COMPARISONS OF HOT WATER MICROCLIMATE HEATING AND CONVENTIONAL OVERHEAD HEATING ON THE DEVELOPMENT AND NUTRITIONAL STATUS OF SEEDLING GERANIUMS AS WELL AS FUEL CONSUMPTION OF THESE HEATING REGIMES

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PREFACE

This study was conducted to determine geranium performance under a warm growing medium, cool air temperature regime; and whether this is a viable method for commercial growers to reduce production costs. Development patterns, flowering habit, nutritional status and the actual amount of fuel required to produce a crop was monitored.

I'd like to express my gratitude to Dr. Richard N. Payne, my major advisor, for his help on the project and especially his confidence in me.

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CHAPTER I

A COMPARISON OF HOT WATER MICROCLIMATE HEATING AND CONVENTIONAL OVERHEAD HEATING ON THE DEVELOPMENT OF SEEDLING GERANIUMS

Key Words: *Pelargonium* X *hortorum* Bailey, microclimate heating, conventional heating, leaf analysis

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ABSTRACT

The development of October-sown and December-sown crops of seedling geraniums (*Pelargonium* X *hortorum* Bailey) was monitored, each for a 16 week period, to determine plant response to a hot water microclimate heating system. This method of heating uses a low ambient air temperature ($10^{o}C$) and an elevated medium temperature (21.1^{o}). Development of the microclimate-heated crops was compared to crops grown under a conventional overhead forced air heating system (16.6^{o} air temperature).

The microclimate heating system produced a taller plant a majority of the first six weeks during the October crop

when compared to the conventional crop, but there were no differences in the December crop except for weeks 3 and 4 when the conventional heating system produced taller plants. After week six there were few differences in height due to the heating method. When microclimate heated plants were compared to conventional heated plants there were no height differences in the October-sown crop, and the only significant difference in the December crop was during week 14 when the microclimate heated plants were taller. Switching the heating method on some 8 week old plants caused no significant differences during weeks 10-16 of the October crop, but the plants that went from 8 weeks of conventional heat to 8 weeks of microclimate heat were significantly taller on week 10, 14 and 16 than plants that moved from microclimate to conventional heat. There was a cultivar X retardant interaction during weeks 10-16. Treating with chlormequat reduced plant height in all cases. Shoot dry weight during the initial 8 weeks of the October-sown crop under microclimate heating was slightly greater during weeks 3 and 6 when compared to the conventional heated crop. In the December crop, microclimate heating increased the shoot dry weight in week 3 and conventional heating caused increased shoot dry weights in weeks 1, 4 and 6. During the last 8 weeks, the type of heating had no effect on the shoot dry weight for the October crop, however in the December-sown crop the conventional heat produced heavier dry weights during weeks 10, 12, 14 and 16. Rotating the heat method after 8 weeks caused a significant weight difference in week 10 of both the October and December-sown crop. For the October crop the plants that went from microclimate to conventional heat were significantly heavier than the reverse heating method, but in the December crop the conventional to microclimate system produced a heavier shoot dry weight. Chlormequat reduced shoot dry weights for both cultivars in the October-sown crop but only 'Smash Hit' was affected in the December-sown crop. The differences in root dry weights due to the heating method were only during the October-sown crop. During the last 8 weeks, microclimate heat produced a heavier root dry weight in week 14 of the October-sown crop, but conventional heat caused a heavier dry weight in week 14 and 16 of the December crop. Moving plants from one heating system to the other had no effect on root dry weights in the October crop, however going from conventional to microclimate heat caused heavier weights during week 10 of the December crop. The chlormequat treatment had no effect on the root dry weight of 'Ice Queen' in either the October or December-sown crop, but the retardant reduced root dry weights for 'Smash Hit' in both crops. The microclimate heated crop flowered seven to ten days (mean first flowering date) later than the conventional heated crop. Tissue analysis after 8 weeks on the respective heating systems produced contradicting results. The October-sown crop had greater N, P and K concentrations in the conventionally heated plants but Ca and Mg concentrations were higher in two microclimate heated treatments and the Fe concentration was increased once due to microclimate heat. Analysis after 8 weeks in the December-sown crop showed leaf concentrations of all elements (N, P, K, Ca, Mg and Fe) to be higher in the microclimate heated plants. Chlormequat treated plants also had higher levels of all elements when compared to untreated plants. By week 16, when comparing microclimate to conventional heating, the conventional methods seemed to increase the concentrations of N, P, Ca and Mg, and the microclimate system raised the concentration of Fe. Chlormequat caused 'Smash Hit' to increase accumulation of N, P, K, Mg and Fe and 'Ice Queen' to accumulate P, K and Fe. The 16 week old December-sown crop had significantly higher levels of P and K only due to the microclimate heat source, but there was a significant cultivar X retardant interaction. Chlormequat treatments significantly increased concentrations of N, P, K, Ca, Mg and Fe in 'Smash Hit' but only increased P and K in 'Ice Queen'.

INTRODUCTION

Increased greenhouse heating costs are forcing growers to seek alternatives to reduce costs. Double polyethylene coverings, insulated north walls and the use of heat shields or thermal blankets are common practices today. Root zone or microclimate heating is a possible alternative to the widely used overhead unit heater-fan jet method of heating. Root-zone heating has been used in Europe for at least 20 years (7, 10) and American growers are beginning to try this method. Root zone heating provides heat to the root zone, while microclimate heating raises the temperature of the air near the plants and elevates the growing medium temperature (7). This produces a microclimate around the plants (9), giving a uniform temperature and a more even heat distribution, reduces chances for root diseases, increases media temperature and energy conservation (7).

