth and chlorosis in *Gardenia vietchii* was determined by Jones (19). Interveinal chlorosis developed at 18.0°C and became increasingly worse as the soil temperature was lowered. However, a progressive return of green color was brought about by sharply increasing the soil temperature and holding it constant for 13 days. Soil temperatures were also found to have an effect on leaf size with an increase in leaf length as soil temperature increased. In addition, lowering the soil temperature hastened the natural senescence of the oldest leaves.

A study by Davidson (8) on Gardenia veitchii concluded that the proper air temperature could offset the effects of both high and low soil temperatures provided the soil temperatures were above a low of 14.4°C. Davidson (8) also experimented on the 'Belmont' variety of the grandiflora gardenia. This variety appeared to be more inhibited in growth and production at low root temperatures than G. vietchii, but was still highly productive at higher (27.8°C) soil temperatures. Again, slower growth and foliage chlorosis at low soil temperatures could be effectively offset by an increase in daylength, light intensity, or an increase in air temperature.

Bailey and Jones (2) found that a similar chlorosis in blueberry bushes was not significantly related to soil temperatures. It was found, however, that plants wilted slightly at cooler (12.8 and 15.6°C) temperatures but soon recovered. Soil temperatures were found to be related to plant height and total linear growth. Plants subjected to 18.3°C and lower soil temperatures expressed short and spreading habits while 18.3°C and higher soil temperatures produced tall and upright plants.

Allen (1) tested the effects of soil temperatures on greenhouse stocks, Calendula, and Freesia at soil temperatures of 11.1, 15.6, and 22.2°C. Although his data were not analyzed for statistical significance, he found that soil temperatures had little effect on the growth and production of Column-type stock, while the 'Bismark' strain bloomed earlier in the cool soil (114, 126, and 132 days respectively). There was also a slight difference in the length, increasing with the higher temperatures. With the Calendula, Allen found that with an increase in temperature, there followed an increase in stem length and number of flowers per plant but a slight decrease in the flower diameter. Temperatures from 10.0 to 15.6°C caused Freesias to produce more flowers per corm with a slightly less time to harvest. A marked increase in production time and great reduction in flowers per corm were noted at temperatures from 15.6 to 22.2°C. Allen did point out that the differences seen could not solely be attributed to soil temperatures because part of the treatments showed nitrogen deficiency, which was improved by adding ammonium sulfate. Since improvements were noted at 11.1°C and decreased with progression to 22.2°C, Allen postulated that part of the effect of high temperatures was to hasten nitrification in the soil.

Cathey (6) reported that *Iris tingitana* var. 'Wedgewood' flowered earlier with relatively high soil temperatures if the air temperatures were maintained from 4.4 to 15.6°C. Reduction in the forcing period and a repeatedly high percentage of flowers were found to be associated with a soil temperature equal to 8.3°C above the air temperature (18.3°C soil, 10.0°C air). This treatment produced more uniform flowers of a higher grade when compared to flowers produced in 26.7°C soil. Switching from 26.7°C soil to equal air-soil temperatures of 4.4 or 10.0°C at the time of bud initiation produced more flowers in shorter time than continuous 26.7°C soil with either 4.4 or 10.0°C air temperatures.

Kofranek (20) found that poinsettia plants subjected to a constant 4.4°C soil temperature remained wilted throughout the entire length of two experiments (six days and two days respectively), while soil temperatures of 10.0, 15.6, and 26.7°C caused no wilting. He also found that leaf abscission in plants subjected to soil temperatures of 4.4°C nights and 15.6°C days was about one-half that observed on plants having constant 4.4°C soil temperature.

Emsweller and Tavernetti (10) concluded that, although there was no difference in the quality of gladiolus flowers produced in heated (25.0°C) soil versus unheated (15.6°C) soil, at least 80% of the corms in the heated treatment bloomed before those in the unheated treatment. Larger corms resulted in the heated treatment as well as a greater percentage of cormels.

Goldsberry and Halkett (11) observed that radish tops grew faster in 14.4 to 16.1°C soil than in unheated

(6.7 to 12.8°C) soil, but the root diameters were smaller. They found significant differences (20%) in fresh weight of lettuce in heated versus non-heated soil when planted in March. Swiss chard grew faster in heated soil and cauliflower matured faster with 80% greater head diameter 98 days after transplanting.

Agronomic Crops

According to Earley and Cartter (9), irrespective of light intensity, the production of dry weight in soybeans was affected greatly by soil temperatures. Temperatures as low as 12.0°C and as high as 37.0°C prevented optimum plant development. The most favorable root temperatures for soybean dry weight production were from 22.0 to 27.0°C when the plants were subjected to a wide range of greenhouse air temperatures.

Other agronomic crops have also been investigated for their yield response to soil heating (30). With a heat source temperature of 35.0 to 38.0°C, which warmed the average soil temperature 10.0°C, 0 to 100 cm deep, sudangrass (*Sorghum bicolor* L.) attained a 50% increase over unheated plots. Field corn, not normally a good crop for the location of this experiment (Willamette Valley, Oregon), germinated faster, had a faster growth rate, and produced a 22% average increase in the heated soil.

Vegetables including broccoli, strawberries, tomatoes, peppers, lima beans, and bush beans were evaluated in a companion experiment (31). All crops performed significantly better in warm soil with the greatest growth increase occurring in the early spring. This early increase in growth would be of particular advantage in the double-cropping of bush beans.

Soil heating on a variety of horticultural field crops was assessed in Oregon (17). An increased growth rate was significant in cucumbers and leaf lettuce, and increases up to 95% in total weight and number of asparagus spears were noted. Soil heating with warm water (32.2 to 43.0^{o}C) was also found to increase root growth on certain ornamentals which cut production time up to a full year.

Systems

Systems which have been incorporated into soil temperature experiments include hot-water applications to the soil (27, 28, 34), controlled temperature nutrient solutions (29), controlled temperature circulating water baths (2, 3, 8, 19, 20, 24, 26, 35, 36, 38), sub-soil electrical heating cables (1, 10, 11, 15, 18, 21, 22, 33, 34), and warm or waste-water circulation through sub-surface pipes (4, 5, 17, 30, 31, 37).

With increased concern about energy conservation, waste-water utilization for warming greenhouses and soil has been widely studied (4, 5, 11, 17, 30, 31, 32, 37). Skaggs, et al. (37) reported that for every one kilowatt-hour of energy produced at the average electrical power plant, two kilowatt-hours of energy are given off in condenser cooling water. Experiments simulating waste-water usage with electrical heating cables (11), and working models of waste-heat soil warming (4, 17, 30, 31, 37) have been conducted. Increased yields in test crops and the added benefit of lengthening the growing season would allow double-cropping of such crops as bush beans (31). This would permit warmer soil crops to be grown in areas of inhibitory soil temperatures (31), and larger, earlier crops would have access to off-season markets (32, 37).

Major considerations for evaluating the effects of soil heating on various crops are the benefits gained from increased production versus the expense of the control system and the return on the crop (11, 32). Some crops benefit most from soil heat applied early in the spring (30, 31) or during their first stages of development (14). Greenhouse or cold frame crops may only need supplemental soil heating during the coldest months (6, 11, 32). Ultimately, the economic feasibility relies on the marketability of the crop.

Summary and Conclusions

Based on the information contained in this review, there are several items which sould be given consideration before proceeding with a soil heating project. They are:

1. Temperature requirements for the crop. Will the intended crop easily adapt to various air and root temperatures?
2. Economic feasibility. Will the return justify the cost?
3. Steady market value of the intended crop. Is there an ever-present demand for this crop during the season(s) it is produced?
4. Environmental effects of the system. Ultimately, is the system beneficial or harmful?

