THE EFFECT OF IRRIGATION WATER TEMPERATURE ON THE GROWTH AND NUTRIENT UPTAKE OF GREENHOUSE-GROWN GERANIUMS (*Pelargonium hortorum*)

by

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B.S., Kansas State University, 1966

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture and Forestry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

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ACKNOWLEDGMENTS

The author wishes to thank Dr. Richard Mattson for the time and guidance he has provided in the completion of this Master's thesis. Appreciation is also expressed to the other committee members, Dr. Ronald Campbell, Dr. Neal Miles, and Dr. William Powers, for their assistance and encouragement.

A special note of thanks is extended to the author's wife, Bonnie, and his two children for their continued moral support, patience, and sacrifices in permitting their husband and father to complete this portion of his education.

INTRODUCTION

The temperature of soil or growing medium is an important environmental factor controlling plant growth. In colder climates, soil warming must occur in the spring before seeds will germinate or new growth of perennials is initiated. Investigations have determined critical or optimum temperatures to increase plant growth and hasten maturity. In earlier studies, soil was warmed by electric cables, steam lines, or hot water pipes that maintained stable temperatures.

The practice of applying heated irrigation water to the soil to warm the root zone has been attempted with varying effects on plant growth and development. The results obtained depend upon plant species, water temperature, and other prevailing environmental conditions. Temporary soil heating occurs with hot water as compared to the controlled stable temperature achieved in the earlier experiments. Heated irrigation water may be beneficial to plant growth because of (1) decreased shock, (2) increased water uptake by roots, and (3) stimulated biological activity due to a higher Q_{10} value. Other investigators claim that the temporary increase in soil temperature has no significant effect on plant growth and may even retard growth if high water temperatures are used.

The objectives of this study were (1) to investigate the effect of irrigation water temperature applied to greenhouse-grown geraniums during the spring months, and (2) to determine geranium cultivar response as measured by growth indices and nutrient content in the shoots. Soil temperatures were recorded prior to and after irrigation to determine magnitude and duration of temperature change.

REVIEW OF LITERATURE

Effect of Soil Temperature on Plant Growth and Development

Soil temperature effects on plant growth and development depend upon species, growth parameter, and other environmental conditions. One investigator (4) found an increase in flowering of chrysanthemums in heated soil, and Davidson (20) observed more buds and larger flowers when *Gardenia veitchii* was grown at higher than normal root zone temperatures. In gardenias, the greatest amount of bud drop occurred at the higher soil temperatures, resulting in reduced total flower production. Other investigators have found no increase or a decrease in flowering when the soil is heated (10,19,36,56).

David (19) reports that soil heating did not increase total flower yields in gerbera production but did bring about earlier flowering. Earlier maturation has also been observed in chrysanthemums, strawberries, and many of the vegetable crops permitting an earlier harvest date (4,10,19,26,54,55, 65,66). Rykbost *et al.* (54) found soil heating most beneficial for crops which had climatic limitations. He concluded that, in nearly all cases of the thirteen crops studied, soil warming resulted in earlier maturation which could be attributed to a faster germination rate and greater growth rates early in the season when soil temperatures would be limiting.

Increased plant size has generally been attributed to plants growing in heated soil (1,6,16,17,21,31,34,39,40,44,45,52,58,66,67,73). Martin and Wilcox (43) found that increasing the soil temperature from 13.3°C to 14.4° more than doubled tomato plant dry weight and the increment between 15.6°C and 21.1° was considerable. In a geranium study, Mastalerz (44) reported

that a soil temperature of 15.6°C at night and 21.1° by day produced heavier plants than those grown at higher or lower temperatures. He found that height was little affected. Taller plants have been reported by others (1,30,45,49,57), however.

Increases in the yield of food crops have followed a similar pattern. Usually, as soil temperatures increase, so do yields (11,16,48,61,65). For example, Nielson et al. (48) report yields of corn increasing with increments in temperature from 5°C to 26.7°.

The soil temperature also appears to be an important factor in plant root initiation and development. In a propagation study by Jacobs et al. (29), it was reported that begonia cuttings rooted better at a soil temperature of 22.5°C than at 19° or 20°. Other optimum rooting temperatures reported were 25°C for Areopanax reticulata and 31° for Ficus decora leaf cuttings. Carpenter et al. (15) found root initiation and growth of callused geranium cv. 'Irene' and poinsettia cv. 'Eckespoint D-3' to be increased growing in soil at 30°C and 25°, respectively, for 5 days and least at 5.0°C and 35.6°. Slight browning of poinsettia roots were observed after 5 days at 30°C, but geranium roots remained white. Knoll (34) found corn top and root growth restricted at 15°C as opposed to 25°. Del Valle and Harmon (22) determined in a turnip study that the optimum soil temperature for roots was lower than that for the tops. Jacobs et al. (29) observed a scorched root appearance in his begonias at a temperature of 25°C, and Holtzman (28) found that root elongation was retarded in tomatoes grown at 35°C.

The effects of soil temperature are dependent upon air temperature and possibly light intensity. Van Dijk (63) concluded that soil warming could give positive results with cucumber production in April and May when air temperatures were naturally high. Sato (55) also noticed a relationship between soil temperature and air temperature. In strawberry production, he reported that the higher the night air and soil temperature, the faster the growth and the earlier the plants flowered. Theron (61) found turnip yields to increase with soil temperature in the summer, while, in the winter, the optimum soil temperature for growth was lower (20°C). In a study by Fröhlich (25), it was determined that, with January planted tomatoes, soil heating at 15° and 23°C from January to April resulted in reduced yields and quality. He concluded that the optimum soil temperature corresponds to the optimum air temperature, which was dependent on the prevailing light conditions.

The Effect of Soil Temperature on Plant Nutrient Uptake

Nutrient uptake has been shown to vary with soil temperature by several investigators. In a study by Cannell et al. (16), it was determined that Ca, K, P, N, Cu, Fe, Mn, and Zn varied significantly with temperature changes in tomato plants. Del Valle and Harmon (21) found total mineral uptake to be highest at the optimum temperature for dry weight production. In collards, this temperature was 23.9°C. Mack et al. (41) observed increases in dry weight and P content of peas to be generally similar at 12.2°C, 16.7°, 21.1°, and 25.6° regardless of the level of P fertilizer applied. Others have found similar correlations between increases in temperature, dry weight and nutrient accumulation of certain elements (43, 59,61).

Allen (3) concluded that at least part of the effect of high temparatures on the growth of plants was to hasten the process of nitrification in the soil. More recent studies by Hogg et al. (27) and Francis and Callahan (24) confirm these results. Batjer et al. (7) found that lower root temperatures (4.4°C) interfered with translocation of N reserve to the tops of apple trees. Shanks and Laurie (58) drew similar conclusions when they reported a greater concentration of N fractions in rose roots grown at lower temperatures.