Microclimate heating systems use small diameter tubing to carry hot water. EPDM, (ethylene propylene diene monomer), a synthetic rubber, is a popular tubing. This material can withstand temperatures from 148^{o}C to below freezing and not be harmed (10). The tubing can be placed under the bench, within the medium of a bench, or on top of the bench. The heat is transferred from the tubes to the air surrounding the pot and to the potting medium (4, 7). A soil heating system used in combination with a thermal blanket (heat shield) might provide significant energy savings (10). According to Henley (4), the most cost effective time for bottom heating of foliage plants is during propagation and early growing-on. Others agree that there is potential to allow the grower to conserve energy and still produce quality plants (5, 8).

Different species of plants as well as cultivars respond differently to microclimate heating (2, 3, 6, 10). Holcomb (5) found that *Begonia semperflorens*, *Dianthus barbatus* and 3 cultivars of ornamental pepper did not respond to heated soils. Zinnias produced more flowers on heated soil but height and plant diameter were not affected. Cosmos 'Sunny Gold' was taller, had a larger diameter, greater fresh weight and more open flowers due to soil heat. Doing work with poinsettias, Janes and McAvoy (6) showed that some cultivars produced shorter stems, shortened internodes and a lower stem fresh weight, while others had shorter stems but heavier stem fresh weights. 'V-10' bracts developed earlier on warm soils but 'Annette Hegg Supreme' was not affected by warm soils. The amount of anthocyanin in the bracts of axillary shoots increased as the growing medium was heated, adding to the appearance of the plant.

In this experiment, in addition to determining natural gas usage, we evaluated the performance of October and December-sown crops of seedling geraniums' in a microclimate heating environment compared to a conventional overhead air-heated situation. The overall growth, shoot and root dry weight, flowering pattern and foliar elemental concentration of plants in these two regimes were evaluated to determine if microclimate heating is an alternative to the conventional system.

MATERIALS AND METHODS

A 'Gro-Mat' (Bio Energy Systems, Ellenville, New York) microclimate hot water heating system was installed in a 11 x 24 meter uninsulated fiberglass greenhouse. The EPDM tubing was placed 5cm apart, on open welded wire benches, directly under the plants. The wire benches occupied 52.5% of the greenhouse floor space. A Paloma instantaneous hot water heater was used to heat circulating water to maintain a 21.1°C medium temperature. Overhead unit heaters were used as supplemental heat only to maintain a 10° air temperature. An adjacent, identical uninsulated greenhouse using a conventional overhead heating system (unit heaters, fan jets, poly tubes) with a 16.6° night temperature was compared to the microclimate system. Temperatures in both houses were allowed to rise naturally during the day to 26.6° before ventilating.

Seedling geraniums (*Pelargonium* X *hortorum* Bailey) 'Smash Hit' (red) and 'Ice Queen' (white) were used. The seeds for the two crops were sown October 3, 1983 and December 12, 1983, respectively in a commercial perlite medium. Seedlings were transplanted directly into 11.4 cm pots 14 days after sowing and placed in either the microclimate house or the conventional house. The 21 day period (sowing to experiment initiation) is not included in stating number of weeks of crop time, such as "week 16", on any one given heating system.

Plants were given monthly 89ml per pot drenches of Sodium diazenesulfonate/Benomyl (237ml/378.5 l of each) and some plants received a split application of chlormequat ((2-chloroethyl) trimethylammonium chloride, American Cyanamid Co., Wayne, NJ) 1500 ppm spray to runoff twice, 6 and 7 weeks after sowing. Fertilization was a constant liquid program using a 20-4.4-16.6 (N-P-K) "peat-lite special" fertilizer at 200ppmN - 44ppmP- 166ppmK. A separate group of plants with all the same treatments and cultural techniques were randomized and used to obtain flowering data and for foliar analysis only.

Experimental treatments were: 1) 16 weeks on microclimate heating, 2) 16 weeks on conventional heating, 3) 8 weeks on microclimate heating and the last 8 weeks on conventional heat and 4) 8 weeks on conventional heat and the last 8 weeks on microclimate heating, each with and without chlormequat treatment. These treatments were applied to 'Smash Hit' and 'Ice Queen'. A randomized complete block design was used with 6 single pot replications per treatment. At weeks 1, 2, 3, 4, 6, 8, 10, 12, 14 and 16, plants were evaluated for vegetative height, shoot dry weight and root dry weight. At the end of each evaluation period the plants to be measured were collected and brought into the headhouse. Vegetative height was measured (highest leaf-petiole point above the pot rim), the plants were cut off at the medium line, placed in paper bags and oven dried at 75^{o}C. The medium ball was then washed in water until the medium was removed, and placed in a 75^{o} oven and dried.

The date of first flowering (6 florets opened) was recorded for each plant in the separate group grown to observe flowering and to obtain leaves for foliar analysis. The fourth set of leaves from the terminal growing tip were used for foliar analysis. Leaves were collected at week 8 and week 16, dried at 75^{o}C and ground to pass through a 20 mesh screen in a Wiley mill. All samples were stored in air tight jars until analyzed. Before analysis, samples were re-dried for 24 hours at 80^{o}. N was determined by the macro-Kjeldahl method, P colorimetrically and K, Ca, Mg and Fe on a Perkin-Elmer 303 atomic absorption spectrophotometer. Each crop was grown for 16 weeks and both crops were analyzed.

RESULTS AND DISCUSSION

There were few interactions between heating systems and chlormequat treatments or heating systems and cultivar early in the crop so these factors were examined separately. From week 8 through 16 there was a significant cultivar X retardant interaction.

Vegetative Height

During the initial 8 weeks of the October crop, plants on the microclimate heating system were usually significantly taller than those on the conventional heating system (Table I). For the December crop, conventionally heated plants were significantly taller than microclimate heated plants during weeks 3 and 4, and they were slightly taller during weeks 1, 2, 6 and 8, but the differences were not significant. From week 10 on there were no significant height difference in microclimate and conventionally heated plants for the October crop, and in only one case (week 14) was there any differences in the December crop (Table II). For plants grown for 8 weeks on one heating system, then moved to the other heating system, there were no significant height differences for the October crop, but in the December crop, plants moved from conventional to microclimate heat were usually significantly taller (weeks 10, 14 and 16) than those grown first on microclimate heat and then moved to conventional heat. There appeared to be a carry-over effect, and final height depended somewhat on conditions present during weeks 1-8.

