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HEATING SYSTEM ALONE DOES NOT AFFECT CARNATION YIELD

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The effects of infrared heating versus forced hot-air on carnation production were evaluated over a two year period. More miniature and standard cut flower carnations were produced under forced hot-air, whereas the infrared section consumed more gas. We suggest the differences were due more to position of the houses than to the heating system involved.

Introduction

Fuel savings as the result of a particular heating system are difficult to verify on a commercial basis, due to variations in climatic conditions from year-to-year, as well as the fact that identical structures of commercial size for scientific testing are practically non-existent in the U.S.

Differences in fuel savings exceeding 50% have been touted for a number of years for one kind of system versus another, and several commercial species' responses have been examined under infrared heating. These results have been highly variable, in part resulting from different growth habits — i.e., a "two dimensional" pot crop versus a "three dimensional" cut flower crop, as well as the particular system and manner of installation.

Materials and Methods

We had available a 6000 sq.ft., fiberglass-covered greenhouse, 60 × 100 ft, which we divided into two sections by installing a double polyethylene curtain wall under the north-south gutter between the two 30 ft sections. Preliminary reports on this work were published in CGGA Bulletins 399 and 407-409. A conventional infrared heating system was installed in the west section (Fig. 1), consisting of two lines of radiative tubing with reflective shielding above the tubes. The lines extended the house length about 10 ft. above the crop. A common, forced hot-air system was installed in the east section, utilizing two gas-fired unit heaters blowing into a fan-jet to distribute hot air the length of the greenhouse.

Each heating system was two-staged and constituted the only difference between houses other than position. Climate control was via a remotely installed HP model 85 desk calculator and two digital acquisition/control units. This system executed every 90 seconds throughout the study with data accumulated from four aspirated temperature sensors in each house, one wet bulb temperature sensor, one radiation sensing unit, and one infrared thermometer focused on the carnation canopy.

Temperatures were set at minimums 52°F nights and 63°F days during the first year in both houses, using the average of the four sensors. However, the higher plant temperatures observed in the east house during the first year resulted in controlling the day temperatures at a minimum 62 in the east house (forced hot-air) versus 63 in the west house (infrared) in the second year. In both houses, the ventilation temperatures were adjusted upward as the outside temperatures dropped, so that when the temperature difference between inside and outside exceeded 30°F, the houses never ventilated on clear days. During certain times of the year, with a high radiant load in the daytime, air temperatures in the houses could exceed 70°F. However, CO_2 was injected during the time there was no ventilation.

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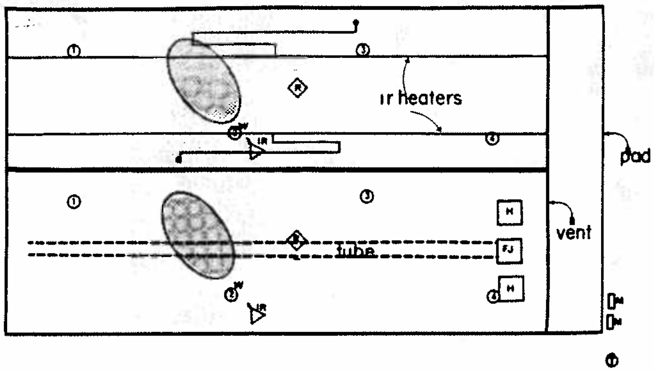

Fig. 1. Diagram of a 6000 ft^2 greenhouse used to compare forced-air and infrared heating systems. The west house contained the infrared heat system, while the east contained the forced air system.
Labels indicate:
- #1-4. aspirated thermocouple tubes,
- W. wet bulb thermocouples,
- R. pyranometers,
- IR. infrared thermometers,
- H. unit heaters,
- FJ. fan jet,
- M. gas meters, and
- T. outside aspirated thermocouple

The large shaded area was the area in the greenhouse where the carnations were grown. Calceolaria were grown to the north of this area, across both greenhouses. The shaded oval areas were those at which the infrared thermometers were aimed. The wall separating the two greenhouses was double polyethylene. The polyethylene tube on the east side distributed hot air from the heaters the length of the house.