Knoll (34) reported increases in the percentage of phosphorus in corn plants grown at higher soil temperatures. Top:root ratios of the percentage of P were greater than 1 at 25°C and less than 1 at 15°, suggesting translocation interference. Determination of total P accumulated in the roots, however, showed that there were no differences due to soil temperature in the percentage of P translocated from the roots to the tops but that P uptake was restricted at the lower soil temperatures. Others have also observed increases in P uptake at warmer soil temperatures (2,5,39, 41,71). Van Koot (64) performed a unique experiment in which he found that symptoms of P deficiency in tomato seedlings could be corrected by immersing the pots in warm water (40°C) in which 2% mono-ammonium phosphate was dissolved.

Potassium uptake has also been shown to increase with an increase in soil temperature. Del Valle and Harmon (21) found that increasing the soil temperature from 7.2°C to 35° exerted the strongest influence on K concentrations in collard growth. A plant nutrient uptake study by Wallace (68) with barley and soybeans was made at soil temperatures of 12°C, 22°, and 32°. He observed that, with increasing temperatures, the K content increased and then decreased in barley and steadily increased in soybeans. He cited a literature review by Richards et al. done in 1952 where seasonal differences in the composition of fruit trees was discussed. It was determined that the Ca:K ratio of 7-month-old citrus tree leaves was 12:1 for leaves developed early in the spring, 8:1 for leaves developed early in the summer, and 5:1 for leaves developed late in the summer. It was thought by Wallace that these differences could be due to differences in soil temperature at the various times of the year.

Woolbridge (72), Del Valle and Harmon (21), and Lingle and Davis (39) all found plant calcium concentrations to increase with soil temperature increases up to approximately 24°C. Lingle and Davis (39), Kabu and Loop (32), and MacMillan and Hamilton (42) concluded in separate studies that magnesium concentration also increased with temperature to a point.

Rosenthal <u>et al</u>. (53) reviewed the literature in 1973 and concluded that generally as soil temperature decreases, macronutrient uptake remains constant or decreases. Calcium was an exception, increasing as soil temperature decreased in some crops. Micronutrient uptake varied with soil temperature. These generalizations tend to agree with Wallace's explanation of the seasonal differences in the Ca:K ratio in young fruit tree leaves.

Phillips and Bukovak (51) noted that the absorption of radiophosphorus and radiocalcium by bean and pea leaves increased with an increase in temperature of the root medium.

Plant Physiological Responses to Soil Temperature

In 1940, Kramer (37) found that the rate of water movement through the root systems of tomato and sunflower decreased with lower temperatures between 40°C and 0°. The rate of movement through sunflower roots at temperatures slightly above freezing averaged about 20% of the rate through the same roots at 25°C. The rate at 40°C averaged 160% of the rate at 25°. Kramer concluded that increases in root resistance with decreasing temperature was probably effective in slowing down physiological or active absorption of water and possibly the absorption of solutes by the roots. Batjer et al. (7), Bialoglowski (8), Cameron (13), and Abd et al. (1) observed a drop in transpiration rate as soil temperatures dropped. Bialoglowski (8) also noticed a marked decrease at temperatures above 35°C.

Kuiper (38) concluded in a study of beans that two soil temperature ranges could be distinguished, one with a high and one with a low Q_{10} value. Above a certain critical temperature, only the effect of viscosity of water could be observed to limit water uptake, indicating the existence of water filled pores in the root cell membranes. Below this critical temperature, the root cell membranes are assumed to be more homogenous and characterized by a high potential energy barrier for water. According to Kuiper, water transport appears to be limited by the capacity of a metabolic process involved in the establishment of the membrane. He found the critical temperature to depend on cultural conditions during growth, being lower with decreasing root temperature and/or decreasing aeration conditions.

Plant Response to Irrigation Water Temperature

Some plants show obvious sensitivity to cold irrigation water. In a study by Böhnert and Von Hentig (9) and Von Hentig (67), Gloxinias and Saintpaulias not only showed retarded growth and delayed flowering, but leaf spot as well when watered with tap water ranging from 5°C to 17°. Satisfactory development and quality were reported with warmer water up to

30°C. Temperatures above this point were reported to depress growth.

Carpenter and Rasmussen (14) found that the use of cold irrigation water (1.7°C) during midwinter significantly reduced greenhouse soil temperatures, lessened rose and chrysanthemum relative turgidities, partially or completely closed the stomata, and decreased plant height and fresh weight. Urgurchinski (62) also reported detrimental effects in cotton irrigated with cold water (10°C to 12°). He found that the loss of young bolls by shedding was 30% higher than when the temperature of the irrigation water was 25°C to 27°. Yield of seed cotton was reduced from 15.1 kg/ha grown at the higher temperature to 11.5 kg/ha when irrigated with cold water.

Nave (46) concluded that 32.2°C appeared to be the best irrigation water temperature for carnations, geraniums, foliage plants, and stocks.

Other investigators have found little if any plant response due to the effects of water temperature (47,56,60,69). Pfahl et al. (50) concluded in 1949 that it would not be commercially practical to heat the water or the soil for greenhouse roses. He found that warm water applied to the soil did not significantly increase the growth, production, quality of the flowers, or basal cane renewal. Seeley and Stener (57) came to similar conclusions from their study with carnations. They found that water temperature treatments had no significant effect on flower production, number of split flowers, or the interval of time from the cutting of one flower until harvest of the next flower on the same stem. They thought that a high water temperature of 65.5°C may have had a detrimental effect on plant growth over a long time period.

Field studies with heated irrigation water have likewise shown few significant results. In a study by Derco et al. (23), water at 25°C, 30°, 40°, and 45° was taken from a discharge canal and used for irrigation. Water in the range from 25°C to 40° had no effect on the root and leaf yields of sugar beet or on the grain yields of maize. Water at 45°C decreased sugar beet yields but increased maize yields, indicating a difference in heat tolerance.

Soil Temperature Response to Heated Irrigation Water

The effect of the temperature of irrigation water on that of the soil in fields of lucerne, mixed pasture, and maize at two different sites was reported by Wierenga et al. (70) to be small and brief. Differences in soil temperature from irrigation water at 27°C and 14° lasted for less than 24 hours at depths of 5 and 10 cm and for 60 hours at 30 cm. Evaporative cooling from the soil surface significantly reduced soil temperatures after irrigation in mid-April but not in mid-February. Seeley and Stener (57) reported minimal effects of 15.6°C and 26.7° water on soil temperatures in the greenhouse. They determined that 4.4°C water lowered the soil temperature in the bench by about 3.90° at the 2.54 cm depth, 1.68° at the 7.62 cm depth, and .56° at the 12.7 cm depth. 65.5°C water raised the temperature by about 23.33° at the 2.54 cm depth and the soil remained warmer than the original temperature for about an hour.

Investigations pertaining to soil temperature response in pots were not found in the literature search. More work is needed in this area to determine if the magnitude and duration of soil temperature change is sufficient to elicit a response in growth parameters and nutrient uptake of potted plants.