From week 8-16 there were differences in height, and a significant cultivar and retardant interaction (Table III). The chlormequat treated plants were significantly shorter, for both cultivars, during the entire 8 week period (8-16). 'Ice Queen' was less affected by the chlormequat than was 'Smash Hit'. Janes (6) found that poinsettias were shorter when given warm soil temperatures.

TABLE I

EFFECT OF HEATING METHOD ON VEGETATIVE PLANT HEIGHT DURING WEEKS 1-8 OF THE TWO 16 WEEK CROP CYCLES[z]

Treatment	Avg. vegetative plant height (cm) for week 1	2	3	4	6	8
			October sowing			
Microclimate Heat	1.7	3.1	6.1	6.3	11.5	13.8
Conventional Heat	1.2	3.1	5.4	5.8	10.7	13.6
	***	NS	***	*	**	NS
			December sowing			
Microclimate Heat	2.2	2.7	3.7	3.9	7.6	14.2
Conventional Heat	2.4	3.0	4.6	5.4	8.4	14.8
	NS	NS	**	***	NS	NS

[z] Includes 'Smash Hit' and 'Ice Queen'. Each figure is the mean of 48 plants. In the majority of cases there was no interaction between heating method and cultivar, or cultivar and retardant, so data for the two cultivars and the cycocel treatments were combined. There was a cultivar x retardant interaction for weeks 3 and 6 for the October-sown crop and a heating method X retardant interaction for week 6 for the December-sown crop.

*, **, ***, NS - Significance at 5% (*), 1% (**), 0.1% (***) or non-significant (NS).

TABLE II

EFFECT OF HEATING METHOD ON VEGETATIVE PLANT HEIGHT DURING WEEKS 10-16 OF THE TWO 16 WEEK CROP CYCLES

Heat source weeks 1-8	Heat source weeks 9-16	Avg. vegetative plant height (cm) for weeks			
		10	12	14	16
			October sowing		
Microclimate	Microclimate	18.9[x]	25.4	25.6	32.5
Microclimate	Conventional	19.3	24.8	25.8	32.4
Conventional	Conventional	18.2	25.7	26.3	32.6
Conventional	Microclimate	18.6	25.3	26.7	31.1
$LSD_{.05}$		1.2	1.1	1.6	1.8
			December sowing		
Microclimate	Microclimate	19.0	24.0	29.0	33.2
Microclimate	Conventional	16.6	23.8	26.6	31.2
Conventional	Conventional	18.9	24.0	27.4	31.5
Conventional	Microclimate	19.8	24.5	28.2	34.5
$LSD_{.05}$		1.2	1.2	1.6	2.2

[x] Each figure is mean of 24 plants. Includes 'Smash Hit' and 'Ice Queen' with and without chlormequat.

TABLE III

VEGETATIVE PLANT HEIGHT OF 'SMASH HIT' AND 'ICE QUEEN' WITH AND WITHOUT CHLORMEQUAT FOR WEEKS 8-16 OF THE TWO 16 WEEK CROP CYCLES[z]

	Vegetative height (cm) for week				
Treatment	8	10	12	13	16
			October sowing		
'Smash Hit' CCC[y]	9.4	13.3	18.7	20.0	26.0
'Smash Hit' no CCC	16.9	21.8	28.8	29.0	35.2
'Ice Queen' CCC	12.9	18.2	25.2	25.9	31.5
'Ice Queen' no CCC	15.6	21.5	28.5	29.5	35.8
$LSD_{.05}$	1.3	1.7	1.4	2.3	2.5
			December sowing		
'Smash Hit' CCC	11.5	14.1	19.4	22.4	27.7
'Smash Hit' no CCC	17.6	22.6	28.8	33.7	35.5
'Ice Queen' CCC	13.0	17.8	22.8	26.4	31.9
'Ice Queen' no CCC	16.0	19.9	25.4	28.9	35.3
$LSD_{.05}$	1.5	1.7	1.7	2.3	3.1

[z] Each figure is the mean of 24 plants. Since there was no interaction between heating system and chlormequat, these factors were examined separately (Tables I and III).

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

Shoot and Root Dry Weight

The shoot dry weights for weeks 1-8 gave conflicting results. On the October crop, microclimate heat produced heavier dry weights in weeks 3 and 6, but in the December crop conventional heat caused heavier shoot weights in weeks 1, 4 and 6, and microclimate heat yielded a heavier shoot weight in week 3 (Table IV). For our average medium temperature on each heating regime, see Chapter II. Barrett (2) reported similar results using mums. His highest shoot fresh weight was in the coolest soil temperature. During the last 8 weeks, microclimate compared to conventional heating had no effect on the October crop, but conventional heat produced heavier dry weights for weeks 10, 12, 14 and 16 of the December-sown crop (Table V). During the last 8 weeks the type of heating had no effect on the shoot dry weight for the October crop, however in the December-sown crop the conventional heat produced heavier dry weights during weeks 10, 12, 14 and 16. Rotating the heating method after 8 weeks caused a significant weight difference in week 10 of both the October and December-sown crops. For the October crop the plants that went from microclimate to conventional were significantly heavier than the reversed heating method, but in the December crop the conventional to microclimate system produced a heavier shoot dry weight.

There was a significant cultivar X retardant interaction for weeks 8-16. In the October crop, both 'Ice Queen' and 'Smash Hit' were significantly heavier when not treated with chlormequat for weeks 8-16, and 'Smash Hit' was more susceptible. The December sown 'Smash Hit' was also heavier when no chlormequat was applied but 'Ice Queen' was not affected during weeks 8-16 (Table VI).

