THE EFFECT OF SOIL TEMPERATURE UPON THE GROWTH OF CARNATION (DIANTHUS CARYOPHYLLUS, L.)

EASTER LILY (LILIUM LONGIFLORUM, THUNB) AND GERANIUM (PELARGONIUM HORTORUM BAILEY)

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

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ABSTRACT

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By Changhu Peng

Body of Abstract

Submitted to
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This study was undertaken to study the effect of soil temperatures of 40°, 60°, and 80° F, on growth of carnation (Dianthus caryophyllus, L.), Easter lily (Lilium longiflorum, Thumb), and Geranium (Pelargonium hortorum, Bailey) in Plant Science Greenhouse, Michigan State University.

Growth was measured as dry weight, number of leaves, and days to flowering. In addition, measurements were made on size of flower, number and total growth of side shoots in carnation; days to emergence, size of flower, number of flower in Easter lily; leaf area, number of leaves, number of flower clusters, number of floret per flower in Geranium.

Results show that in carnation plants, no significant differences were found among treatments involving flowering data and root dry weight. The only difference was that 40° F treated plants were inferior to others in number and total growth of side shoots and stem length.

In Easter lily, 40° F soil temperature delayed emergence of shoots, the plants were unable to bloom by the end of the experiment. No significant difference was found between 60° and 80° soil temperature treatment as regard to days to emergence, but plants in 80° treatment flowered 6.6 days earlier than 60° treatment.

In Geranium, besides flowering date, plants in 40° F treatment were inferior to those in 80° and 60° treatments in every respect. 60° F soil temperature was considered as the best for growing geranium.

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INTRODUCTION

Among many environmental factors influencing plant growth, soil temperature is an important one. In natural conditions, the seasonal changes in soil temperature determine to a certain extent the germination of seeds, emergence and growth of plants. Some cultural practices such as time of seeding, mulching, shading, use of compost in hot bed are all related to soil temperature.

Soil temperature is also important in greenhouse plant growing, for a proper soil temperature may have a favorable influence on the growth, time of harvesting, production and quality of plants as well as fuel consumption. In the case of Michigan, because of a short growing season, commercial flower production is mainly confined to greenhouse culture. So it is important to study the effects of soil temperature on flowering plants.

The present work was designed to study the effects of different soil temperatures upon the growth of several flowering plants under greenhouse conditions, in order to establish the limits of appropriate soil temperature range for flowering plants. It is hoped that this work may have some help to Michigan flower growers.

LITERATURE REVIEW

Air temperature and soil temperature and plant growth

Only limited researches have been done on the effect of both air and soil temperature upon plant growth.

For forage crops, under conditions of equal soil and air temperatures, Brown (13) found that the optimum temperature for root and rhizome production in Canada bluegrass was 10° c, Kentucky bluegrass, 15.6° c; and orchard grass, 21° c. For Bermuda grass, growth increased with rising temperature up to 37.8° c, the highest temperature employed. Using plants in growth chambers with controlled temperature alterations, Sprague (74), found at the end of a 6-week period that the best root growth in Ladino clover was at 4.4° c to 12.8° c; in Kentucky bluegrass, orchard grass, meadow fescue, brome grass, colonial bluegrass, and timothy, 12.8° to 21° c; and Sudan grass, 21° to 29.4° c.

Bushnell (16) studied potato growth in a controlled temperature chamber in which the air temperature and soil temperature were maintained the same. He found the average weight of tubers per plant 6 weeks after emergence was 20.9 gram at 20° c, 5.0 gram at 23° c, and 1.6 gram at 26° c, while no tubers appeared at 29° c. The root growth was not appreciably reduced at 23° c or 26° c, but somewhat nudified at 29° c.

Calvert A. (17) grew tomato plants in greenhouses in 1953 and 1954. The air temperature and soil temperature used were as follows:

Year	Air Temperature Day	Air Temperature Night	Soil Temperature
1953	60° F	52° F	61.4° F
	60° F	52° F	56.8° F
1953	65° F	57° F	64.4° F
	65° F	57° F	60.9° F
1954	63° F	58° F	65.7° F
	63° F	58° F	58.7° F
1954	60° F	52° F	65.6° F
	60° F	52° F	56.5° F

Concluded that "when the control soil temperature was 56°-57° F at planting out time, increases of from 5° F to 9° F produced no significant increases in yields of ripe fruit, either for early or for total crop," and "reduction in air temperature produced marked decreases in early yield, but had no clear effect on the total crop."