MATERIALS AND METHODS

Fifty terminal cuttings each of 'Sincerity', 'Springfield Violet', and 'Salmon Pink Irene' (Pelargonium hortorum) were taken from stock plants at a local greenhouse on March 10, 1975. Thirty-six cuttings of each cultivar, 12 to 15 cm long, were selected for uniformity and their fresh weight recorded. Cuttings were dipped in 0.03% IBA and directly "stuck" into 10 cm plastic pots. The potting medium used was equal parts sandy loam, peat moss, and perlite. Osmocote, a slow-release fertilizer (14-14-14), was incorporated at the rate of 607.1 g/m^3 (6 oz/ft^3). Immediately after "sticking", the cuttings were placed on the greenhouse bench, watered in with tap water, and allowed to root with only minimal daily misting.

The three geranium cultivars were irrigated with three water temperatures starting on March 17, 1975. The average water temperatures applied in each treatment during the 82 day experiment were 48°C, 31°, and 21°. All geraniums were watered daily, or less frequently, depending upon environmental conditions. An experimental unit was six plants of one cultivar receiving the same temperature of irrigation water. A randomized-block design was used with each pot color coded to distinguish its water temperature treatment. Guard rows were set up between reps and on either side of the bench. (See Appendix for experimental layout diagram.)

The plants were watered individually with 75 ml applied at each watering. The unheated 21°C water (control treatment) was drawn from the greenhouse tap after it had run for three minutes. The 31°C and 48° water were heated in plastic containers by 100-watt aquarium-type heaters. The containers were wrapped with fiberglass insulation and the water stirred prior to application to equalize temperatures at the various gradient levels. Water was transferred from the tanks to a preheated or cooled thermos bottle, measured, and then applied.

A 24-multipoint Honeywell potentiometer was used to monitor changes in air and soil temperature. Thermocouples were positioned at plant height and buried in the soil at a depth of 2 cm. The potentiometer ran for 24-hour cycles and was used to calibrate the water heating systems.

On June 6, 1975, geranium heights were measured and plants were cut at soil level. Fresh weights were recorded and the plant shoots dried at 60°C for 48 hours. The dried plant material was then weighed, ground in a Wiley mill containing a 2 mm screen, and stored in plastic vials. Flower buds were removed daily throughout the entire experiment but counts were not started until May 1, 1975.

Nutrient analyses were determined from 0.5 g samples of dried geranium shoots. The standard wet digestion with nitric and perchloric acid was utilized for analysis of P, K, Ca, Mg, Mn, and Zn. Total Ca, Mg, Mn, and Zn were determined by atomic absorption spectrophotometry. K was determined by flame emission photometry and total P colorimetrically by developing a yellow vanadomolybdophosphoricacid color. Samples were analyzed for N by the micro-Kjeldahl method after a sulfuric-peroxide digest of 0.5 g samples of dried plant material.

Analysis of variance on data was made using the AARDVARK program by the Kansas State University Statistics Department. The model statements used for the analysis of growth parameter data and nutrient content values are listed in the Appendix. Temperatures recorded on the potentiometer were converted to Celcius and computed using the PLOTTER program.

RESULTS

Growth Parameters

Cultivar effects

'Springfield Violet' was significantly taller than either 'Sincerity' or 'Salmon Pink Irene' (Table 1). 'Salmon Pink Irene' had significantly less final fresh weight, change in fresh weight, and dry weight as compared to the other two cultivars. 'Sincerity' and 'Salmon Pink Irene' had significantly higher flower bud counts than 'Springfield Violet'.

'Springfield Violet' was the largest cultivar with the smallest bud count. 'Salmon Pink Irene' had the least growth with the highest bud count while 'Sincerity' was intermediate between the others.

Cultivar and water temperature interactions

For the 'Salmon Pink Irene' cultivar, the 31°C water appeared to be the most conducive to plant growth and development (Table 2). Plants irrigated with warm water had significantly higher mean values for final fresh weight, change in fresh weight, dry weight, and flower bud count. These plants were also taller but the mean differences were not significant.

'Sincerity' geraniums in the 48°C water treatment had significantly less final fresh weight, change in fresh weight, and dry weight than those receiving cooler water treatments. At 48°C, 'Sincerity' had significantly fewer flower buds than those irrigated with 31° water.

The 48°C water had the opposite effect on 'Springfield Violet'. This cultivar responded favorably to hot water which resulted in significantly increased height, final fresh weight, and change in fresh weight for plants.

Table 1. Growth and flowering characteristics of three geranium cultivars[z]

Cultivar	Height (cm)	Final fresh weight (g)	Change in fresh weight (g)	Dry weight (g)	Flower bud count (no.)
'Salmon Pink Irene'	12.7 b[y]	30.7 b	21.7 b	4.72 b	4.4 a
'Sincerity"	12.9 b	45.4 a	35.2 a	6.44 a	3.7 b
'Springfield Violet'	15.1 a	46.9 a	37.7 a	6.97 a	1.8 c

[z]Data were averages of 36 plants per cultivar receiving 3 water temperature treatments.

[y]Mean values not having a letter in common are significantly different at the 5% level (Duncan's Multiple Range Test).

Table 2. Effect of irrigation water temperature on growth parameters of three geranium cultivars^{z}

Cultivar	Water temp. (°C)	Height (cm)	Final fresh weight (g)	Change in fresh weight (g)	Dry Weight (g)	Flower bud count (no.)
'Salmon Pink Irene'	48	12.1 c^{y}	25.7 d	16.3 e	4.41 de	3.2 c
'Salmon Pink Irene'	31	13.7 bc	40.6 c	30.2 cd	5.72 bc	5.7 a
'Salmon Pink Irene'	21	12.2 c	25.9 d	18.7 e	4.03 e	4.4 b
'Sincerity'	48	11.8 c	35.0 c	24.7 de	5.36 cd	3.2 c
'Sincerity'	31	13.1 bc	50.5 ab	41.3 ab	6.54 ab	4.3 b
'Sincerity'	21	13.8 bc	50.9 ab	39.5 ab	7.43 a	3.7 bc
'Springfield Violet'	48	16.6 a	53.4 a	44.5 a	7.56 ab	1.9 d
'Springfield Violet'	31	14.5 b	43.7 bc	34.0 bc	6.74 ab	2.0 d
'Springfield Violet'	21	14.2 b	43.8 bc	34.7 bc	6.61 ab	1.5 d
L.S.D.		1.97	8.8	8.72	1.088	1.05

^{z}Data were averages of 36 plants per treatment.

^{y}Mean values not having a letter in common are significantly different at the 5% level (Duncan's Multiple Range Test).

Dry weight and bud count were similar in all water treatments.