TABLE IV

EFFECT OF HEATING METHOD ON SHOOT DRY WEIGHT DURING WEEKS 1-8 OF THE TWO 16 WEEK CROP CYCLES[z]

	Shoot dry weight (g) for week					
Treatment	1	2	3	4	6	8
			October sowing			
Microclimate Heat	.05	.11	.36	.82	2.45	5.24
Conventional Heat	.05	.11	.31	.73	2.20	5.43
	NS	NS	**	NS	*	NS
			December sowing			
Microclimate Heat	.04	.08	.27	.30	1.77	5.56
Conventional Heat	.07	.10	.26	.60	2.59	5.53
	**	NS	**	***	***	NS

[z] Each figure is the mean of 48 plants. Includes 'Smash Hit' and 'Ice Queen'. In the majority of cases there were no interactions between heating method and cultivar, or cultivar and retardant, so data for the two cultivars and cycocel treatments were combined. There was a cultivar X heating method interaction for weeks 3 and 4 for the October-sown crop and a heating X retardant interaction for week 2 and 3 for the December-sown crop.

*, **, ***, NS Significance at 5% (*), 1% (**) and 0.1% (***) or non-significant (NS).

TABLE V

EFFECT OF HEATING METHOD ON SHOOT DRY WEIGHT DURING WEEKS 10-16 OF THE TWO 16 WEEK CROP CYCLES

Heat source weeks 1-8	Heat source weeks 9-16	Shoot dry weight (g) for week 10	12	14	16
		October sowing			
Microclimate	Microclimate	8.59[x]	13.49	17.94	23.57
Microclimate	Conventional	9.99	13.83	17.96	23.63
Conventional	Conventional	8.89	13.88	17.43	22.96
Conventional	Microclimate	8.08	13.63	17.22	22.83
$LSD_{.05}$		.96	1.27	1.19	1.57
		December sowing			
Microclimate	Microclimate	10.15	14.09	20.01	25.75
Microclimate	Conventional	10.57	15.45	20.52	26.67
Conventional	Conventional	13.78	16.81	22.14	27.72
Conventional	Microclimate	12.14	15.59	20.36	26.11
$LSD_{.05}$		.98	1.15	1.46	1.75

[x] Each figure is the mean of 24 plants. Includes 'Smash Hit' and 'Ice Queen' with and without chlormequat.

TABLE VI

SHOOT DRY WEIGHT OF 'SMASH HIT' AND 'ICE QUEEN' GERANIUMS WITH AND WITHOUT CHLORMEQUAT FOR WEEKS 8-16 OF THE TWO 16 WEEK CROP CYCLES[z]

	Shoot dry weight (g) for week				
Treatment	8	10	12	14	16
			October sowing		
'Smash Hit' CCC[y]	3.9	6.3	9.7	11.8	15.7
'Smash Hit' no CCC	6.2	10.4	15.9	21.0	26.6
'Ice Queen' CCC	5.3	8.9	13.1	17.7	23.7
'Ice Queen' no CCC	6.0	10.1	16.1	20.1	26.9
$LSD_{.05}$	.8	1.4	1.8	1.7	2.2
			December sowing		
'Smash Hit' CCC	4.8	10.3	13.6	18.9	22.3
'Smash Hit' no CCC	6.7	14.0	18.0	23.9	30.0
'Ice Queen' CCC	4.9	11.2	14.5	19.5	25.9
'Ice Queen' no CCC	5.8	11.2	15.9	20.7	28.1
$LSD_{.05}$	1.0	1.4	1.6	2.0	2.4

[z] Each figure is the mean of 24 plants. Since there was no interaction between heating systems and chlormequat treatment, these factors were examined separately (Tables IV and VI).

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

Root dry weights were significantly higher on the microclimate system for weeks 1 and 4 of the October crop and week 1 of the December crop. Conventional heat produced heavier root dry weight for week 2 of the October crop and week 4 of the December crop (Table VII). These early results were to inconsistent to make any definitive assumptions. For weeks 10-16 in the October crop, root weights were usually not significantly different between microclimate and conventional heated plants. For the December crop, differences were not significant until weeks 14-16 when conventionally heated plants had greater root weights (Table VIII). Differences between plants switched after 8 weeks from one system to the other were largely not significant. However, in the December crop, plants switched from microclimate to conventional heating finished with significantly higher root weights (weeks 14 and 16) than plants grown on microclimate heating for the entire 16 week period. There appeared to be a slight tendency for reduced root growth in the microclimate system, possibly being too warm for best root growth. Chlormequat treatment had no effect on the root dry weight of 'Ice Queen' in either the October or December-sown crop. It did cause a lower root dry weight in both October and December crops of 'Smash Hit' (Table IX).

Foliar Nutrient Analysis

The elemental analysis on 8 week old plants of the October crop indicated a significant cultivar X retardant X

TABLE VII

EFFECT OF HEATING METHOD ON ROOT DRY WEIGHT DURING WEEKS 1-8 OF THE TWO 16 WEEK CROP CYCLES[z]

	Root dry weight (g) for week					
Treatment	1	2	3	4	6	8
				October sowing		
Microclimate Heat	.06	.09	.22	.82	1.01	.96
Conventional Heat	.04	.15	.23	.63	.92	1.01
	***	*	NS	**	NS	NS
				December sowing		
Microclimate Heat	.10	.03	.21	.16	.73	1.05
Conventional Heat	.05	.04	.23	.32	.73	.99
	**	NS	NS	***	NS	NS

[z] Each figure is the mean of 48 plants. Includes 'Smash Hit' and 'Ice Queen'. In the majority of cases there were no interactions between heating method and cultivar, or cultivar and retardant, so data for the two cultivars and chlormequat treatments were combined. There was a cultivar X heating method interaction for weeks 1 and 3 for the October-sown crop and a heating X retardant interaction for week 1 of the December-sown crop.