Hellmers, Henry (40) using redwood seedlings of 6 weeks and 20 weeks old maintained soil temperatures of 8° c, 18° c, 28° c and two sets of air temperatures of 30° c day temperature (8 hours) and 24° c night (16 hours), and 17° c day temperature and 11° c night temperature. A 16 hour photoperiod was obtained through supplemental lighting in the morning and evening. He found the growth response of redwood seedlings to air and soil temperature depends to some extent upon their age or size. High air temperature stimulated top growth with each of the three soil temperatures. Low air temperature combined with warm soils stimulated root growth. A high air temperature effect tended to counterbalance a cool soil effect and vice versa. Roots grown in 18° c soil temperature appeared to be the healthiest, but in case of 20 week seedlings, the dry weights of the roots were not significantly different among treatments.

Nelson (56) studied the growth of hemp (<u>cannabis satious</u>), using seedlings transplanted to gravel cultures 11 days after germination, having tops at 15° c with roots at 15° c and 30° c, and tops at 30° c with roots at 15° c and 30° c. Differences in growth began to appear after 4 weeks and became marked after 7 weeks. At an air temperature of 15° c, the plants grown in the 30° soil produced a large number of leaves, thicker stems, and greater total dry weight of tops than those in 15° soil. There was little difference, however, in the size of the leaves or the height of plants grown at these two soil temperatures. The higher air temperature of 30° c was less favorable for the development of the hemp, and the growth differences caused by soil temperature, though smaller, reflected the same trend.

Went, F. W. (83) found that at variations in root temperatures between 32.5° c and 15.5° c the growth rate of tomatoes was determined entirely by the temperature at which the tops were kept.

In summary, it is obvious that both air temperature and soil temperature affect the growth of plants, and these varied with kinds, varieties and age of plants.

Factors influencing soil temperature. According to S. J. Richard's review (62), among many factors influencing soil temperatures, radiation from the sun is the primary heat source. The rate at which radiant energy reaches the earth's atmosphere from the sun (solar constant) has the value 1.94 calories per minute per square centimeter normal to the direction of the radiation, absorption by the earth's atmosphere, however, causes large variations in the rate at which radiant energy reaches the soil. Another factor influencing soil temperature is the loss that heat energy from the soil. The net rate of heat gain or loss determines whether the soil temperature is being raised or lowered. Radiation from the soil surface is an effective way of losing heat to the atmosphere. The surface characteristics of soils vary greatly. Brooks (12) lists data to show that the soils for which data are available limit long-wave radiations at rates varying between 0.4 and 0.5 of a black body surface. Although the instaneous rate of long wave radiation is much smaller than the peak value of solar radiation. Long-wave radiation is still important, since it operates continuously and not just during the daylight hours. Assuming a surface emissivity of 0.5 and an average temperature of 30° c, the amount of heat radiated from one square centimeter of soil surface in 24 hours amounts to approximately 500 calories. Water vapor, carbon dioxide, and Ozone in the atmosphere are good absorbers of radiation in the range of wave lengths that comes from the soil surface. These absorbers in turn become emitters of radiation as well. The intensity of solar radiation per unit of surface area is proportional to the cosine of the angle between the direction of radiation normal to the surface. This relation accounts for the continual decimal change in radiation intensity as the sun's position changes, and is also one of the factors in the soil temperature relations, since the angle indicated above depends on the latitude and the slope of the soil surface. Shade and insulation are also important factors in influencing soil temperatures, largely to the extent they affect the exchange of heat at the soil surface by radiation. Evaporation of water from a soil surface also effects soil temperature. For every gram of water evaporating from the soil surface, a quantity of heat energy equivalent to approximately 580 calories is lost by the soil. When the soil surface is wet, evaporation is dependent on vapor-pressure gradients and wind velocity in the air just above the surface, as well as the amount of radiant heat energy available. When the soil surface is very dry, the rate at which water evaporates from the soil surface depends on the rate at which water is transported from the lower layers of the soil to the surface. Convection is another process whereby heat is transferred to or away from the soil surface. The direction and rate of heat transfer by the air will depend on the relative temperature of the soil surface and the air just above the soil. For a given temperature gradient, this transfer rate will also be affected by the wind velocity and turbulence. Guild (35) presented the magnitude of this convective term as 20 to 40% of the net radiation term on clear nights at Gila Bend in the Arizona desert in April, 1947. Cultural practices used to influence soil temperature are shading, mulching and moisture control.