The first item should be given top priority. If soil heating is feasible for a particular crop, one should investigate the possibilities of modifying air temperatures to further increase yield (6, 8, 18). If a crop does not respond to soil temperature modifications, a grower need not consider the other three items.

Factors 2 and 3 are closely related. It is extremely important to consider all cost and return factors. What is the use of producing greater quantities of a higher quality crop if there is no demand for it?

The last item is of importance. Few of the papers researched herein mentioned any environmental impact of the systems employed. It was suggested that, by utilizing waste-water for soil or greenhouse heating, streams would not have to be used for hot water dumping (37). However, in using waste water for field heating, it is possible that doing so would change that area's microclimate and have important impact on the indigenous flora and fauna. Could creating an extended growing season increase chances of prolonged insect attack and thereby increase costs?

Until more research is conducted concerning manipulation of air temperatures and photoperiod in conjunction with soil heating, it appears that for most crops soil heating is not feasible. Field soil heating would only be advisable if a grower had inexpensive access to large quantities of waste-water.

The literature reviewed has been in two basic categories. Basic research on root temperature limitations of plants is the first. These experiments have occasionally been limited to a small sample size. While it is possible to get valid results from a small experimental population, wide assumptions cannot be, and for the most part were not, made. These experiments, however, do find possible causes for extensive root-temperature-related problems such as Gardenia chlorosis and stunting, and poinsettia leaf-drop. Basic reasearch has also found optimum air-soil temperature combinations and has dispelled once-popular practices such as watering roses with warm water.

The other type of research is centered on large-scale soil heating measures. While some projects simulating waste-heat utilization base conclusions on small sample sizes, most of the research is on a larger scale and the results are more significant. These projects serve to project soil heating results and feasibility only for the area in which the experiments were run. They do serve as models for future experiments for similar situations.

MATERIALS AND METHODS

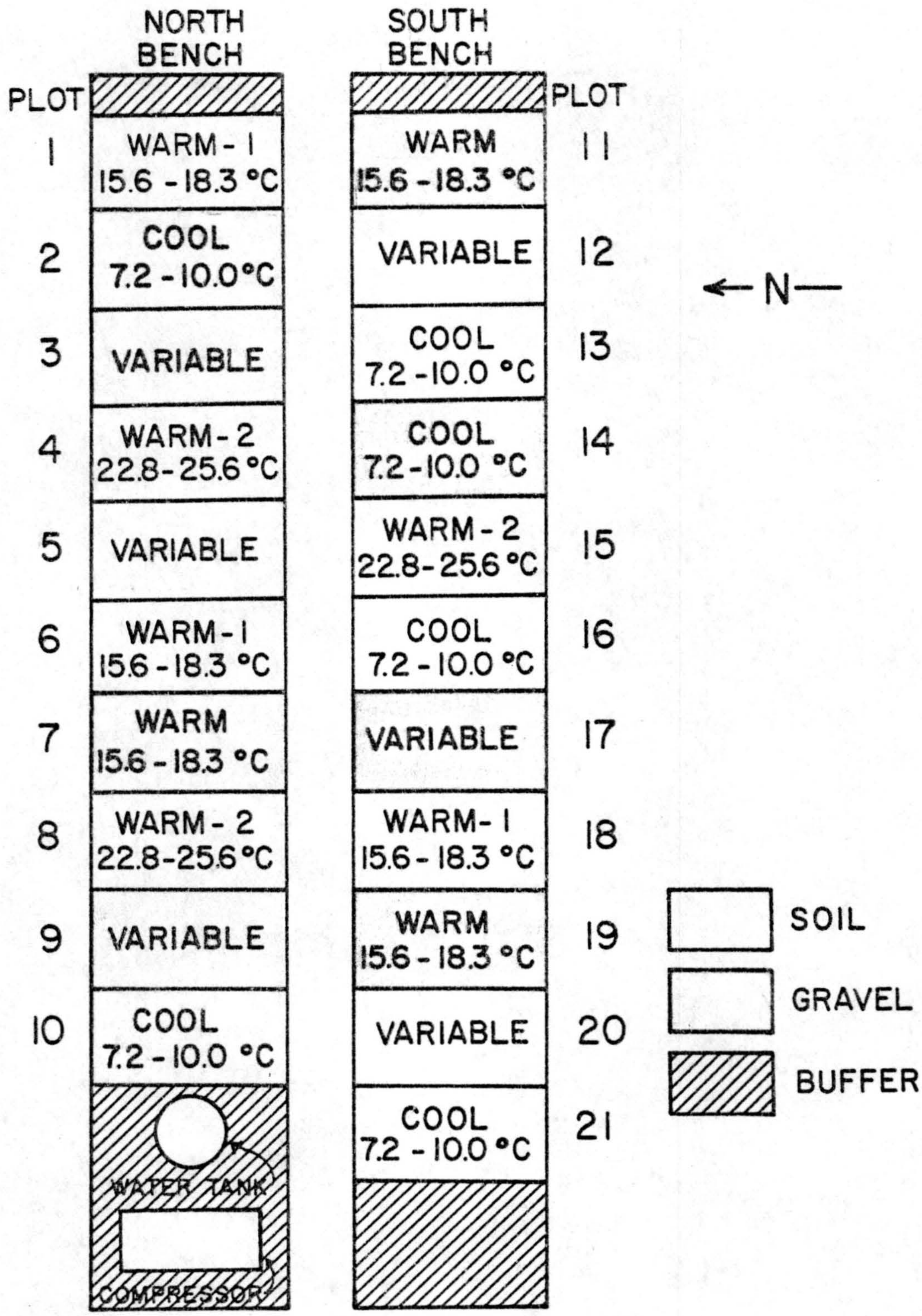
All plant material for this study was grown in the main research range of the W.D. Holley Plant Environmental Research Center at the Colorado State University. Research on the effects of substrate temperature on carnation growth and production was conducted from May 27, 1977, to May 29, 1978.

Experimental Design

Two benches in an east-west oriented greenhouse were divided into twenty-one experimental plots. There were ten plots in the north bed and eleven in the south bed (Fig. 1). The plots were numbered one to ten from east to west in the north bed and 11 to 21 in the south bed in the same direction. The west end of the north bench housed equipment essential for the experiment. The north and south beds were the second and third beds of six in the house. The house was covered with fiberglass and had glass walls. The air temperature controls were automatic and cooling during warm months was applied by pad and fan evaporative cooling. During the day, the greenhouse was heated to $16.7^{o}C$ and cooling began at 18.3 to $20.0^{o}C$. Night temperatures were maintained at $11.1^{o}C$.

Two growing media were used in this experiment. Pea gravel, with 83.0% particle size greater than 3.1 mm in diameter (13), was used in nine of the plots. A

Fig. 1. Bench design of soil and gravel treatments and temperatures.


NORTH BENCH
SOUTH BENCH
PLOT
1 WARM - I 15.6 - 18.3 °C
2 COOL 7.2 - 10.0 °C
3 VARIABLE
4 WARM - 2 22.8 - 25.6 °C
5 VARIABLE
6 WARM - I 15.6 - 18.3 °C
7 WARM 15.6 - 18.3 °C
8 WARM - 2 22.8 - 25.6 °C
9 VARIABLE
10 COOL 7.2 - 10.0 °C
WATER TANK
COMPRESSOR
PLOT
11 WARM 15.6 - 18.3 °C
12 VARIABLE
13 COOL 7.2 - 10.0 °C
14 COOL 7.2 - 10.0 °C
15 WARM - 2 22.8 - 25.6 °C
16 COOL 7.2 - 10.0 °C
17 VARIABLE
18 WARM - I 15.6 - 18.3 °C
19 WARM 15.6 - 18.3 °C
20 VARIABLE
21 COOL 7.2 - 10.0 °C
← N —
SOIL
GRAVEL
BUFFER

well-aggregated friable greenhouse soil, originally Fort Collins silt loam, to which yearly applications of organic matter had been made, was used in the remaining 12 plots. The treatments are outlined in Table 1.