Overall, 'Springfield Violet' plants irrigated with 48°C water were heavier and significantly taller than any other combination observed. Bud count was the least with 'Springfield Violet' at 48°C, while the highest bud count was recorded on 'Salmon Pink Irene' irrigated with 31°C water.

Nutrient Uptake

Cultivar effects

'Salmon Pink Irene' contained significantly less nitrogen, phosphorus, potassium, calcium, magnesium, and zinc than the other two cultivars (Table 3). The total manganese content of 'Salmon Pink Irene' was significantly lower than in 'Springfield Violet' but not 'Sincerity'. 'Springfield Violet' accumulated significantly more P than the other two cultivars.

Elemental Ca and Zn percent of dry weight recorded for 'Salmon Pink Irene' was significantly less than 'Sincerity' and 'Springfield Violet'.

Cultivar and water temperature interactions

As shown in Table 4, 'Sincerity' geraniums irrigated with 48°C water accumulated significantly less total P, K, and Zn than those plants in 31° and 21° water treatments. 'Sincerity' watered with 21°C water accumulated significantly higher levels of Mg and Ca. 'Springfield Violet' had similar nutrient content in all water temperature treatments.

'Salmon Pink Irene' plants contained significantly more K, Ca, Mg, and Mn when irrigated with 31°C water as compared to 21° or 48° treatments. Total P content was significantly greater in plants watered with 31°C than those receiving 21° water, but P content in 48°C and 21° water were similar.

Table 3. Nutrient content of three geranium cultivars[z]

Cultivar	Element: N	P	K	Ca	Mg	Mn	Zn
	Total uptake of shoots (mg)						
'Salmon Pink Irene'	82 b[y]	14.5 c	86.9 b	38.3 b	9.3 b	.88 b	.191 b
'Sincerity'	138 a	20.3 b	112.2 a	56.4 a	12.6 a	1.00 ab	.388 a
'Springfield Violet'	130 a	24.3 a	111.1 a	61.9 a	13.9 a	1.07 a	.356 a
L.S.D.	35	2.7	14.8	7.0	1.4	.15	.072
	Percent dry weight					ppm (µg/gm dry weight)	
'Salmon Pink Irene'	1.6 a	.30 a	1.8 a	.79 b	.19 a	174 a	41 b
'Sincerity'	2.2 a	.31 a	1.8 a	.87 a	.20 a	156 a	60 a
'Springfield Violet'	1.9 a	.35 a	1.6 a	.88 a	.20 a	154 a	51 a
L.S.D.	NS	NS	NS	.06	NS	NS	10

[z] Data were averages of 36 plants per cultivar receiving 3 water temperature treatments.

[y] Mean separation by Duncan's Multiple Range Test, 5% level.

Table 4. Effect of irrigation water temperature on total nutrient content of shoots in three geranium cultivars[z]

Cultivar	Water temp. (°C)	Element						
		N	P	K	Ca	Mg	Mn	Zn
		Total uptake of shoots (mg)						
'S. P. Irene'[x]	48	71.3 a[y]	14.0 cd	69.9 c	31.89 e	7.96 e	.61 d	.20 de
'S. P. Irene'	31	111.8 a	17.7 bc	116.6 a	50.13 cd	11.65 cd	1.23 a	.22 de
'S. P. Irene'	21	63.5 a	11.8 d	74.1 c	32.92 e	8.37 de	.79 cd	.16 e
'Sincerity'	48	99.8 a	16.5 c	90.3 bc	45.99 d	10.75 cd	.87 cd	.25 cde
'Sincerity'	31	166.6 a	21.4 ab	120.8 a	53.15 bcd	12.20 bc	.95 bc	.42 ab
'Sincerity'	21	147.6 a	23.0 a	125.3 a	69.91 a	14.96 a	1.19 ab	.50 a
'S. Violet'[x]	48	154.2 a	24.9 a	115.2 ab	63.82 ab	14.50 ab	1.14 ab	.40 ab
'S. Violet'	31	112.6 a	25.3 a	113.2 ab	62.59 ab	14.13 ab	1.14 ab	.37 bc
'S. Violet'	21	123.3 a	22.8 a	104.8 ab	59.17 abc	12.95 abc	.94 bc	.30 bcd
L.S.D.		NS	4.6	25.7	12.16	2.40	.26	.12

[z]Data were averages of 36 plants per treatment.

[y]Mean separation by Duncan's Multiple Range Test, 5% level.

[x]'Salmon Pink Irene', 'Springfield Violet'.

The three cultivars each had a different optimum irrigation water temperature: 'Salmon Pink Irene' (31°C), 'Sincerity' (21°C), and 'Springfield Violet' (48°C). In general, the highest nutrient levels were found in 'Sincerity' irrigated with 21°C water. The interaction producing the lowest nutrient accumulation was 'Salmon Pink Irene' watered with 21°C water.

Soil Temperature Response to Irrigation Water Temperature

Figure 1 reflects typical springtime greenhouse soil temperature data recorded by the potentiometer on June 1, 1975, from 11:00 AM to 3:00 PM. The plants were watered between 11:20 and 11:50 AM. The curves represent soil temperature fluctuations in 10 cm plastic pots due to irrigation water temperature and subsequent cooling or heating because of other environmental factors. The air temperature in the greenhouse was plotted as a point of reference. Thermocouples were positioned at 15 cm above and 2 cm below soil level.

The 21°C water cooled the soil from 23.3° to 18.9°. Evaporative cooling may explain the reduction in soil temperature. The 48°C water elevated the soil temperature from 22.2° to 40.6° within one minute. Twenty minutes later the temperature decreased to 28.3°C and, within ninety minutes from the time of watering, it was at the same temperature as the soil irrigated with the 21°C water. At 11:40 AM, the 31°C water treatment was applied and by 12:40 PM the soil temperature was similar to the soil watered with 21°C water. From that time on, the 31°C treated soil remained approximately one to two degrees cooler than either of the other two soils. Air temperature variation was caused by air movement in the greenhouse influenced by automatic ventilator fans. Air temperatures were higher and increased more