Soil temperature is also influenced by bed direction. Shodbolt, C. A. (71) studied outdoor vegetable culture with furrow irrigation in SW United States. On all beds except those investigated in a NW-SE direction, with soil 1" deep, one side was 5°-7° F warmer than the other. In all cases the S or E exposures were warmer. Warmest bed by degrees above 70° F was N-S. Coolest was NE-SW direction. These findings are attributed to the combined effect of wind and sun angle.

It appears that the wind has a greater influence on soil temperature than the angle of the sun.

From the above, many factors are found to be influencing soil temperature, the most important one is solar radiation. What man can do concerning soil temperature is limited to cultural methods, such as mulching, shading and adjusting the direction of beds, etc.

Soil temperature and plant growth. Many researches have been done on the effect of soil temperature or plant growth. Many plants have been used, including grasses, vegetables, ornamentals and trees.

Wort, D. S. (85) found that at day temperature 100° F and night temperature 90° F. Greatest total dry weight of Marquis wheat at harvest time were from plants grown at a soil temperature of 71.6° F.

Ranay, etc. (61) and Kouds, etc. (47) stated caloro rice was found to yield the most rice at a constant root temperature of 27° c. Japanese varieties of rice have been shown to require root temperatures as high as 32° c for optimum germination and growth.

Hoagland, (41) stated for barley, root growth at 20° c was about double that at either 10° or 30° c.

Bailey, J. S. and L. H. Jones, (4) growing blue-berries with soil temperatures of 35° through 90° with 5° increases found that plants with soil temperatures below 70° F were slower in starting growth than those above 70° F. Total linear growth increased as soil temperature increased. Plants grown at a soil temperature of 70° F or above tended to be tall and upright, while those grown at 65° F soil temperature or lower tended to be short and spreading.

Nelson, S. H. and Tukey, H. B. (56) studied the effects of controlled root temperature on the growth of East Malling Rootstock, used 44°, 55°, 66°, 77° F root temperature, but at the same air temperature. The onset of new growth in shoot and root was accelerated by a rise in temperature from 44° to 77° F. All rootstocks showed very slight root growth at 44° F, greatest root growth of MI, M II, M IX was at 55° F, M II, M IX were killed at temperature above 55° F. Others continued root growth with increasing temperature to 77° F. At 44° F, the roots were thick, pearly white and non-branched, while at 77° F they were slender, much branched, more or less discoloured. Raising the root temperature increases root cell maturation. As illustrated by differentiation of primary tissue, vascular cambial activity and subsequent deposition of secondary tissue. Shoot growth were proportional to root growth.

Halms, F. F. (38) grew Eureke lemon, Marsh grapefruit, and Valencia orange with soil temperature ranges of 61° - 81°, 54° - 72° F and 37° - 68° F at the Citrus Experiment station in southern California. Plants, from rooted cuttings, were grown one year outdoors. Based on total linear growth, dry weight and fresh weight, he found lemon was the most adaptable, grapefruit second, and the orange least adaptable.

Frances (32) studied the effect of soil temperature on the growth of coffee-tree tops and roots. Air and soil temperatures of 26° c during the day and 20° c during the night were found optimum for both top and root development. A 5° c increase or decrease of soil temperature caused a marked retardation of top growth, and at constant soil temperatures of 38° c or 13° c, top growth practically ceased, although the air was maintained at optimum temperature.

Benedict (7) found that the maximum weight of guayule-shrub tops and the maximum rubber yield occurred at a soil temperature of 27° - 29° c. The maximum weight of roots were obtained at 18° c soil temperature while temperatures of 4° to 7° c inhibited growth. An air temperature of 28° c was maintained during the experiment.

According to Nightingale (57), root and top growth of peach and apple trees, was best at 18° c soil temperature. At 7° c soil temperature, root primordia were present but did not emerge, and at 35° c soil temperature the old roots died and no new roots formed. The uncontrolled air temperature varied between 21° c and 15.5° c during the study.

Stone and Schubert (76) worked with ponderosa pine seedlings transplanted into the greenhouse. They obtained maximum increase in root length with a 25° c soil temperature during the winter months. Little or no root elongation occurred during summer, when inside greenhouse temperatures reached a peak of 35° c or higher. Practically no root growth took place at 10° c soil temperature at any time of year.