There were three plots per treatment. The treatments were arranged in a completely random design. All end plots were buffered by border areas.

Bench Construction and Equipment

The wooden benches measured 1.02 m X 10.67 m with 20.3 cm sides. One and one-third cm spacings between boards in the bottom of the benches allowed for drainage of excess water. Loosely-woven (approximately 8 threads/in.) black saran cloth was placed in the bottom of the gravel-filled plots to prevent the gravel from falling through the drainage spaces. Adequate drainage was still maintained. The plots were separated by plywood partitions containing a 2.5 cm "dead air" space to buffer heat transfer from one plot to the other.

The cool plots were maintained by circulating cold (2.2^{o}C) water through 1.3 cm copper tubing buried 15.2 cm beneath the media surface. Approximately 4.57 m of piping was bent "trombone style." A layer of 64 mm mesh hardware cloth was placed on top of the cooling pipes for even temperature distribution. Water was pumped through the tubing from a 190 l barrel of cold water. An electrical normally closed solenoid valve was activated when

Table 1. Treatment temperatures, codes, and plot listings.

Treatments	Code	Temperature °C	Plots
Gravel Cool	GC	7.2 - 10.0	2, 10, 14
Gravel Variable	GV	8.3 - 16.7	3, 9, 17
Gravel Warm	GW	15.6 - 18.3	7, 11, 19
Soil Cool	SC	7.2 - 10.0	13, 16, 21
Soil Variable	SV	10.0 - 16.7	5, 12, 20
Soil Warm 1	SW1	15.6 - 18.3	1, 6, 18
Soil Warm 2	SW2	22.8 - 25.6	4, 8, 15

The codes will be used in the text when referring to specific treatments.

temperatures rose above a designated point. Cold water would bypass plots not calling for cooling and was kept on a continuous recirculating cycle. The water was cooled by a one-ton refrigeration unit.

Heat was supplied to each of the warm plots by a 7.32 m, 168 watt, 120 volt electrical heating tape. The tape was arranged in similar fashion to the cooling pipe and fastened to 64 mm wire mesh for even heat distribution.

All plots were equipped with twin-wall drip irrigation systems. The gravel plots were watered automatically from three to five times daily, depending on the season. Each of the soil plots was equipped with a separate hand valve so that they could be watered independently. The time for watering each soil plot was determined by testing a soil core sample for moisture content by its ability to form a ball when pressed together. The plots were watered with the nutrient solution recommended by Holley and Baker (15). All plots were watered to leaching.

Temperatures were recorded four times daily for each plot. Rubber-insulated thermocouples were inserted in the center of the plot at a depth of 6.0 to 8.0 cm. A 24-point Bristol recorder was activated by a time clock for one hour at six-hour intervals beginning at 8:00 each morning. The thermocouples were accurate to $\pm$ 0.6°C. Constant monitoring of the cold water temperature was recorded on a 24-point Foxboro recorder.

Substrate Temperature Changes

A series thermocouple circuit was constructed to study substrate temperature changes after watering, and temperature variations within each plot. Five pairs of thermocouples made from 21 gauge copper and constantin wires were connected in series. Each pair of thermocouples was fastened to a wooden pot label so that when inserted into the soil or gravel, one thermocouple would be at a depth of 15.2 cm and the other at 7.6 cm. The five pairs were placed in each plot at random. Three sets of "top" and "bottom" temperatures were taken in each plot, and the readings analyzed for differences. A General Electric Thermocouple Potentiometer was used to make the readings.

On January 15, 1978, a preliminary study was conducted to determine the effects of cold (6.1°C) irrigation water on plot temperature fluctuations. One plot each of the warm gravel (GW), warm soil (SW1), and warmest soil (SW2) (Table 1) treatments were irrigated and their temperatures recorded at 5, 10, 15, 20, 30, 40, 50, and 60 minutes after watering stopped. The sensors were the in-bench thermocouples and the temperatures were transcribed from the 24-point Bristol recorder.

On April 24, 1978, a follow-up study was done using the thermocouple circuit constructed for the plot temperature profiles. Five random locations for depths of 7.6 and 15.2 cm were measured for temperature reductions at previously mentioned time intervals. One plot from each treatment on the south bench was used in this test.

Production Data

Rooted cuttings of 'CSU White' carnations were planted on May 27, 1977, and pinched to four nodes on June 11, 1977. Thirty plants were planted per plot in five rows of six plants. The planting density was approximately 37.6 plants per square meter (3.5 plants per square foot). Whenever possible, current commercial practices for pinching, supporting, disbudding, and spraying were employed (16).

The first flowers were cut in the week beginning August 29, 1977. For the next 39 weeks, data were taken on each flower cut from the 21 plots. Grading criteria were based on guidelines set by the Society of American Florists and weight suggestions from Holley and Baker (16). A listing of the grading requirements for this experiment is given in Table 2.

Flowers were cut below the sixth node from the flower. This length provided either a Standard or a Fancy grade for length, depending on total shoot height, and resulted in a consistent basis for stem length analysis. Records were kept on length, internode length between the fourth and fifth internode, and weight of the flowers.

All of the grading requirements listed in Table 2 were of equal importance. For example, if a carnation had a 64 cm stem length, and a 9 cm diameter head, but the stem

Table 2. Minimum requirements for carnation grading based on standards set by the Society of American Florists and weight suggestions by Holley and Baker (15).

	Grade			
	Fancy	Standard	Short	Design
Flower size (cm)	8	7	6	none
Stem length (cm)	56	43	30	none
Weight (g)	25	19	13	none
Stem strength	All grades, excepting Design, must possess a straight stem with less than 30° bend from horizongal when held 2.5 cm from the cut end.			

strength could not support that head and bent more than 30° from horizontal, that carnation was not graded as a Fancy. It would go to the grade for which all requirements were met. Defects in flower head shape and malformed or very weak stems were automatically classified as Design grade carnations.

Tinting Quality and Keeping Life

A combination tinting quality and keeping life study was conducted to determine the effects of the different treatments. Six flowers from each plot or 18 flowers from each treatment were stored for 0, 3, and 5 days. On the beginning test day, the flower stems were cut to 50 cm and immediately placed in a 18.9 l bucket containing 7.6 l of blue tint. The tint was mixed at two teaspoons powdered dye plus ten drops 'Tween-20' surfactant per liter. The tinting solution temperature was between 32.2 and 37.8°C.

The flowers were removed from the dye solution after 3.5 minutes and rinsed in warm tap water. The stems were then placed in a solution containing 200 ppm hydroxyquinoline citrate. The flowers were kept in a room with fluorescent lighting and indirect sunlight during the day and constant fluorescent lighting at night. Data were kept on tinting quality and the number of days it took for 2, 4, and 6 flowers to senesce per plot per treatment per storage time. Keeping solutions were replenished or replaced when necessary.

Dry Weight Production

Dry weights of flower heads and stems cut to the seventh node were taken on a sample of flowers from each plot weekly from April 16, to May 17, 1978. Sample sizes ranged from 15 to 24 flowers per plot. Flower heads were removed from the stem at the base of the calyx. The heads and stems were then wrapped in newspaper and dried at 93^{o}C for five days. Data were taken on total head and total stem dry weight per sample date. At the end of the sampling period, averages were obtained on the dry weights.