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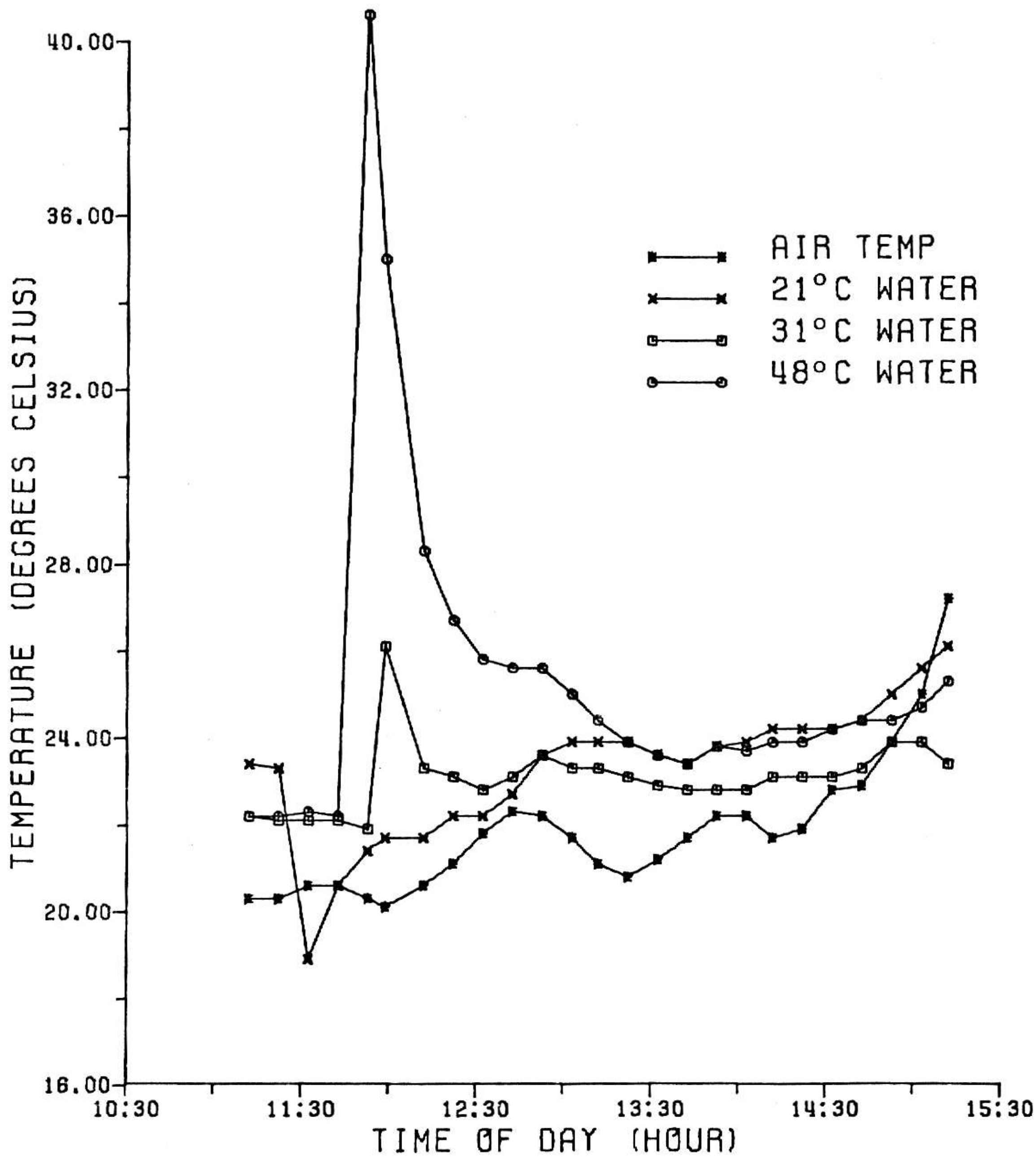
Figure 1. Soil temperature changes in 10 cm plastic pots due to the irrigation water temperature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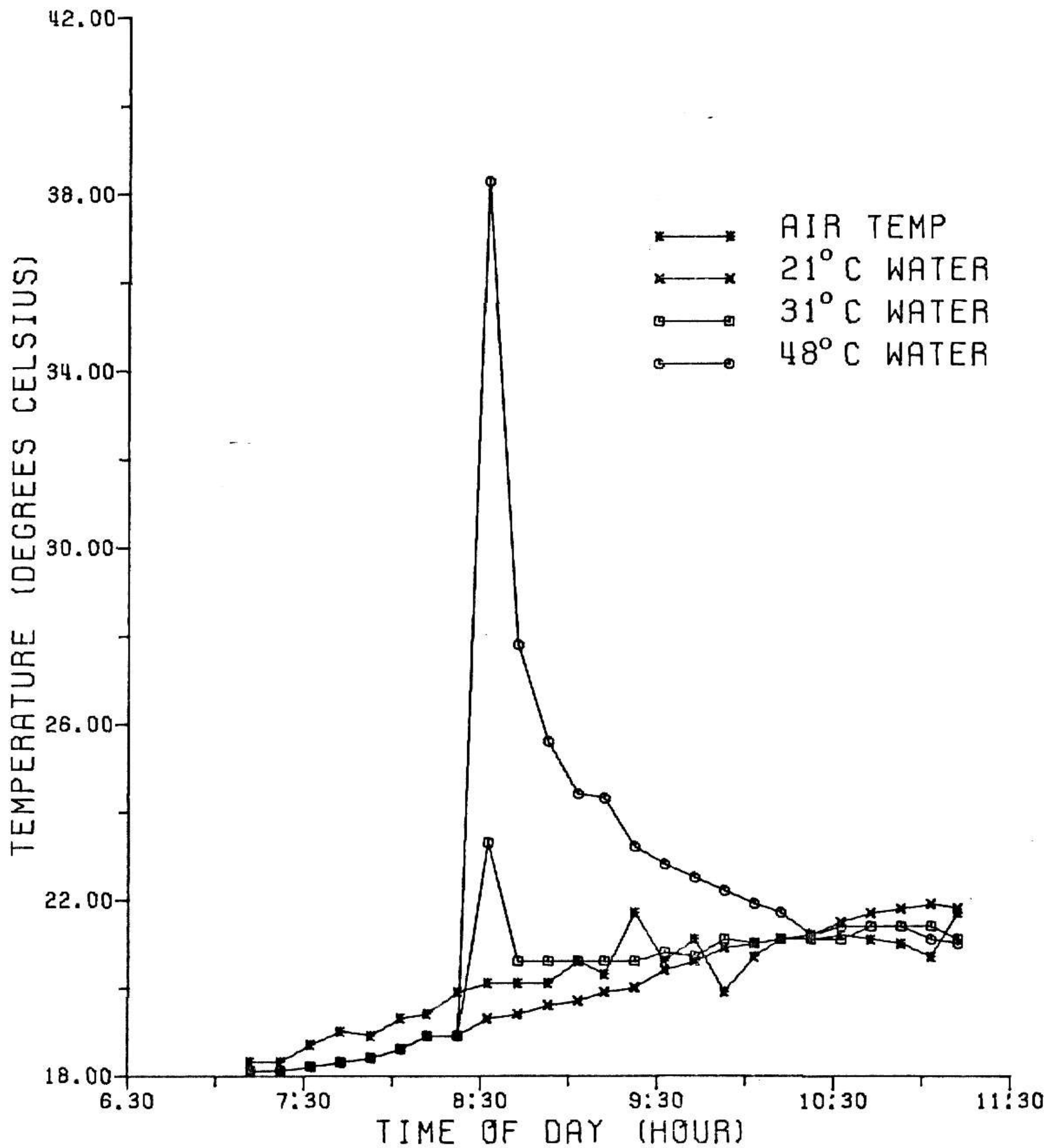
TEMPERATURE (DEGREES CELSIUS)
AIR TEMP
21°C WATER
31°C WATER
48°C WATER
10:30
11:30
12:30
13:30
14:30
15:30
TIME OF DAY (HOUR)

rapidly than soil temperature as the day progressed.