Table 1: Tests for heating system effects, bench location effects, production ft^{-1} yr^{-2} and production totals for miniature carnation cultivars 'Cappello,' 'Etna,' and 'Georgia Ann.' Data are from flowers cut between August 27, 1984, and May 10, 1985, grown under either forced-air (FA) or infrared (IR) heat. Means are averages of 37 weeks. Tukey's HSD tests are calculated at the .05 level.

	Cultivar		
	'Cappello'	'Etna'	'Georgia Ann'
Flowers cut wk^{-1} plot^{-1}			
FA	10	14	16
IR	6	11	11
HSD	1	2	1
Mean no. cut wk^{-1} plot^{-1}			
FA East Bench	12	14	14
Middle Bench	9	15	16
West Bench	9	13	18
HSD	3	ns	ns
IR East Bench	7	11	11
Middle Bench	6	10	12
West Bench	7	11	10
HSD	ns	ns	ns
Flowers ft^{-2} yr^{-1}*			
FA East Bench	61	80	87
Middle Bench	48	85	94
West Bench	49	76	99
IR East Bench	40	64	64
Middle Bench	37	61	72
West Bench	40	68	59
Total Flowers cut			
FA	1706	2617	3013
IR	1266	2083	2098
Total	2972	4700	5111

*Based upon average flowers cut wk^{-1} plot^{-1} over one year, 3.2 plants ft^{-2}, 30 plants per plot^{-1}.

Three miniature carnation cultivars, 'Capello,' 'Etna,' and 'Georgia Ann,' and three standard cultivars, 'CSU Red,' 'Nora,' and 'White #1,' were planted in a gravel medium in raised benches on June 21, 1983, with a 6 × 8-inch spacing, 3.2 plants per sq.ft. Each of the six benches in each house contained three plots (30 plants each) with the miniature and standard cultivars randomized on each bench. The two types were planted on alternating benches. Chapin twin-wall trickle tubing provided water, controlled by an automatic timer with the standard Colorado State carnation solution injected at each irrigation. Flowers were cut and graded three times weekly. Only the data for the second year are presented in this report.

Results and Discussion

Miniature carnations — The average weekly yield for miniature carnations was higher in the forced hot-air house (FA) compared to those grown in the infrared heated house (IR). 'Georgia Ann,' for example, produced 16 flowers per week per plot under FA heat, compared to 11 flowers in the IR section. There was significant differences between benches in some instances. 'Capello' produced 12 flowers per week per plot in the east bench but only 9 in the middle and west benches (Table 1). Production per unit area was consistently lower in the west IR treatment.

Standard carnations — The mean total flowers cut per week was not statistically different between heating systems for 'CSU Red' and 'White #1' (Table 2). 'Nora,' however, produced 9 flowers per week per plot in the FA house, compared to 8 flowers under IR. 'CSU Red' produced 10 flowers per week per plot in the east and middle benches versus 7 in the west bench under FA heat. The fewest flowers from 'Nora' were produced in the west benches. More total flowers were cut from the FA-heated house for all three cultivars than from those grown under IR heat (Table 2).

Regression analysis — The computer system provided summarized data on air and plant temperature, solar radiation, and wet bulb temperatures (humidity). A statistical package was employed, which provided the means to test any desired combination of the above variables and any transformations which might have contributed toward controlling carnation response under these conditions. The independent variables were the differences between FA- and IR-heated structures for average weekly solar radiation, day and night air temperatures, day and night plant temperatures, and vapor pressures, as calculated from the wet bulb measurements. Unfortunately, the equations selected varied between standard and miniature carnation yield. The program selected solar radiation, day plant temperature, day vapor pressure, night vapor pressure, radiation × day plant temperature, and day plant temperature for miniature carnations as giving the best results; versus day plant tem-

Table 2: Tests for heating system effects, bench location effects, production ft^{-2} yr^{-1} and production totals for standard carnation cultivars 'Colorado State Red,' 'Nora,' and 'White #1'. Data are from flowers cut between August 27, 1984, and May 10, 1985, grown under either forced-air (FA) or infrared (IR) heat. Means are averages of 37 weeks. Tukey's HSD tests are calculated at the .05 level.