RESULTS AND DISCUSSION

Temperatures

Two distinct time periods were seen in the daily temperature recordings. During the first 4½ months, temperatures were very difficult to control. The plants were small and the canopy had not developed enough to keep incoming solar radiation from the media. Therefore, radiation caused the media temperature to rise, making adequate control of treatment temperatures difficult. The following five months were the coldest months of the year. Since by that time the incoming radiation was blocked from the media surface by the plant canopy, temperatures were somewhat easier to control. The remaining 2½ months began another warm period. The temperature ranges and averages for these time periods are given in Tables 3, 4, and 5.

The maximum and minimum temperatures occurred during times of rapid weather changes, equipment malfunctions or due to needed modifications to the control systems. Generally, as indicated by average temperatures, the control systems worked well and temperatures were maintained according to schedule. The average temperatures were derived from 20 random samples during each period.

A soil temperature profile was completed on each plot. The results are listed in Table 6. Each temperature is an average of three readings taken at that same point over a two-hour period.

Table 3. Temperature variation and average temperature for each treatment from May 27, to September 15, 1977.

Treatment	Code	Temperature (°C)		
		Max.	Min.	Mean
Gravel Cool	GC	17.2	10.0	11.7
Gravel Variable	GV	23.9	19.4	21.7
Gravel Warm	GW	24.4	19.4	21.1
Soil Cool	SC	15.6	10.0	12.2
Soil Variable	SV	23.3	20.0	21.1
Soil Warm 1	SW1	32.8	20.6	22.8
Soil Warm 2	SW2	28.9	20.0	22.2

Table 4. Temperature variation and average temperature for each treatment from September 16, 1977 to March 15, 1978.

Treatment	Code	Temperature (^{o}C)		
		Max.	Min.	Mean
Gravel Cool	GC	10.6	5.6	7.8
Gravel Variable	GV	16.7	8.3	12.8
Gravel Warm	GW	27.8	16.7	18.3
Soil Cool	SC	11.1	6.7	7.8
Soil Variable	SV	16.7	10.0	12.8
Soil Warm 1	SW1	20.6	15.6	17.8
Soil Warm 2	SW2	32.2	21.7	23.9

Table 5. Temperature variation and average temperature for each treatment from March 16, to May 29, 1978.

Treatment	Code	Temperature (°C)		
		Max.	Min.	Mean
Gravel Cool	GC	10.6	6.7	7.8
Gravel Variable	GV	15.6	13.9	14.4
Gravel Warm	GW	26.7	16.1	17.8
Soil Cool	SC	10.0	6.7	8.3
Soil Variable	SV	16.1	13.9	15.0
Soil Warm 1	SW1	20.0	15.0	17.2
Soil Warm 2	SW2	32.2	21.7	23.9

Table 6. Substrate temperature profile data taken from March 16-21, 1978. Readings are averages of three temperature readings taken within two hours. The temperatures are taken from a depth of 7.6 and 15.2 cm. Mean temperatures are given for each plot at the two depths.

Treatment	Plot	15.2 cm Depth						7.6 cm Depth					
		Temperatures (°C)					Mean	Temperatures (°C)					Mean
Gravel Cool	2	10.0	9.4	10.6	10.0	9.4	10.0	9.4	8.3	8.9	8.9	8.9	8.9
	10	8.3	8.9	9.4	8.9	9.4	8.9	8.3	8.3	8.9	8.3	8.9	8.3
	14	10.0	10.0	9.4	8.9	9.4	9.4	8.9	9.4	8.9	8.3	8.3	8.9
Gravel Variable	3	15.6	15.0	15.6	15.6	15.6	15.6	15.0	15.0	15.0	15.6	15.6	15.0
	9	15.6	15.6	15.0	15.6	16.1	15.6	15.6	15.6	15.0	15.6	16.1	15.6
	17	15.0	16.1	14.4	15.0	15.0	15.0	15.0	15.6	15.6	15.0	14.4	15.0
Gravel Warm	7	16.7	17.2	16.7	17.8	16.7	17.2	17.8	18.9	18.3	18.3	17.8	18.3
	11	17.2	16.7	17.2	16.7	17.2	17.2	18.3	17.8	18.3	17.8	18.3	18.3
	19	16.7	17.2	17.8	18.3	17.8	17.8	17.2	18.3	18.9	18.3	17.8	18.3
Soil Cool	13	8.3	6.7	6.7	7.8	7.2	7.2	7.2	7.2	7.2	7.8	7.8	7.2
	16	7.2	7.8	7.8	7.8	8.3	7.8	8.9	8.3	7.2	7.8	7.2	7.8
	21	10.0	9.4	10.6	10.0	11.1	10.0	10.0	10.0	9.4	9.4	9.4	9.4
Soil Variable	5	16.1	15.0	15.6	15.0	15.0	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	12	15.6	15.0	15.6	14.4	15.0	15.0	15.0	15.6	15.0	15.6	15.6	15.6
	20	15.6	13.9	14.4	14.4	15.0	14.4	15.0	16.1	13.9	15.0	15.0	15.0
Soil Warm 1	1	17.2	17.8	18.3	17.8	18.3	17.8	17.8	17.8	18.3	18,3	18.9	18.3
	6	16.1	16.1	16.1	15.6	16.1	16.1	16.7	16.7	16.1	16.7	16.1	16.7
	18	17.2	16.7	17.2	17.8	17.2	17.2	17.8	17.8	17.8	18.3	18.3	17.8
Soil Warm 2	4	25.0	25.6	25.6	25.0	25.0	25.0	25.6	26.1	25.6	25.6	26.1	25.6
	8	22.8	22.8	22.8	22.8	22.2	22.8	23.3	22.8	23.9	23.9	23.3	23.3
	15	23.9	24.4	23.9	25.0	24.4	24.4	24.4	25.0	24.4	25.6	25.0	25.0

A two-way analysis of variance was run on each plot. For all plots, no significant difference was found between temperatures at 7.6 and 15.2 cm below the soil surface. There was no significant difference between the daily recorded temperatures and the average profile temperatures. At a depth of 15.2 cm there were differences between temperatures directly over a heat tape and those between loops of the tape. There were consistent differences among treatment temperatures, and the average temperatures within the treatments were consistently within prescribed limits.

Temperature Changes With Cold Water Applications

The results from a study on the effects of 6.1^{o}C irrigation water on the warm treatments is shown in Table 7. The warmest soil (SW2) treatment was affected the most with a 3.9^{o}C drop in temperature. Within an hour after watering ceased, all three plots were returning to their original temperatures.

Table 8 outlines the results from a more intensive follow-up study on April 24, 1978. Each temperature is an average from five random points at the same level in the bench. The water temperature was 6.1^{o}C. In all cases the temperature at a depth of 15.2 cm returned to the starting point. At the 7.6 cm depth, the warm gravel (GW) plot also returned to the original temperature. All other temperature controlled plots at the 7.6 cm depth were within one degree of the starting temperature. The variable plots

Table 7. The effect on substrate temperature of watering with 6.1°C water on January 15, 1978. Temperatures are recorded for time intervals from 5 to 60 minutes after watering ceased.

Treatment	Plot	Orig. Temp.	Temperature (°C) / Minutes After Watering							
			5	10	15	20	30	40	50	60
Gravel Warm	19	18.3	15.6	15.6	15.6	16.1	16.7	16.7	16.7	17.2
Soil Warm 1	18	15.6	15.6	15.6	15.6	16.1	16.1	16.1	16.1	16.7
Soil Warm 2	15	25.6	21.7	22.2	22.2	23.3	23.9	23.9	24.4	24.4

Table 8. The effect on substrate temperature of watering with 6.1°C water, conducted April 24-25, 1978. Temperatures recorded are averages of five temperatures at each of two depths. Temperatures are recorded for time intervals from 5 to 60 minutes after watering ceased. Original temperatures are given. All treatment plots tested were on the south bench.