*, **, ***, NS Significance at 5% (*), 1% (**), and 0.1% (***) or non-significant (NS).

TABLE VIII

EFFECT OF HEATING METHOD ON ROOT DRY WEIGHT DURING WEEKS 10-16 OF THE TWO 16 WEEK CROP CYCLES

Heat source weeks 1-8	Heat source weeks 9-16	Root dry weight (g) for week 10	12	14	16
			October sowing		
Microclimate	Microclimate	1.26[x]	1.50	2.89	2.07
Microclimate	Conventional	1.68	1.28	2.03	2.23
Conventional	Conventional	1.04	1.41	1.75	2.38
Conventional	Microclimate	1.41	1.44	2.37	2.32
$LSD_{.05}$		.29	.24	.39	.58
			December sowing		
Microclimate	Microclimate	1.44	1.52	1.84	2.23
Microclimate	Conventional	1.38	1.72	2.14	3.00
Conventional	Conventional	1.61	1.72	2.18	2.92
Conventional	Microclimate	1.62	1.87	2.02	2.76
$LSD_{.05}$		.21	.30	.25	.40

[x] Each figure is the mean of 24 plants. Includes 'Smash Hit' and 'Ice Queen' with and without chlormequat.

TABLE IX

ROOT DRY WEIGHT OF 'SMASH HIT' AND 'ICE QUEEN' GERANIUMS WITH AND WITHOUT CHLORMEQUAT FOR WEEKS 8-16 OF THE TWO 16 WEEK CROP CYCLES[z]

	Root dry weight (g) for week				
Treatment	8	10	12	14	16
			October sowing		
'Smash Hit' CCC[y]	.79	.93	1.11	1.37	1.32
'Smash Hit' no CCC	1.02	1.71	1.67	2.66	2.44
'Ice Queen' CCC	1.04	1.24	1.35	2.24	2.29
'Ice Queen' no CCC	1.09	1.50	1.56	2.78	2.95
$LSD_{.05}$	.18	.42	.34	.55	.83
			December sowing		
'Smash Hit' CCC	1.01	1.48	1.54	1.79	2.20
'Smash Hit' no CCC	1.20	1.83	1.95	2.26	3.16
'Ice Queen' CCC	.90	1.34	1.63	1.94	2.65
'Ice Queen' no CCC	.98	1.40	1.70	2.21	3.00
$LSD_{.05}$	.18	.30	.42	.36	.57

[z] Each figure is the mean of 24 plants. Since there was no interaction between heating systems and chlormequat treatment, these variables were examined separately (Tables VII and IX).

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

house (heating system) interaction (Table X). The conventional heating system produced greater leaf N and P concentrations, and K concentration generally followed the same trend. Ca was unaffected except on 'Smash Hit' treated with chlormequat and 'Ice Queen' with no chlormequat both on microclimate heating, which gave increased concentrations. Mg concentrations were increased on both 'Smash Hit' and 'Ice Queen' when treated with chlormequat and microclimate heat. The Fe concentration was increased only on 'Smash Hit' treated with chlormequat and microclimate heat. The December-sown 8 week old microclimate heated plants had significantly greater concentrations of all elements (N, P, K, Ca, Mg and Fe) than the conventional heated plants (Table XI). 'Ice Queen' had a greater concentration of all elements except N and Fe than 'Smash Hit' and chlormequat increased elemental concentrations of all elements.

However, by week 16 the heat source had a lesser effect on the elemental concentration, but there was a significant cultivar X retardant interaction. On the October-sown crop when comparing microclimate to conventional heating, the conventional heating method seemed to increase the accumulation of N, P, Ca and Mg, and microclimate heating raised the concentration of Fe (Table XII). In the December crop the heating method had little effect on the elemental concentrations except for increased concentrations of P and K with the microclimate heating (Table XIII). The plants that were alternated from one heating method to the other

TABLE X

ELEMENTAL CONCENTRATION OF 8 WEEK OLD 'SMASH HIT' AND 'ICE QUEEN' GERANIUMS IN THE OCTOBER CROP

Cultivar	Growth retardant	Heating method	% Dry weight N	P	K	Ca	Mg	μg/g dry weight Fe
'Smash Hit'	chlormequat	Microclimate heat	5.02[x]	.761	3.15	1.73	.33	93
		Conventional heat	5.53	.818	3.30	1.31	.26	57
	no chlormequat	Microclimate heat	3.78	.546	3.22	1.29	.27	61
		Conventional heat	4.72	.738	4.00	1.22	.28	59
'Ice Queen'	chlormequat	Microclimate heat	4.57	.781	3.75	1.80	.33	82
		Conventional heat	5.03	.950	4.39	1.65	.29	64
	no chlormequat	Microclimate heat	4.29	.696	3.76	1.58	.32	64
		Conventional heat	4.81	.808	4.41	1.37	.29	65
		$LSD_{.05}$	.18	.085	.40	.19	.04	24

[x] Each number is the mean of 6 samples.

TABLE XI

FOLIAR ELEMENTAL CONCENTRATION OF 8 WEEK OLD GERANIUM PLANTS IN THE DECEMBER-SOWN CROP

		% Dry weight			μg/g Dry weight	
Treatment	N	P	K	Ca	Mg	Fe
Microclimate Heat	4.94	.913	3.51	1.34	.31	70
Conventional Heat	4.74	.820	3.24	1.12	.27	53
	***	*	**	***	***	***
'Smash Hit'	4.81	.722	3.04	1.05	.27	59
'Ice Queen'	4.87	.961	3.71	1.42	.31	64
	NS	***	***	***	***	NS
CCC[y]	5.04	.915	3.51	1.34	.31	66
No CCC	4.65	.818	3.24	1.12	.27	57
	***	**	**	***	***	**

*, **, ***, NS Significance at 5% (*), 1% (**), 0 1% (***) or non significant (NS).