Data diagramed in Figure 2 indicates the effects of irrigation water temperature on soil temperature in 15 cm clay pots containing Brassaia actinophylla seedlings. The thermocouple was placed at a depth of 4 cm. These results were sought in an effort to determine what effect a different kind of pot containing more soil would have on the magnitude and duration of soil temperature change. Water was applied at 8:20 AM on May 29, 1975, when all soil and air temperatures were approximately the same (19°C). The 48°C water increased the soil temperature to 38.3° within one minute. After ten minutes, the soil temperature had cooled to 27.8°C and by 10:20 AM the soil was at the same temperature as the soil watered with the 21°C water. The 31°C water treatment increased the soil temperature to 23.3° initially and ten minutes later it was back down to 20.6°. By 9:30 AM, it was at the same temperature as the 21°C watered soil.

Figure 2. Soil temperature changes in 15 cm clay pots due to the irrigation water temperature


42.00
38.00
34.00
30.00
26.00
22.00
18.00
TEMPERATURE (DEGREES CELSIUS)
6.30
7:30
8:30
9:30
10:30
11:30
TIME OF DAY (HOUR)
AIR TEMP
21°C WATER
31°C WATER
48°C WATER

DISCUSSION

Cultivar Differences in Growth Parameters and Nutrient Uptake

Significant differences were observed in growth parameters and nutrient uptake due to genetic effects. Two distinct genetic types, the 'Irenes' and the 'A. M. Maynes' were studied. The 'Irenes' are tetraploids and not considered to be heat tolerant. 'Sincerity' is also an 'Irene' type, similar to 'Pink Cloud' developed at Iowa State University, which has a fair degree of heat tolerance. 'A. M. Mayne' was a French cultivar brought into the U.S. in 1914 by Good and Reese of Springfield, Illinois. These plants, later renamed 'Springfield' are diploid and tolerant of higher night temperatures.[1]

In this study, 'Springfield Violet' plants were the largest with the fewest flowers. 'Salmon Pink Irene' was the smallest with the most flower buds produced, while 'Sincerity' was intermediate in these parameters. These results are in agreement with Knicely (33) who classified geraniums into two types, Standards and French (Syn. Bruant), which differ in physical characteristics and ploidy number. The Standards are diploid having a chromosome number of 18. These plants generally have a taller growth form with a sparse breaking habit in 10 cm pots. The stems are slimmer with small thin leaves. The French types are tetraploid with 36 chromosomes and growth characteristics opposite those described for the Standards. Included in Knicely's data are the somatic chromosome numbers of the cultivars used in this investigation. He reported that 'Irene' and 'Pink Cloud' have 36, while

[1]Personal conversation, G. J. Buck, Professor of Horticulture, Iowa State University, Ames, Iowa, 1976.

'Springfield' has 18 chromosomes.

'Salmon Pink Irene' were the smallest plants and belonged to the nonheat tolerant French group. The significantly greater number of flower buds produced by 'Salmon Pink Irene' may be due to the "suicidal" tendency of geraniums to increase flowering when in a weakened or dying condition (G. J. Buck, personal communication). 'Salmon Pink Irene' were observed to have an unhealthy and stunted appearance during the growing phase of the investigation. Another explanation for the higher bud count and smaller size of 'Salmon Pink Irene' plants could be the possibility that they matured quicker and put more energy into flower bud development and less in vegetative growth (C/N ratio).

Total nutrient uptake was significantly smaller in 'Salmon Pink Irene' for N, P, K, Ca, Mg, and Zn. This was expected due to its smaller size. 'Springfield Violet', the largest of the cultivars tested, accumulated significantly more P than the other two cultivars. Higher values for Ca, Mg, and Mn were also recorded for 'Springfield Violet' but were not considered significant.

The only significant differences in mineral content on a percentage of dry weight basis was in 'Salmon Pink Irene' which had lower percentages of Ca and Zn than either 'Sincerity' or 'Springfield Violet'. A study of critical nutrient levels in geraniums by Kofranek and Lunt (35) suggests that in all three cultivars, the N, P, and K percentages of dry weight were below the ranges found in normal tissue. According to data gathered by Criley and Carlson (18), the N percentage for the three cultivars was in the critical range which was suspected due to the light green color of some plants. P and K levels were not considered critical but were below optimal. Ca and Mg levels were in the optimal range in all cultivars except 'Salmon Pink Irene' plants which were slightly below. Mn and Zn levels were above those considered optimal in all three cultivars. The low macronutrient percentages found in the geranium shoots indicate a deficiency in nutrient availability. The initial Osmocote addition to the soil mix was inadequate and additional fertilizer could have been applied.

Cultivar Differences in Growth Parameters and Nutrient Uptake Due to Irrigation Water Temperature

The data contained in Tables 2 and 4 show that cultivars respond differently to similar environmental conditions. The cultivars used in this study have different optimum root zone temperatures. For example, 'Sincerity' and 'Salmon Pink Irene' geraniums were affected adversely by 48°C water, whereas 'Springfield Violet' responded favorably to the same treatment. 'Springfield Violet' plants watered with 48°C water were significantly taller than those watered with 31° or 21° water. 'Sincerity' plants irrigated with 48°C water were shorter and significantly lighter in weight than those receiving the other treatments. 'Salmon Pink Irene' responded similarly to the 48°C and 21° treatments but plants watered with 31° water were taller and significantly heavier. In field studies, work by Derco et al. (23) demonstrated that 45°C water decreased sugar beet yields but increased maize yields. Seeley and Stener (57) thought that 66°C water may have had a detrimental effect on their carnation growth.

Flower bud count was significantly higher in 'Salmon Pink Irene' and 'Sincerity' plants irrigated with 31°C water than those watered with 48° water. Flower bud count differences were not significant among 'Springfield

Violet' plants. Carpenter and Rasmussen (14) and Nave (46) produced larger and earlier maturing plants at water temperatures of 30°C than those produced with cooler water temperatures.

Although the differences were not all significant, the same trend was observed in total nutrient uptake (Table 4) as was seen in growth parameters (Table 2). 'Springfield Violet' had greater uptake at 48°C than at 31° or 21°. 'Sincerity' plants had the least uptake at 48°C irrigation temperature. 'Salmon Pink Irene' geraniums had the greatest accumulation when irrigated with 31°C water, with only slight differences between the 48° and 21° water.