Treatment	Depth (cm)	Orig. Temp.	Temperature (°C) / Minutes After Watering							
			5	10	15	20	30	40	50	60
Gravel Cool	7.6	7.8	6.7	6.7	6.7	6.7	6.7	7.2	7.2	7.2
	15.2	6.7	6.1	6.1	6.1	6.1	6.7	6.7	6.7	6.7
Gravel Variable	7.6	15.6	13.3	13.3	13.3	13.3	13.9	13.9	13.9	13.9
	15.2	15.6	13.9	13.9	13.9	14.4	14.4	14.4	14.4	14.4
Gravel Warm	7.6	17.8	15.6	15.6	16.1	16.1	16.7	16.7	17.2	17.8
	15.2	18.3	17.2	17.2	17.2	17.8	17.8	17.8	18.3	18.3
Soil Cool	7.6	8.3	6.7	6.7	7.2	7.2	7.2	7.2	7.8	7.8
	15.2	7.2	6.7	6.7	6.7	7.2	7.2	7.2	7.2	7.2
Soil Variable	7.6	15.0	13.3	13.3	13.3	13.3	13.3	13.3	13.9	13.9
	15.2	15.6	14.4	14.4	15.0	15.0	15.0	15.0	15.6	15.6
Soil Warm 1	7.6	17.2	15.6	15.6	16.1	16.1	16.1	16.1	16.7	16.7
	15.2	18.9	17.8	17.8	17.8	17.8	18.3	18.3	18.3	18.9
Soil Warm 2	7.6	23.9	21.1	21.7	21.7	21.7	22.2	22.2	22.8	22.8
	15.2	25.0	24.4	24.4	25.0	25.0	25.0	25.0	25.0	25.0

were within 1.7°C and 1.9°C, for gravel and soil respectively. These results indicated that the soil and gravel used in this experiment possessed high heat holding capacities which enabled the plots to buffer temperature changes. These results also substantiated findings by Pfahl, et al. (28) and Seeley and Steiner (34). The return to normal temperatures was slower farther away from the heating or cooling source. The use of cold water for irrigation purposes had little effect on temperature fluctuations.

Flower Production and Quality

The weekly total flower production expressed as a moving mean of three weeks' data is shown in Figures 2 and 3. The curves shown approximated production curves for commercial greenhouses which were planted in May and pinched in Mid-June. There were three distinct production peaks. All treatments exhibited a sharp peak the week of September 16, 1977, except the cool soil (SC) plot which peaked the following week. The second peak, which was spread out over a period of three to four weeks, occurred from December 31, 1977, to January 29, 1978. The third production peak appeared to have leveled out when the experiment was terminated.

There were slight differences in peak production, but analyses showed no significant differences in production for any one production period. Based on normal carnation cropping, arbitrary crop cut-off dates were set for the

Fig. 2. Total weekly production of gravel treatments expressed as a three week moving mean. Divisions separate arbitrary crop periods: Aug. 29, to Nov. 19, 1977, Nov. 20, 1977 to Mar. 4, 1978, and Mar. 5, to May 29, 1978.

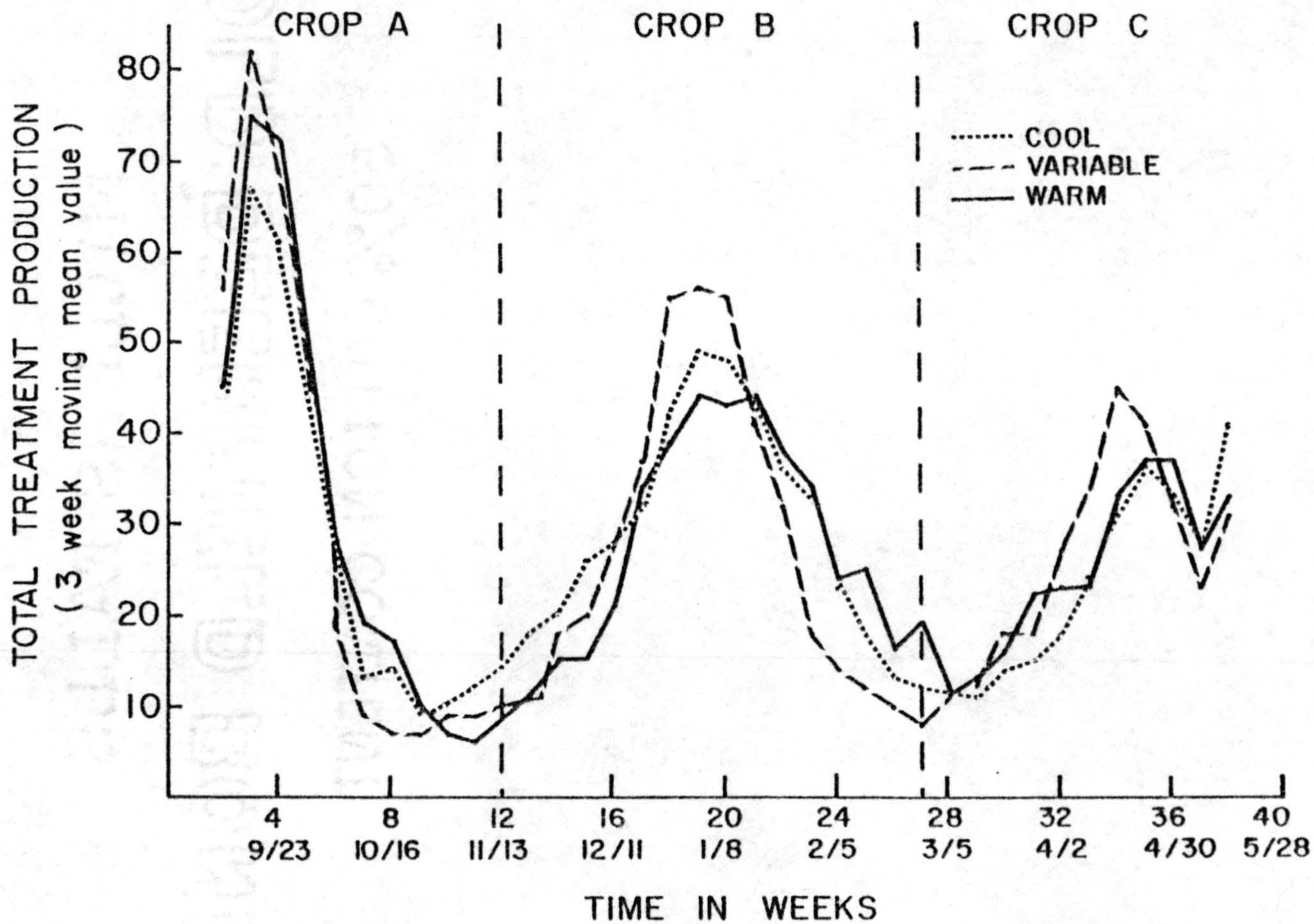
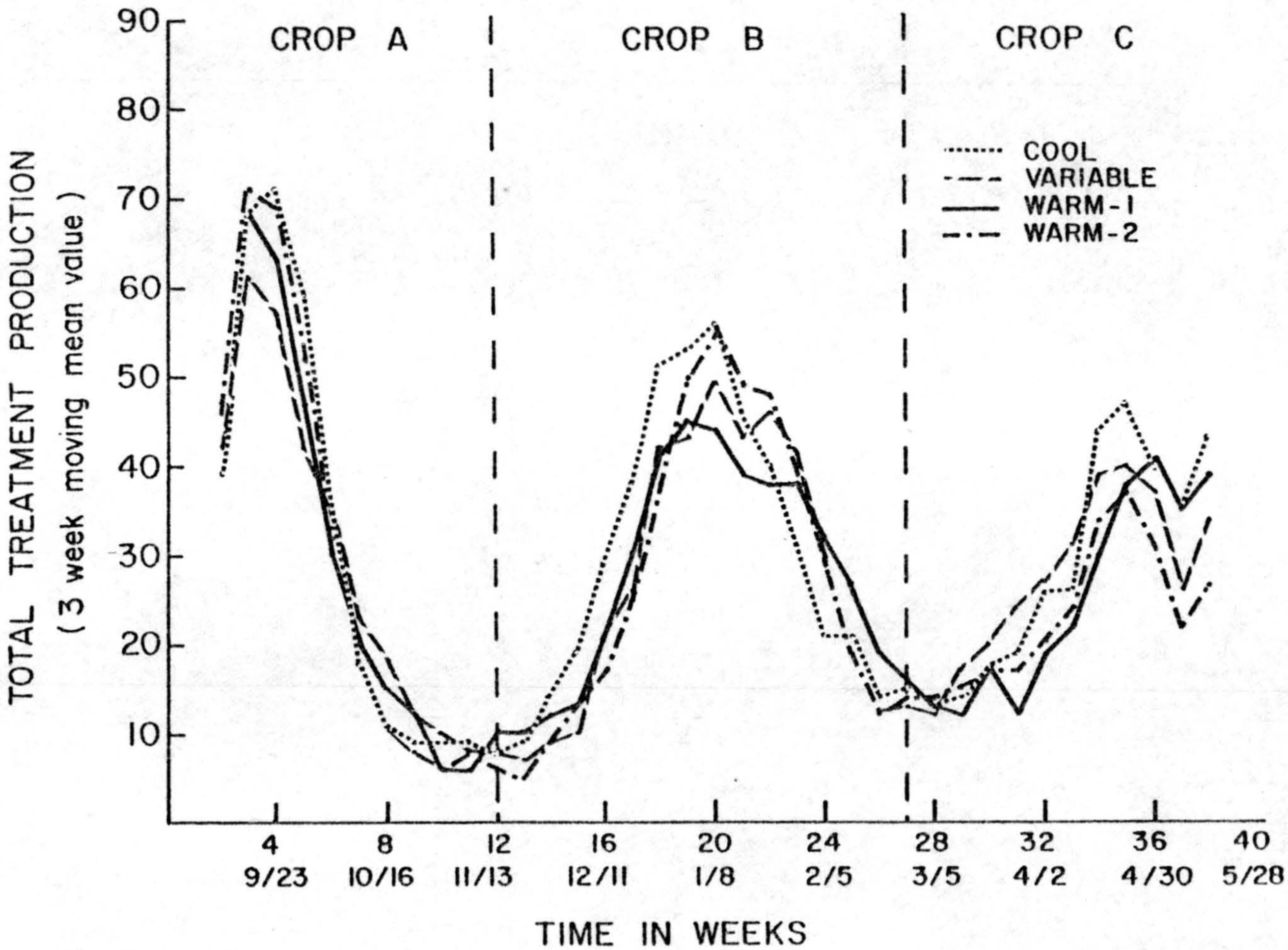