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

TABLE XII

ELEMENTAL CONCENTRATION OF 16 WEEK OLD 'SMASH' HIT' AND 'ICE QUEEN' GERANIUMS IN THE OCTOBER CROP

				% Dry weight					µg/g Dry weight
Cultivar	Retardant	Heat source weeks 1-8	Heat source weeks 9-16	N	P	K	Ca	Mg	Fe
'Smash Hit'	CCC[y]	Microclimate	Microclimate	4.64[x]	.997	3.49	1.73	0.34	112
		Microclimate	Conventional	4.40	.916	3.46	1.51	0.34	93
		Conventional	Conventional	4.88	1.21	3.71	1.99	0.41	74
		Conventional	Microclimate	5.08	1.16	3.78	1.92	0.40	77
	no CCC	Microclimate	Microclimate	4.29	.680	2.69	1.63	0.31	58
		Microclimate	Conventional	4.44	.700	2.48	1.90	0.33	57
		Conventional	Conventional	4.60	.766	2.80	1.82	0.36	69
		Conventional	Microclimate	4.61	.800	2.84	1.85	0.37	67
'Ice Queen'	CCC	Microclimate	Microclimate	4.43	.840	3.77	1.84	0.34	127
		Microclimate	Conventional	4.65	.766	3.43	1.77	0.32	80
		Conventional	Conventional	4.94	.940	3.65	1.88	0.37	71
		Conventional	Microclimate	4.79	.907	3.63	2.20	0.38	71
	no CCC	Microclimate	Microclimate	4.47	.693	3.10	1.79	0.33	59
		Microclimate	Conventional	4.36	.643	3.03	1.75	0.32	51
		Conventional	Conventional	4.87	.923	3.43	2.01	0.42	71
		Conventional	Microclimate	4.50	.843	3.28	1.93	0.35	64
$LSD_{.05}$				.27	.063	.28	.19	.03	21

[x] Each figure is the mean of 3 samples.

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

TABLE XIII

ELEMENTAL CONCENTRATION OF 16 WEEK OLD 'SMASH HIT' AND 'ICE QUEEN' GERANIUMS IN THE DECEMBER CROP

				% Dry weight					µg/g Dry weight
Cultivar	Retardant	Heat source weeks 1-8	Heat source weeks 9-16	N	P	K	Ca	Mg	Fe
'Smash Hit'	CCC[y]	Microclimate	Microclimate	3.90[x]	.693	3.13	1.77	0.35	98
		Microclimate	Conventional	3.90	.703	2.82	1.83	0.34	55
		Conventional	Conventional	3.84	.663	2.90	1.98	0.39	57
		Conventional	Microclimate	3.93	.670	3.04	1.90	0.38	59
	no CCC	Microclimate	Microclimate	3.65	.497	2.38	1.59	0.32	47
		Microclimate	Conventional	3.67	.520	2.29	1.54	0.32	53
		Conventional	Conventional	3.66	.480	2.19	1.62	0.32	54
		Conventional	Microclimate	3.66	.483	2.21	1.59	0.31	59
'Ice Queen'	CCC	Microclimate	Microclimate	3.88	.643	3.41	2.01	0.38	63
		Microclimate	Conventional	3.96	.630	3.23	2.25	0.40	61
		Conventional	Conventional	3.85	.507	2.81	2.05	0.40	61
		Conventional	Microclimate	3.67	.533	2.96	2.11	0.41	72
	no CCC	Microclimate	Microclimate	3.94	.650	2.95	2.05	0.39	53
		Microclimate	Conventional	3.89	.560	2.92	2.21	0.40	56
		Conventional	Conventional	3.86	.487	2.55	2.13	0.41	56
		Conventional	Microclimate	3.79	.483	2.51	2.10	0.39	97
$LSD_{.05}$				.15	.063	.33	.19	.03	30

[x] Each figure is the mean of 3 samples.

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

after 8 weeks showed that the plants on microclimate heat for the last 8 weeks had increased concentrations of P, K, Ca and Mg, but N and Fe were not affected. Only the October crop showed a benefit from the heating switch, and the December crop was unaffected. Chlormequat caused 'Smash Hit' to accumulate increased concentrations of N, P, K, Mg and Fe than the untreated plants in both October and December, but 'Ice Queen' only had increased concentrations of P, K and Fe due to chlormequat in the October and P and K in December crop (Table XIV, XV).

Brown and Ormrod (3) found that increased fertility levels improved the stem diameter and the fresh and dry weight of cut flowers. They suggest the higher soil temperatures may alter the ability of roots to take up nutrients. Cell walls that thicken faster along with fewer root hairs are a possible reason. They also suggest that increased nutrition levels may be needed to compensate for this loss of efficiency. Our study showed that the higher media temperatures did not affect the nutrient uptake and may have helped in the nutrient uptake.

<u>Flowering Performance</u>

Plants that spent all 16 weeks under the conventional heating system flowered earliest (Table XVI). The October-sown crop averaged 103 days from the start of the experiment and the December crop 108 days. The continuous 16 weeks of

TABLE XIV

FOLIAR ELEMENTAL CONCENTRATION OF 16 WEEK OLD GERANIUM PLANTS IN THE OCTOBER CROP

			% Dry weight				µg/g Dry weight
Cultivar	Retardant	N	P	K	Ca	Mg	Fe
'Smash Hit'	CCC[y]	4.75[x]	1.070	3.61	1.79	.37	89
	no CCC	4.49	.737	2.70	1.80	.34	63
'Ice Queen'	CCC	4.70	.863	3.62	1.92	.35	87
	no CCC	4.55	.776	3.21	1.87	.35	61
$LSD_{.05}$		.19	.045	.20	.09	.02	15

[x] Each figure is the mean of 12 samples.