Darrow, R. A. (23) grew bluegrass (Poa pratensis) at 15°, 24°, and 35° c root temperature. At 35°, he found erect short top growth, small brown roots, densely tufted. At 15°, top growth was tall, and succulent, with many leaves, while roots were large, white, succulent, and coarsely branched.

Stuckey, I. H. (77) used tanks with uniform temperature of 50°, 60° and 80° F, air temperature 60° F to grow colonial bentgrass. Those grown with a soil temperature of 60° gave best growth and most extensive root system, those at 50° F almost as good, but those at 80° F had very poor growth, the roots matured early and finally died.

According to Arndt (3), in cotton plants, the minimum temperatures for growth of primary roots was clearly below 18° c; the maximum for any growth was above 39° and visible injury soon appeared at the latter temperature. A temperature range from 33° to 36° c was optimum for elongation of the primary roots during the first few days of growth and produced the earliest emergence of secondary roots. After 7 days of culture, the roots had the greatest total length at 30° c and were most numerous at 27° c.

Johnson and Hartman (42) studied root growth of tobacco in relation to soil temperature, found the best root development in White Burley tobacco at 23° to 24° c, with a marked decrease at higher temperatures, and in the Connecticut Havana variety, the best root development was at 26° to 29° with a decided falling off at 31° to 32° c.

With soybean, soil temperature below 18° c retard root growth whereas those between 18° c and 26° c showed little difference. (Jones, F. R. & Tisdale) (43). These results were re-examined by Earley and Cartter (28), who found root temperatures from about 22° to 27° c appeared to be most favorable for maximum dry-weight production of roots and tops under a great variety of aerial environmental conditions in the greenhouse.

F. R. Jones and Tisdale (43) stated that Canadian field peas did not flourish at a soil temperature of 30° c and were intolerant to higher temperatures.

Burkholder (15) found no noticeable influence in root growth of beans in soils at 18° and 26° c, suggested the optimum soil temperature for beans lies between 22° and 26° c.

Emsweller, S. L. and Tavernetti, J. R. (30) grew gladiolus in cable heated soil, the average soil temperature 77° F (av. max. 80° F, av. min. 73° f), compared to unheated soil average soil temperature 60° F (av. max. 63° F, av. min. 58° F), the plants in heated soil flowered two weeks ahead of the unheated soil plants, quality was the same, and the former gave larger corms and more cormels.

According to Jones, Linus H. (44), _Gardenia veitchii_ developed chlorosis at a soil temperature of 18° c or less, and more intense chlorosis as soil temperature was lowered. At soil temperature of 20° c and 22° c there were traces of chlorosis, but it did not increase in intensity with time. Davidson (24) found when gardenia plants grown at high root temperatures (82° F, 74° F) produce more buds and larger flowers but also highest amount of bud drop with result that highest total production was less than those grown in relatively cool soil (58° F, 66° F). The length of internodes, total linear growth and flower size was reduced by low root temperature (58° F) with 70° - 74° F air temperature, or by low air temperature (65° - 68°) in spite of warm 74° root temperature. The percentage of dry matter in young stems increased with lower temperature. _Gardenia veitchii_ is more temperature

sensitive than Gardenia grandiflora.

Kopanek, Suton M. (46) grew Poinsettia (Euphorbia pulchirrima) plants in a greenhouse in which the air temperatures were automatically maintained at 60° F during the night, and 70° F on cloudy days and 75° F on sunny days. In a six-day trial, the plants were grown with their roots exposed to 40°, 50°, 60° and 80° F temperatures continuously. Plants in the 40° plot wilted severely, and lost leaves. Plants at other soil temperatures did not show wilting.

Allen (1) studied the effect of soil temperature on flowers, used 52°, 60° and 72° F soil temperature with an air temperature of 50° F. Column stocks flowered earliest at soil temperature of 52° F, stem length unaffected. Calendulas produced nearly twice as many flowers from plots with 60° and 72° compared to 52° F also slightly longer stems and stems having slightly less diameter. Snapdragon, Cheviot Maid Supreme, at 60° and 72° soil temperature had more florets per spike but took 10 days longer to bloom and had shorter flower clusters, although stem length remained the same compared with those grown at 52° F soil temperature. Freesia at soil temperature of 60° gave more blooms than at 52° F and over twice as many blooms as those at a soil temperature of 72° F, but stem length was same in all treatments. Soil temperature of 70° F resulted in earlier flowering by 2 weeks in Freesias.