CROP A
CROP B
CROP C
COOL
VARIABLE
WARM
TOTAL TREATMENT PRODUCTION
(3 week moving mean value)
80
70
60
50
40
30
20
10
4
8
12
16
20
24
28
32
36
40
9/23
10/16
11/13
12/11
1/8
2/5
3/5
4/2
4/30
5/28
TIME IN WEEKS

Fig. 3. Total weekly production of soil treatments expressed as a three week moving mean. Divisions separate arbitrary crop periods: Aug. 29, to Nov. 19, 1977, Nov. 20, 1977, to Mar. 4, 1978, and Mar. 5, to May 29, 1978.



CROP A
CROP B
CROP C
COOL
VARIABLE
WARM-1
WARM-2
TOTAL TREATMENT PRODUCTION
(3 week moving mean value)
90
80
70
60
50
40
30
20
10
4
9/23
8
10/16
12
11/13
16
12/11
20
1/8
24
2/5
28
3/5
32
4/2
36
4/30
40
5/28
TIME IN WEEKS

first 12 weeks of production (Aug. 29, 1977 to Nov. 19, 1977), the next 15 weeks (Nov. 20, 1977 to Mar. 4, 1978) and the final 12 weeks (Mar. 5, 1978 to May 29, 1978). All flowers were cut with as long a stem as possible during the last 12 weeks. When comparisons were made, only treatments within crops were compared. Crop A was not compared to Crop B or C.

There were several differences which were not statistically detected. In gravel (Fig. 2) the variable treatment (GV) peaked earlier than the other gravel treatments in Crops B and C. The warm (GW) treatment averaged 7 and 12 less flowers per week than the cool (GC) and variable (GV) treatments, during the peak of Crop B and peaked approximately 1½ weeks later. Both the cool (GC) and warm (GW) gravel treatments were one week late for the first "peak" in Crop C, as compared to the variable (GV) treatments. However, the average production during weeks 34 through 38 appeared to be equal among the three treatments.

In the soil treatments (Fig. 3) the cool (SC) and warmest (SW2) treatments produced highest, and equally well during the first peak (Crop A). For Crop B, both SC and SW2 treatments had the highest average weekly production in the 20th week, but the cool treatment (SC) consistently produced 15 more flowers per week for the preceeding four weeks. In crop B, the warm (SW) treatment produced less flowers later than any other crop. This indicated that the soil temperatures encountered during the coldest part of the year (and with decreased light) were not conducive to optimum production. Although controlling substrate temperature had no beneficial effects on carnation production, trends indicated in Figures 2 and 3 show that, especially with gravel, it was possible to maintain temperatures too high for carnation growth.

When analyzed for total production the cool soil (SC) treatment had greater average weekly production than the warmest soil (SW2) or the cool gravel (GC) treatments (Fig. 4). The difference was three flowers per week per plot. The reason for this difference could have been a position effect. All three of the cool soil (SC) plots (13, 16, and 21) were located on the south bench. The south side of this bench bordered the central greenhouse aisle. While the aisle was only 30.5 cm wider than the other aisles in the house, this could have allowed greater sunlight penetration and subsequent increased growth. The remaining treatments were divided between both benches.

There were no significant differences among treatments (Table 9) for grade, length, internode length or weight. However, there was a difference in the number of Fancy grade carnations. The number of Fancy grade carnations in the variable soil (SV), warm soil (SW1), and warmest soil (SW2) treatments was reduced. This difference could be the difference between margin and profit for a grower. There

Fig. 4. LDS plots of mean weekly production for all treatments. LSD = 2.14 at the 95% confidence level.