Cold water has been shown to be unfavorable to plant growth and development. Carpenter and Rasmussen (14) demonstrated that 1.7°C tap water in the winter reduced greenhouse soil temperatures to a level detrimental to rose and chrysanthemum growth. In addition to reduced plant heights and fresh weights, they observed a partial or complete closing of stomata when soil temperatures dropped. Others have also observed physiological changes due to soil temperatures (1,7,8,13,37,38). This does not appear to be the case in this investigation since the tap water, which averaged 21°C, was about the same temperature as the soil. Some mornings the soil temperature was even cooler than the tap water at the time of watering (Figure 1). The soil temperature did not change appreciably when watered with 21°C water. It is conceivable that, had this investigation been performed during the colder winter months, the effects of water temperature on plant growth and nutrient uptake would have been more obvious, especially with regard to the colder water temperatures.

Soil Temperature Response to Irrigation Water Temperature

Relatively small changes in the soil temperature occurred due to the temperature of the irrigation water applied. As seen in Figures 1 and 2, after the initial rise or fall in the temperature of the soil, the temperatures were practically the same after 1½ to 2 hours. Seeley and Stener (57) came to similar conclusions with their water temperature study on carnations. They found the soil temperature in greenhouse benches remained different for a maximum of five hours but still considered this time interval too short to have any significant effect on flowering.

Significant differences were expected in the uptake of N since the soil temperature has been known to affect the rate of nitrification. Allen (3) concluded that at least part of the effect of high temperatures in the greenhouse bench is to hasten the process of nitrification. It was determined in a study by Francis and Callahan (24) that, between 15°C and 30°, biological denitrification responds typically to temperature changes for biological systems, e.e., the nitrification rate doubles for a 10°C rise in temperature. A review of the literature by these two investigators in 1975 revealed that others have found temperatures between 20°C and 30° had no significant effect on the rate of denitrification in laboratory continuous-flow stirred-reactor studies. Only when the temperature decreased to 10°C was the biological activity significantly decreased. Bremmer (12) found the rate of denitrification in soils to increase rapidly from 2°C to 25° with an optimum near 60° which was probably due to thermophilic bacterial strains.

The results of this investigation reveal no significant differences in N content expressed on a total or percent of dry weight. The highest values were found in 31°C watered plants and the lowest in the 48° treated ones.

CONCLUSIONS

Geranium cultivar growth response and nutrient uptake were dependent on genetic background. 'Springfield Violet' was the largest of the cultivars tested, also having the greatest nutrient content on a total basis. 'Salmon Pink Irene' was smallest with the lowest uptake, while 'Sincerity' was intermediate between the other two cultivars in growth parameters and nutrient uptake.

Cultivar response to heated water varied. Each cultivar appeared to have its own optimum root zone temperature depending on the variable observed. Heating the irrigation water to 31°C or 48° prior to its application for 'Sincerity' would not be recommended. Heated water (48°C) was beneficial to the growth and development of 'Springfield Violet'. 'Salmon Pink Irene' responded to 31°C water with increased growth and nutrient uptake. Even though heated irrigation water may be beneficial for some plants under specificconditions, the general application of heated water is not recommended for all plants.

Nutrient analysis of geranium shoots indicated that N, P, and K levels were below that considered optimal. A single application of Osmocote was not sufficient to meet the nutritional requirements of the greenhouse geraniums grown out in 10 cm pots. Additional fertilizer application may be necessary.

Soil temperature response in 10 cm plastic and 15 cm clay pots to irrigation water temperature between 21°C and 48° is rapid and temporary. The effects last a maximum of 2 hours when the water is applied in the morning hours with a greenhouse air temperature of approximately 25°C.

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APPENDIX

STATISTICAL DESIGN

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*                                   *                                   *
*   +   +   +   +   +   +   +   +   +   *   +   +   +   +   +   +   +   +   +   *
*                                   *                                   *
*   +   +   +   +   +   +   +   +   +   *   +   +   +   +   +   +   +   +   +   *
*                                   *                                   *
*   +   +   +   +   +   +   +   +   +   *   +   +   +   +   +   +   +   +   +   *
*                                   *                                   *
*   +   +   +   +   +   +   +   +   +   *   +   +   +   +   +   +   +   +   +   *
*                                   *                                   *
*   +   +   +   +   +   +   +   +   +   *   +   +   +   +   +   +   +   +   +   *
*                                   *                                   *
*   +   +   +   +   +   +   +   +   +   *   +   +   +   +   +   +   +   +   +   *
*                                   *                                   *

    8   1   3   6   4   5   9   7   2       8   5   6   7   2   1   4   3   9
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Figure A-1. Arrangement of Pelargonium hortorum on greenhouse bench. Each row consists of 6 plants all of the same cultivar and receiving the same water treatment. The numbers beneath the rows are defined below

1 - 'Sincerity' irrigated with 48°C water
2 - 'Sincerity' irrigated with 31°C water
3 - 'Sincerity' irrigated with 21°C water
4 - 'Springfield Violet' irrigated with 48°C water
5 - 'Springfield Violet' irrigated with 31°C water
6 - 'Springfield Violet' irrigated with 21°C water
7 - 'Salmon Pink Irene' irrigated with 48°C water
8 - 'Salmon Pink Irene' irrigated with 31°C water
9 - 'Salmon Pink Irene' irrigated with 21°C water

MODEL STATEMENTS

MODEL 1: HGT,GFW,DW,BUD,NPC,NTL,PPC,PTL,KPC,KTL,CAPC,CATL,MGPC,MGTL,MNPPM, MNTL,ZNPPM,ZNTL,TFW=R(I)+C(J)+W(K)+RC(IJ)+RW(IK)+CW(JK)+RCW(IJK)+ E(IJKL)

LIMITS: I=2,J=3,K=3,L=6

MODEL 2: NPC,NTL,PPC,KPC,MGPC,MNPPM=R(I)+C(J)+W(K)+CW(JK)+E(IJKL)

LIMITS: I=2,J=3,K=3,L=6

Where:

CFW = change in fresh weight, DW = dry weight, BUD = number of flower buds produced, NPC = nitrogen % of dry weight, NTL = nitrogen total uptake, PPC = phosphorus % of dry weight, PTL = phosphorus total uptake, KPC = potassium % of dry weight, KTL = potassium total uptake, CAPC = calcium % of dry weight, CATL = calcium total uptake, MGPC = magnesium % of dry weight, MGTL = magnesium total uptake, MNPPM - manganese parts per million of dry weight, MNTL = manganese total uptake, ZNPPM = zinc parts per million of dry weight, ZNTL = zinc total uptake, FFW = final fresh weight of tops, R = replicates, C = cultivar, W = water treatment, CW = cultivar/water temperature interaction, and E = experimental error

All variables were analyzed initially to determine size of experimental error terms. Using Model 1, an "Error A", with 8 degrees of freedom was partitioned from "Total Error", having 90 degrees of freedom. When "Alpha Hat" for "Error A" had a value of .10 or greater, the two error terms were pooled and the variable was analyzed using Model 2.