	Cultivar		
	'CSU Red'	'Nora'	'White #1'
Flowers cut wk^{-1} plot^{-1}			
FA	9	9	10
IR	9	8	9
HSD	ns	1	ns
Mean no. cut wk^{-1} plot^{-1}			
FA East Bench	10	10	10
Middle Bench	10	10	10
West Bench	7	7	8
HSD	2	2	ns
IR East Bench	9	9	10
Middle Bench	9	6	6
West Bench	9	6	6
HSD	ns	2	2
Flowers ft^{-2} yr^{-1}*			
FA East Bench	61	55	61
Middle Bench	62	60	66
West Bench	45	41	51
IR East Bench	50	48	55
Middle Bench	52	42	53
West Bench	50	33	37
Total Flowers cut			
FA	1808	1690	1923
IR	1652	1320	1578
Total	3460	3010	3501

*Based upon average flowers wk^{-1} plot^{-1} over one year, 3.2 plants ft^{-2}, 30 plants per plot.

perature, night vapor pressure, night air temperature, day plant temperature × day air temperature, day plant temperature × night plant temperature, and night vapor pressure × night air temperature for standards. Radiation was not included in the latter.

The differences between the two models did not appear susceptible to explanation. Statistical analysis applied to the average environmental parameters of the two houses (Table 3) showed significant differences between the two treatments in respect to radiation, day and night air temperatures, and day and night vapor pressures. One factor which we failed to take into account was the effect of vigorous air movement in the FA-heated section insofar as it would influence resistance to CO_2 uptake and water loss. The IR-heated house would have only natural convection with a correspondingly higher resistance to CO_2 and water vapor transfer. CGGA Bulletin 408 showed that vigorous, warm air movement could significantly raise carnation temperature above the air temperature, as contrasted to natural convection where the plant temperature tended to drop below the air temperature.

The higher radiation in the east, FA-heated section would be typical of Colorado's climate, due to increasing cloudiness common to the region in late afternoons. Furthermore, the IR heating pipes appeared to cause a significant reduction in total solar radiation. We propose that the results we

Table 3: Results of paired t-tests performed at the .05 level of significance on solar radiation levels, day plant temperatures, day and night air temperatures, and day and night vapor pressures. These factors possibly influenced carnation production under forced-air (FA) or infrared (IR) heat.

Independent Variable	Heating System	Mean	Standard Deviation	t-test
Radiation	FA	72.2	53.4	
(KJ m^{-2} dy^{-1})	IR	59.5	41.2	10.8*
Day air temperature	FA	67	3	
(°F)	IR	68	4	-4.80*
Night air temperature	FA	55	5	
(°F)	IR	56	5	-3.53*
Day plant temperature	FA	66	5	
(°F)	IR	67	4	-1.63
Day vapor pressure	FA	19.6	2.5	
(mb)	IR	18.7	2.3	6.28*
Night vapor pressure	FA	14.0	3.0	
(mb)	IR	13.7	2.9	3.65*

*Significant at .05 level.

obtained represent a combination-position effect, as contrasted to the idea that one heating system or the other is fundamentally "better" for growing a three-dimensional crop.

Natural gas consumption — The gas meters for each section were read daily from August 27, 1984, through January 16, 1985. The results of the analysis are presented in Table 4, showing that more natural gas was consumed in the IR house versus the FA house. This result was unexpected in view of the numerous publications purporting to show a significant advantage for infrared heat. A portion of the difference may be attributed to the fact that the average day and night air temperatures for the duration of the experiment were one to two degrees higher in the IR section than in the FA greenhouse. Secondly, the prevailing wind direction was westerly to north-westerly, and the west (IR) section would tend to consume more gas. Thirdly, the polished aluminum piping has a lower emissivity, compared to black pipe, and might have been less efficient in radiating heat.

In summary, there are other factors to be taken into account when assessing the relative merits of heating systems. We do not feel that there are significant advatages to either system in terms of energy consumption or carnation productivity.

Table 4: Results of a paired t-test, performed at the .05 level of significance, on natural gas meter readings for forced-air (FA) and infrared (IR) heating systems. Data for 142 days were recorded between August 27, 1984, and January 16, 1985. Values of means, standard deviations, and total used are expressed in cu.ft. (× 100) (CCF).

Heat	Mean Daily Consumption (24 hrs)	Standard Deviation	Total Used	t-test
FA	295.5	201.6	41,997.1	4.90*
IR	318.3	217.4	45,130.3	

*Significant at .05 level.