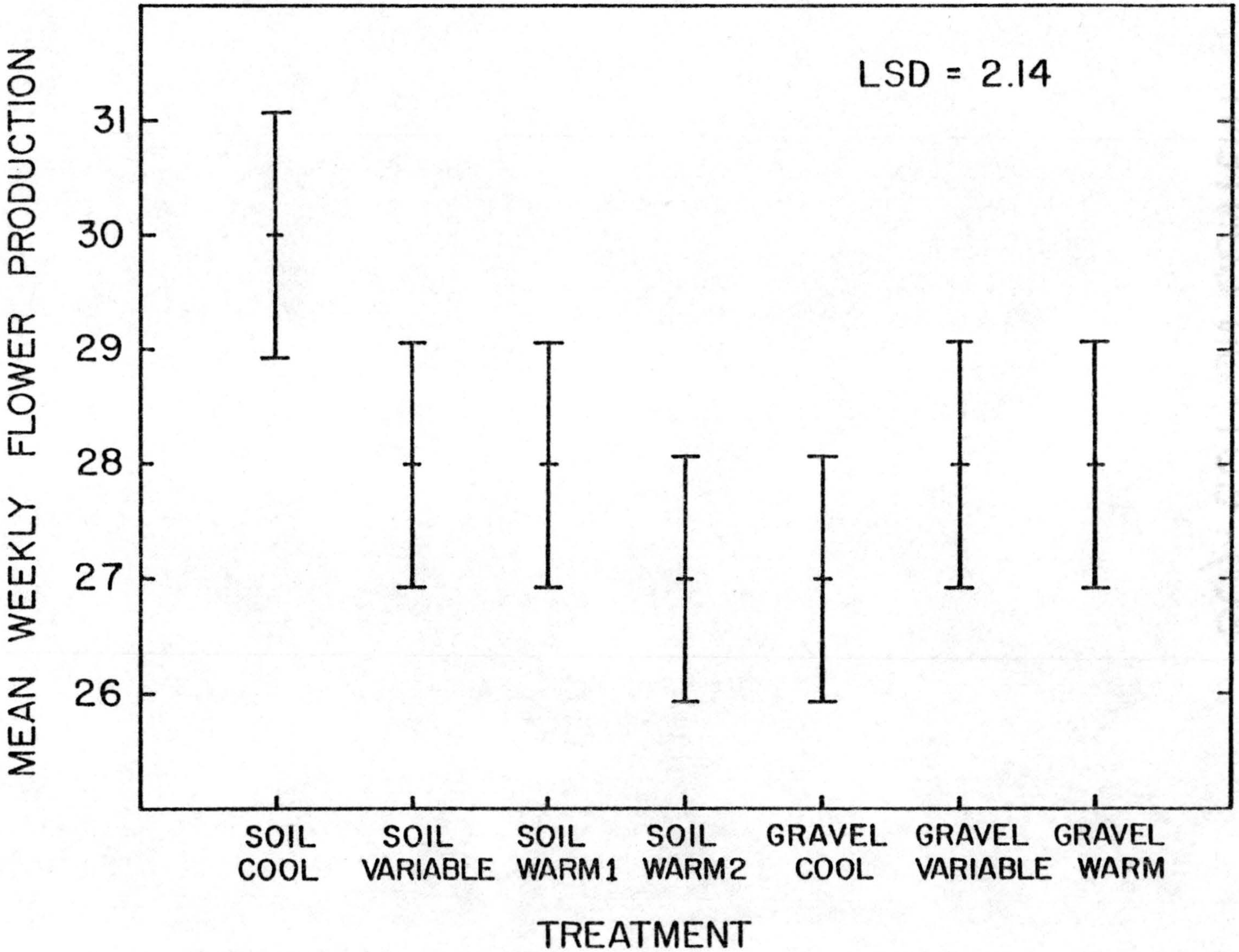

LSD = 2.14
MEAN WEEKLY FLOWER PRODUCTION
31
30
29
28
27
26
SOIL COOL
SOIL VARIABLE
SOIL WARM 1
SOIL WARM 2
GRAVEL COOL
GRAVEL VARIABLE
GRAVEL WARM
TREATMENT

Table 9. Total production, grades expressed as percent of total production, average weighted grade, mean length, mean weight, and mean internode length for each treatment.

	Total Production	% Fancy	% Standard	% Short	% Design	Weighted Mean Grade	Mean Length (cm)	Mean Weight (g)	Mean Internode Length (cm)
Gravel Cool	1108	43	42	11	5	4.23	64.0	27.8	9.3
Gravel Variable	1101	44	39	13	5	4.22	65.6	29.3	9.5
Gravel Warm	1086	46	40	10	4	4.27	64.7	27.2	9.2
Soil Cool	1200	41	41	13	5	4.18	64.1	27.3	9.1
Soil Variable	1084	38	44	13	5	4.16	63.4	26.4	9.0
Gravel Warm 1	1105	39	42	15	5	4.13	63.8	26.7	9.2
Gravel Warm 2	1080	34	42	18	6	4.03	63.2	25.0	9.4

Weighted mean grades computed by assigning the following values: Fancy, 5; Standard, 4; Short, 3; and, Design, 2.

were reasons for the differences. Plots 4 and 5 of the SW2 and SV treatments, respectively, were water stressed during the fifth week of the experiment. Another reason for this difference could be the position effect previously mentioned. Two of the treatments showing lower Fancy production had only one plot on the south bench.

The manipulation of soil and gravel temperatures did not have a significant effect on production, mean grade, average length, average weight or average internode length of 'CSU White' carnations grown in raised beds. These results correspond to those of Seeley and Steiner (34) and Johnson and Haun (18).

Dry Weight Production

Dry weights of flower heads and stems cut to the sixth node were measured for each plot (Table 10). One-way analyses of variance on average stem and head dry weight per plot were performed. No significant difference in dry weight production of plant material among treatments was indicated.

Tinting and Keeping-Life

Tinting evaluations were made on flowers used in a keeping-life study. Six flowers from each plot or 18 from each treatment were stored for 0, 3, and 5 days. The tinting data were not statistically analyzed. One hour after tinting, color and absorption were noted but no pattern in tinting quality could be discerned among treatments or

Table 10. Dry weights and average dry weights of flower stems and heads expressed as averages for plots within treatments.

Treatment	Plot	Dry Weights (g)			
		Stem	Mean	Head	Mean
Gravel Cool	2	3.4		1.8	
	10	3.0		1.7	
	14	3.5	3.3	1.7	1.7
Gravel Variable	3	4.9		1.7	
	9	3.7		1.8	
	17	3.6	4.0	1.9	1.8
Gravel Warm	7	3.4		1.8	
	11	3.1		1.7	
	19	3.6	3.4	1.9	1.8
Soil Cool	13	3.1		1.7	
	16	3.4		1.8	
	21	3.2	3.2	1.7	1.7
Soil Variable	5	4.2		2.3	
	12	3.3		1.7	
	20	3.3	3.6	1.7	1.9
Soil Warm 1	1	3.1		1.7	
	6	3.1		1.6	
	18	3.4	3.2	1.8	1.7
Soil Warm 2	4	3.0		1.7	
	8	3.0		1.6	
	15	3.3	3.1	1.7	1.7

storage times. It was decided that since commercially tinted carnations are not sold until the following day, allowing one day for color development, observations should be made on the second day of the experiment. No difference in tinting quality among any of the carnations was noted.

The results from the keeping-life study indicated no treatment difference in cut flower vase life (Table 11). These data were not statistically analyzed. It was felt that a consistent difference of two or more days keeping life would be significant. Otherwise, the differences and variability could be attributed to normal carnation variability.

Table 11. Keeping life expressed as the average numbers of days required for 18 flowers to senesce per treatment. Flowers were stored for 0, 3, and 5 days prior to the test.