[y] CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

TABLE XV

FOLIAR ELEMENTAL CONCENTRATION OF 16 WEEK OLD GERANIUM PLANTS IN THE DECEMBER-SOWN CROP

		% Dry weight					µg/g Dry weight
Cultivar	Retardant	N	P	K	Ca	Mg	Fe
'Smash Hit'	CCC[y]	3.89[x]	.682	2.97	1.87	.36	67
	no CCC	3.66	.495	2.26	1.58	.32	53
'Ice Queen'	CCC	3.84	.578	3.10	2.10	.39	64
	no CCC	3.86	.545	2.73	2.12	.39	65
$LSD_{.05}$		.08	.031	.05	.13	.02	10

x Each figure is the mean of 12 samples.

y CCC is an abbreviation for chlormequat. Chlormequat was applied as a foliar spray (2 1500 ppm applications) during weeks 3 and 4.

TABLE XVI

EFFECT OF HEATING METHOD ON THE AVERAGE DATE TO FIRST FLOWER AND AVERAGE NUMBER OF FLOWERS PER PLANT FOR 'SMASH HIT' AND 'ICE QUEEN' FROM THE START OF THE EXPERIMENT

Heat source weeks 1-8	Heat source weeks 9-16	No. plants not flowering	Days from exp. start[x]	Calendar date	Average no. flowers per plant by week 16
			October sowing		
Microclimate	Conventional	1	106	Jan. 31	1.8
Microclimate	Microclimate	4	113	Feb. 7	0.9
Conventional	Microclimate	6	109	Feb. 3	1.0
Conventional	Conventional	1	103	Jan. 28	1.9
			December sowing		
Microclimate	Conventional	0	113	April 1	2.4
Microclimate	Microclimate	0	117	April 9	2.2
Conventional	Microclimate	0	111	April 3	3.2
Conventional	Conventional	0	108	March 31	3.3

[x] To determine days from sowing, add 21 days.

microclimate heating required the longest period to flower, 113 days for the October crop and 117 days for the December-sown crop. This was a difference of 10 and 9 days respectively (Table XVI). This delay in flowering could probably be overcome by using heat shields or adjusting the air temperature of the microclimate house during the last few weeks. Barrett (2) suggested that the soil temperature may need to be adjusted for different stages of crop development. John White (10) also suggests a split night temperature may be better than a continuous cold or warm air temperature. Chlormequat treated plants produced more flowers by the end of the experiment than the untreated ones for both the October and December crop. The chlormequat treated plants averaged two flower per plant in the October crop compared to one flower per untreated plant. In the December crop the chlormequat treated plants averaged 3 flowers per plant and the untreated ones had 2 flowers per plant. The plants that spent the last 8 weeks of the cycle in the conventional heated house usually produced more flowers per plant than the microclimate environment (Table XVI).

It seems that microclimate heating is a viable method to reduce energy cost and yet produce a quality plant. It is still in the early stages of development and caution must be used. Each crop has a specific soil-air temperature ratio and this must be determined through experimentation.

Microclimate heating may not be capable of supply all the heat to greenhouses here in Oklahoma, so some type of back up heat must be available, but it should be emphasized that in this experiment only 52.5% of the floor space was utilized for benching (and thus for heated area), so if 70% or more of the floor space was utilized, such as with rolling benches, and this bench space was heated, perhaps no back-up system would be required. Heat shields might further reduce this need.

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CHAPTER II

A COMPARISON OF FUEL CONSUMPTION BETWEEN MICROCLIMATE HOT WATER HEATING AND CONVENTIONAL OVERHEAD FORCED AIR HEATING

Key Words: *Pelargonium* x *hortorum*, Bailey, microclimate hot water heating.

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ABSTRACT

The amount of natural gas required to heat a 11 x 24 meter uninsulated fiberglass greenhouse using a microclimate hot water system was compared to another uninsulated fiberglass greenhouse that used conventional overhead forced air heat. Seedling geraniums were placed in these two greenhouses and grown for 16 weeks. Weekly records of the amount of natural gas consumed were recorded. Two 16 week crops were grown under these heating designs and a 30.3% and 32% energy savings resulted when microclimate heating was used.

INTRODUCTION

The use of modified heating systems which warm the soil temperature and allow for lower than normal air temperature have resulted in plant performance equal to or better than plants grown under conventional heating regimes (1, 3, 5, 6). Zeroni (9) showed that roses grown in an unheated greenhouse with root heating at 20°C produced flowers that were equal in quality and yield to bushes grown in a commercial air-heated greenhouse. Not only was the quality comparable but energy requirements were less. Foliage cuttings placed in 20° soil reduced production time from 25% to 45% depending on species, regardless of the air temperature (7.2°, 10°, 12.7° or 15.5°). The cool air temperature had no effect on number of roots, root length or number of leaves. All plants had high quality at 7.2° air temperature except for one species that was chlorotic (2). The energy required to grow cymbidium orchids was reduced 20% by imbedding microclimate heating tubes into the concrete floor (4). A more even heat distribution pattern also resulted. Regulski (7) used in-bed pipes to circulate 20° water in outdoor propagation structures. He found that this system maintained a 13° root temperature when the outdoor ambient temperature was -8°. Another similar structure was air heated to 15° above the minimum outdoor temperature; the rhododendron cuttings in the microclimate system suffered no cold damage, but 40-50% of the crop was severely damaged in the air heated structure. The cost of the microclimate heating method was 50% less than heating the structure electrically and 6 times cheaper than heating a fiberglass greenhouse of equal growing area with propane.

In this study we were interested to see what type of savings could be achieved.