Table A-1. Analysis of variance for height, final fresh weight, change in fresh weight, dry weight, and flower bud count on *Pelargonium hortorum* shoots in an irrigation water temperature study

Source of variance	Degrees of freedom	Mean squares				
		Height (cm)	Final fresh weight (g)	Change in fresh weight (g)	Dry weight (g)	Flower bud count (no.)
Replicates	1	11.02	244.20	78.72	20.63*	4.48
Cultivar (C)	2	65.34*	2881.57*	2644.23*	49.69*	67.36*
Water temperature (W)	2	1.42	450.06*	404.48*	2.80	13.78*
C x W	4	20.50*	893.74*	827.90*	11.41*	4.35*
Error	98	5.89	119.74	116.48	1.81	1.67
Total	107					

*Significant at the .05 level.

Table A-2. Analysis of variance for N, P, K, Mg, and Mn content of *Pelargonium hortorum* foliage expressed on a percentage of dry weight basis

Source of variance	Degrees of freedom	Mean squares				
		Nitrogen	Phosphorus	Potassium	Magnesium	Manganese
Replicates	1	1.16	0.0876*	0.144	0.0092	23114.69
Cultivar (C)	2	3.12	0.0264	0.410	0.0000	4541.81
Water temperature (W)	2	1.16	0.0095	0.672	0.0013	8476.11
C x W	4	1.16	0.0023	0.099	0.0016	9293.33
Error	8	1.35	0.0101	0.577	0.0013	5180.39
Total	107					

*Significant at the 0.5 level.

Table A-3. Analysis of variance for P, K, Ca, Mg, Mn, and Zn content of *Pelargonium hortorum* foliage expressed on a dry weight basis

Source of variance	Degrees of freedom	Mean squares					
		Phosphorus	Potassium	Calcium	Magnesium	Manganese	Zinc
Replicates	1	1054.98*	8193.94*	4949.91*	203.35*	2.60*	265.40
Cultivar (C)	2	874.00*	7360.09*	5460.94*	197.74*	0.36*	401048.69*
Water temperature (W)	2	88.15	5758.31*	674.09	23.29	0.50*	26287.30
C x W	4	90.57*	3492.62*	1232.36*	44.32*	0.59*	108214.88*
Error	98	32.50	1008.76	266.11	8.80	0.11	23912.09
Total	107						

*Significant at the .05 level.

Table A-4. Analysis of variance for N content of Pelargonium hortorum foliage expressed on a dry weight basis

Source of variance	Degrees of freedom	Mean square Nitrogen
Replicates	1	187.47
Cultivar (C)	2	32745.27*
Water temperature (W)	2	5074.54
C x W	4	11415.67
Error	8	4095.00
Total	107	

*Significant at the .05 level.

Table A-5. Analysis of variance for Ca and Zn content of Pelargonium hortorum foliage expressed on a percentage of dry weight basis

Source of variance	Degrees of freedom	Mean squares	
		Calcium	Zinc
Replicates	1	0.327*	954.08
Cultivar (C)	2	0.082*	3176.44*
Water temperature (W)	2	0.054*	384.03
C x W	4	0.038	622.47
Error	98	0.017	417.54
Total	107		

*Significant at the .05 level.

Table A-6. Effect of irrigation water temperature on percent of dry weight nutrient content of shoots in three geranium cultivars[z]

Cultivar	Water temp. (°C)	Element N	P	K	Ca	Mg	Mn	Zn
		Percent dry weight					ppm (µg/g dry weight)	
'Salmon Pink Irene'	48	1.3 a[y]	.31 a	1.6 a	.72 a	.18 a	128 a	43 a
'Salmon Pink Irene'	31	1.9 a	.31 a	2.0 a	.86 a	.20 a	218 a	41 a
'Salmon Pink Irene'	21	1.5 a	.29 a	1.8 a	.80 a	.20 a	177 a	39 a
'Sincerity'	48	1.9 a	.31 a	1.7 a	.86 a	.20 a	161 a	48 a
'Sincerity'	31	2.6 a	.33 a	1.9 a	.81 a	.19 a	146 a	64 a
'Sincerity'	21	1.9 a	.31 a	1.9 a	.94 a	.20 a	159 a	67 a
'Springfield Violet'	48	2.1 a	.33 a	1.5 a	.84 a	.19 a	151 a	51 a
'Springfield Violet'	31	1.7 a	.39 a	1.7 a	.92 a	.21 a	168 a	56 a
'Springfield Violet'	21	1.8 a	.34 a	1.6 a	.89 a	.20 a	142 a	45 a
L.S.D.	NS	NS	NS	NS	NS	NS	NS	NS

[z]Data were averages of 36 plants per treatment.

[y]Mean separation by Duncan's Multiple Range Test, 5% level.

THE EFFECTS OF IRRIGATION WATER TEMPERATURES ON THE GROWTH AND NUTRIENT UPTAKE OF GREENHOUSE-GROWN GERANIUMS (*Pelargonium hortorum*)

by

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B.S. (Educ.), Kansas State University, 1966

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture and Forestry

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Manhattan, Kansas

1976

The geranium cultivars 'Salmon Pink Irene', 'Sincerity', and 'Springfield Violet' were hand watered daily with either 21° C, 31°, or 48° irrigation water. Thirty-six cuttings per cultivar were grown in 10-cm plastic pots containing equal parts of sandy loam, peat moss, and perlite to which Osmocote (14-14-14) had been incorporated. The plants were arranged on the greenhouse bench in a randomized block design. Flower bud counts were taken during the last 37 days of the 82 day study. At the conclusion of the growing period, the plants were measured for height and harvested at soil level. Fresh and dry weights were determined prior to analysis for nutrient content. Soil temperatures were monitored for 24-hour periods by a potentiometer with thermocouples placed at a depth of 2 cm in 10-cm plastic pots and 4 cm in 15-cm clay pots.

'Salmon Pink Irene' had significantly more flower buds and higher fresh and dry weights when irrigated with 31° C water than with 48° or 21° water. Total dry weight and other growth parameters of 'Sincerity' were significantly decreased by 48° C water as compared to 31° and 21° treatments. 'Springfield Violet' plants had significantly greater height and fresh weight in 48° C treatments. Nutrient uptake followed a similar pattern with 'Salmon Pink Irene' accumulating significantly more N, P, K, Ca, and Mn at 31° C than at 48° or 21°. P and K were significantly less in 'Sincerity' at 48° C irrigation water temperature with N, Ca, Mg, Mn, and Zn content reduced considerably. 'Springfield Violet' plants had similar nutrient levels at all water temperatures. The results suggest a relationship between growth, nutrient uptake, and water temperature that is genetically controlled.

Heated water had temperary effects on soil temperature change. Soil temperature differences of 20° C recorded after watering were equal 1½ hours later in 10-cm plastic pots. In 15-cm clay pots, the temperature difference at the 4 cm depth lasted for almost 2 hours.