Treatment	Average Number of Days for Flowers to Senesce		
	Stored 0 Days	Stored 3 Days	Stored 6 Days
Gravel Cool	10.6	10.3	10.1
Gravel Variable	10.3	10.2	10.1
Gravel Warm	10.1	10.3	9.9
Soil Cool	10.4	10.2	9.7
Soil Variable	10.7	10.3	9.7
Soil Warm 1	10.0	10.2	9.9
Soil Warm 2	10.0	10.1	9.6

SUMMARY AND CONCLUSIONS

Twenty-one plots of 'CSU White' carnations were planted on May 27 and pinched on June 11, 1977. Substrate temperature treatments began on planting day. There were seven treatments: four in soil and three in gravel. Soil treatment temperatures were variable, 7.2 to 10.0, 15.6 to 18.3 and 22.8 to 25.6^{o}C. Gravel treatment temperatures were variable, 7.2 to 10.0, and 15.6 to 18.3^{o}C.

Data were taken on every flower. Measurements were recorded on length, weight, internode length, and final grade. Grading was based on Society of American Florists guidelines and weight suggestions from Holley and Baker (16).

Based on the experimental conditions and results it was concluded that:

1. Soil and gravel temperatures over the range studied have little effect on the quality and production of 'CSU White' carnations.
2. Dry weight production of carnations was not affected by substrate temperatures.
3. Tinting quality and keeping-life of 'CSU White' carnations is not significantly affected by soil temperature.

It can be recommended that carnation growers rely on means other than substrate temperature manipulation for increasing carnation quality and production. The expense of a temperature maintenance system for heating or cooling soil or gravel would be an unnecessary expenditure and drain on the finances of a commercial operation.

Traditional air and substrate temperatures, influenced by the greenhouse climate, proved to be less expensive and equally as productive as heated or cooled soil or gravel.

LITERATURE CITED

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1. Allen, R.C. 1934. Effect of soil temperature on growth and flowering of certain greenhouse crops. Proc. Amer. Soc. Hort. Sci. 32:635-637.

2. Bailey, J.S., and L.H. Jones. 1941. The effect of soil temperature on the growth of cultivated blueberry bushes. Proc. Amer. Soc. Hort. Sci. 38:462-464.

3. Batjer, L.P., J.R. Magness, and L.O. Regeimbal. 1940. The effect of root temperature on growth and nitrogen intake of apple trees. Proc. Amer. Soc. Hort. Sci. 37:11-18.

4. Boersma, L. and K.A. Rykbost. 1975. Soil warming with power plant waste heat in greenhouses. HortScience. 10(1):28-30.

5. Cameron, S.H. 1941. The influence of soil temperature on the rate of transpiration of young orange trees. Proc. Amer. Soc. Hort. Sci. 38:75-79.

6. Cathey, H.M. 1954. Effect of air and soil temperature on the flowering of the Wedgewood iris. N.Y. State Flower Growers Bul. 106:3-4.

7. Chang, J. 1968. Climate and Agriculture. Aldine Publishing Co., Chicago. 304 p.

8. Davidson, O.W. 1941. Effects of temperature on growth and flower production of gardenias. Proc. Amer. Soc. Hort. Sci. 39:387-390.

9. Earley, E.B. and J.L. Cartter. 1945. Effect of the temperature of the root environment on growth of soybeans. Amer. Soc. Agron. J. 37:727-735.

10. Emsweller, S.S. and J.R. Tavernetti. 1931. The effect on gladioli of heating the soil with electricity. Proc. Amer. Soc. Hort. Sci. 28:398-401

11. Goldsberry, K.L. and K. Halkett. 1977. Effects of heated soil on plant growth. Colo. Flower Growers Assoc. Bul. 328:1-5.

12. Hagan, R.M. 1952. Temperature and growth processes. Soil temperature and plant growth. In Soil Physical Conditions and Plant Growth, B.T. Shaw, Ed. MacMillan Co., N.Y. 491 p.

13. Hanan, J.J., W.D. Holley, and K.L. Goldsberry. 1978. Greenhouse Management. Springer-Verlag, Berlin. 530 p.

14. Hartmann, H.T. and D.E. Kester. 1975. Plant Propagation, Third ed. Prentice-Hall, Inc., Englewood, Cal. 662 p.

15. Holley, W.D. 1954. Soil temperature has little effect on carnation timing. Colo. Flower Growers Assoc. Bul. 61:1.

16. Holley, W.D. and R.R. Baker. 1963. Carnation Production. William C. Brown Co., Inc., Dubuque, Iowa. 142 p.

17. Jaworski, N.A. 1974. Hot water equals cool cash for growers. Am. Veg. Grower 22(12):38.

18. Johnson, C.R. and J.R. Haun. 1972. Interaction of soil temperature and daylength on growth and flowering of carnations. HortScience. 7(4):414-416.

19. Jones, L.H. 1938. Relation of soil temperature to chlorosis of gardenias. J. Agr. Res. 57:611-621.

20. Kofranek, A.M. 1952. Some effects of low soil temperature upon the growth of Euphorbia pulcherrima. Proc. Amer. Soc. Hort. Sci. 59:509-515.

21. Kohl, H.C., G.M. Fosler, and F.F. Weinard. 1949. The effect of several soil temperatures on flower production in roses. Proc. Amer. Soc. Hort. Sci. 54:491-494.

22. Kohl, H.C., and Weinard, F.F. 1949. Growth and production of 'Better Times' roses with three soil temperatures. Roses, Inc. Bul. No. 137. Publ. at Columbus, Ohio.

23. Kramer, P.J. 1940. Root resistance as a cause of decreased water absorption by plants at low temperatures. Plant Physiol. 15:63-79.

24. Kramer, P.J. 1942. Species differences with respect to water absorption at low soil temperatures. Am. J. Bot. 29:828-832.

25. Levitt, J. 1972. Responses of Plants to Environmental Stresses. Academic Press, New York. 697 p.

26. Link, G. K.K. 1935. The Chicago soil-nutrient-temperature tank. Science 81:204-207.

27. Orr, H. 1954. Hot water treatments. N.Y. State Flower Growers Bul. 106:7.

28. Pfahl, P.B., H.P. Orr and A. Laurie. 1948. The effect of warm water application to greenhouse roses. Proc. Amer. Soc. Hort. Sci. 53:489-491.

29. Rutland, R.B. and J.E. Pallas, Jr. 1972. Transpiration of Antirrhinum majus L. 'Panama' as influenced by soil temperature. J. Amer. Soc. Hort. Sci. 97(1): 34-37.

30. Rykbost, K.A., L. Boersma, H.J. Mack, and W.E. Schmisseur. 1975. Yield reponse to soil warming: Agronomic crops. Agron J. 67:733-738.

31. Rykbost, K.A., L. Boersma, H.J. Mack and W.E. Schmisseur. 1975. Yield response to soil warming: Vegetable crops. Agron J. 67:738-743.

32. Schmisseur. W.E., L. Boersma, and K.A. Rykbost. 1955. Yield response to soil warming: Economic feasibility. Agron J. 67:793-797.

33. Seeley, J.G. 1965. Soil temperature and the growth of greenhouse snapdragons. Proc. Amer. Soc. Hort. Sci. 86:693-694.

34. Seeley, J.G. and J.R. Steiner. 1965. Soil temperature and the growth of greenhouse carnations. Proc. Amer. Soc. Hort. Sci. 86:631-640.

35. Shanks, J.B. and A. Laurie. 1949. A progress report on some rose root studies. Proc. Amer. Soc. Hort. Sci. 53:473-488.

36. Shanks, J.B. and A. Laurie. 1949. Rose Root studies: Some effects of soil temperature. Proc. Amer. Soc. Hort. Sci. 54:495-499.

37. Skaggs, R.W., D.C. Sanders, and C.R. Willey. Use of waste heat for soil warming in North Carolina. Trans. ASAE (Am. Soc. Agric. Eng.) 19(1):159-167.

38. Walker, J.M. 1967. Soil temperature patterns in surface insulated containers in water baths related Maize behavior. Soil Sci. Amer. Proc. 31:400-403.