MATERIALS AND METHODS

A microclimate hot water heating system using "Gro-Mat" (Bio-Energy Systems, Ellenville, New York), EPDM (ethylene propylene diene monomer) tubing and a Paloma instantaneous hot water heater was installed in a 11 x 24 meter uninsulated fiberglass greenhouse. The tubing was placed 5cm apart on welded wire benches directly under the pots. Overhead forced air unit heaters were used only as supplemental heating to maintain an air temperature of 10°C. The media temperature was set at 21.1°. Another 11 x 24 meter uninsulated fiberglass greenhouse was used to compare conventional overhead heat (unit heaters, fan jet, poly tubes) set at 16.6° night temperature to the microclimate system. Both houses were allowed to drift to 26.6° during the day time before ventilating. A commercial gas meter was installed outside of each greenhouse to measure the amount of gas used.

Seedling geraniums were used as test plants. Weekly readings determined the amount of gas consumed. Media and leaf temperatures were recorded bi-weekly at 10:00 pm during the 16 week crop. A Cole-Parmer 8519-00-5A thermometer was used. The medium temperature was taken at the 5 cm depth and the leaf temperatures were taken on upper leaves of the plant canopy (approximately 25 cm above the microclimate heat tubes). The medium and leaf temperatures were randomly selected and both temperatures were not recorded on the same plant.

RESULTS AND DISCUSSION

The vegetative performance of the seedling geraniums was not greatly affected by the heating method (8). The only noticeable difference between the two heating methods was that the microclimate plants flowered about 10 days later than the conventional-heated plants. This delay could probably be overcome by using heat shields or raising the air temperature a few degrees the last week or two of the crop. In this experiment only 52.5% of the floor space was utilized for benching (and thus for heated areas). If this amount of space was increased and this bench space was heated, the few days of lag time may have been avoided.

The medium and leaf temperatures for both heating methods are presented in Table I. The medium temperature was higher in the microclimate house for both the October and December-sown crop. The leaf temperatures had some variation but were relatively close.

The amount of natural gas consumed is presented in Table II. The total fuel usage for the October crop was 10 m^3 [355.1 mcf (thousand cubic feet)] for the microclimate house compared to 14.4 m^3 (509.5 mcf) for the conventional house. The December crop used 7.5 m^3 (264.2 mcf) for microclimate system and 11.0 m^3 (388.5 mcf) for the conventional method. This resulted in a 30.3% fuel savings for the October-sown crop and 32% savings in the December-sown crop. This is a savings of approximately $685 and $552 for each of the two crops.

From these tests it seems that microclimate heating gives a definite advantage in reducing the cost of heating. The cost could further be reduced by using heat shields or thermal blankets and other energy saving measures.

TABLE I

SOIL, LEAF AND AIR TEMPERATURES (^{o}C) OF 'SMASH HIT' AND 'ICE QUEEN' GERANIUMS AS INFLUENCED BY THE HEATING METHOD

	Soil temp ^{o}C		Leaf temp ^{o}C		Air temp ^{o}C	
Week	Microclimate	Conventional	Microclimate	Conventional	Microclimate	Conventional
			October sowing			
2	21.3[x]	18.4	19.2	19.7	19.4[y]	18.5
4	21.8	17.5	19.8	17.0	21.1	19.2
6	19.4	18.9	18.6	17.9	14.4	17.1
8	19.1	16.6	14.7	18.5	12.9	15.4
10	21.5	18.4	14.3	17.0	13.4	19.1
12	20.9	17.5	14.4	19.3	13.9	18.1
14	20.9	19.5	17.6	18.6	18.3	18.0
16	21.1	19.3	18.7	20.5	19.6	19.0
	20.8	18.3	17.2	18.6	16.6	18.1
			December sowing			
2	16.9	16.7	12.8	19.2	13.9	18.1
4	23.8	19.1	18.2	18.1	18.3	18.0
6	24.1	19.1	18.9	18.7	19.1	18.9
8	23.6	17.1	18.0	15.7	18.2	16.0
10	21.4	17.3	19.6	17.6	19.8	19.3
12	22.2	17.2	16.6	18.3	16.0	17.5
14	20.2	18.1	17.8	17.2	18.4	16.5
16	18.9	18.1	17.0	17.5	16.5	17.4
	21.4	17.8	17.4	17.8	17.5	17.4

[x] Each figure is the mean of 6 samples. The medium temperatures were recorded at a depth of 5cm, the leaf temperatures were recorded 25cm above the bench and the air temperatures were recorded at head height.

[y] Each figure is the mean of 3 samples.

Note: The air temperature was set at 10^{o}C in the microclimate house but these readings were higher due to the rising of heat off the microclimate tubes.

TABLE II

CUBIC METERS OF NATURAL GAS CONSUMED EACH WEEK
TO GROW TWO 16 WEEK CROPS OF GERANIUMS

	October sowing		December sowing	
Week	Microclimate	Conventional	Microclimate	Conventional
1	.09	.01	.43	.54
2	.12	.16	.86	1.37
3	.50	.86	1.31	1.46
4	.37	.18[x]	.54	.76
5	.54	.72	.27	.78
6	.61	1.00	.43	.58
7	.87	.96	.38	.51
8	.53	1.32	.50	.73
9	1.67	2.29	.48	.69
10	.92	1.33	.44	.64
11	.43	.54	.35	.54
12	.86	1.37	.37	.59
13	1.31	1.46	.37	.63
14	.54	.76	.28	.46
15	.27	.77	.22	.33
16	.43	.58	.27	.41
	9.19	14.31	7.50	11.02

[x] This figure is low due to an inoperable heater that week.

Note: Week 1 is October 31, 1983 for the October-sown crop and January 9, 1984 for the December-sown crop.

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VITA 2

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Thesis: COMPARISONS OF HOT WATER MICROCLIMATE HEATING AND CONVENTIONAL OVERHEAD HEATING ON THE DEVELOPMENT AND NUTRITIONAL STATUS OF SEEDLING GERANIUMS AS WELL AS FUEL CONSUMPTION OF THESE HEATING REGIMES.

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