In a temperature study with roses, Kohl et al (48), used Peter's Briarcliff, Better Times and Pink Delight, and soil temperatures of 80° F, 70° F and unheated check plots which averaged 60° - 65° F. Night temperatures were 58° F, day temperature 68° F, dull day 73° - 78° F bright day. The highest soil temperature resulted in lowest flower production. Shanks and Laurie (70) grew Better Times roses at root temperatures varied by 4° F interval between 56° F to 72° F, maintained 60° F at night, 65° - 70° F during the day, found optimum temperature for growth of top was 64° F. Progressive decrease in the amount of roots was found as temperatures increased from 56° to 72° F. Soil temperature influenced the root diameter and number of root hairs, with the largest diameter at 62° F, and root hairs few or absent at 72° F, while the highest root numbers were found at lower temperatures. Laurie and Stillings (52) studied rooting of rose cutting. Their data showed that a rooting medium temperature of about 21° c is generally better than 16° to 19° or 27° c.

Roberts, A. N. and A. L. Kenworthy (64) grew strawberries in 45°, 55°, 65° and 75° F root temperature, maintained night temperature 50° - 60° F the first month, 60° - 65° F, the second month. Day temperature 70° F the first month, 80° F the second month, found that on dry weight accumulation basis, maximum growth of all parts during the vegetative phase of development occurred at the root temperature of 65° and 75° F, with no significant difference in dry weight of roots among all root temperatures.

Guyot, L. (37) grew 18 kinds of plants in clay pots and plastic pots. The plants used were wheat, maize, flax, potato, beet, radish, _Agave_, _Pelargonium_, tulips, _Begonia_, Coleus, Calendula, sweet pea, Zinnia, Petunia, Nasturtium, Marigold. In plastic pots, growth was found to be faster and most vigorous, while flowering was often better (especially with tulip) and yields high (especially with potatoes). One of the reasons given for this improved growth was that the soil temperature is 1° - 4° c higher in plastic pots than in clay pots.

To summarize, under a certain air temperature condition, the growth of plants were found to be influenced by soil or root temperatures. These soil temperature influences varied with kinds, varieties of plants.

Soil temperature and water. Soil temperature has been found to influence absorption and respiration in plants.

Kramer (49, 50) stated: "the principal cause of decreased water absorption by plants at low temperatures appears to be the combined effects of decreasing permeability of the root membranes and increased viscosity of water, resulting in increased resistance to water movement across the living cells of the roots." "Reduction in water absorption caused by cold soil is of considerable ecological and practical importance because it often produces winter injury and even affects the growth of plants in greenhouses." If a temperature of 25° c and the water absorption rate of 100 is used as the base, watermelon and cotton absorbed only 20% as much water at 10° c; Georgia Collards absorbed 75%; Loblolly and slash pine, 40%; and yellow and white pine, 60%. Absorption was reduced in all species, but more in species which normally grow in warm soil than in species which normally grow at least part of the year in cold soil. "The difference between species presumably result chiefly from differences with respect to the changes in viscosity and permuability of the protoplasm of the roots caused by low temperature."

Bohning, K. H. et al (10) grew tomato, sunflower, red kidney bean in eight root temperature regimes: (a) gradual change from 25° c to 5° c (b) abrupt changes from 25° to 20° (c) gradual change 20° to 5° c, (d) abrupt change 25° to 15° (e) gradual change 15° to 5°, (f) abrupt change

25° to 10°, (g) gradual 10° to 5°, and (h) abrupt 25° to 5°. They found gradual reduction in temperature resulted in gradual reduction in absorption rate, while abrupt reduction resulted in abrupt changes to a value slightly below that of gradual change. In red kidney bean sharp reduction in absorption within 10° to 17° c range, indicating a change in viscosity of protoplasm is probably the controlling factor. Absorption rate in tomato and sunflower showed greatest reduction below 10° c with reported changes in water viscosity, indicates that certain protoplasmic changes may have occurred which reduced the viscosity changes in protoplasm as a limiting factor in water absorption. With respect to sudden drops to 25° to 5°, tomato and beans wilted severely but recovered. Beans wilted and severely desiccated at 25 to 10 drop, and uninjured portions recover very slowly.

Schroeder, R. A. (67) found that low soil or culture solution temperature caused water deficiencies in cucumbers and concluded that 70° F or slightly higher was the most practical soil temperature for the crop.

Arndt, C. H. (3) using 9 week cotton plants found intense sunlight and low soil temperature act in conjunction to produce wilting. Wilting occurred in unshaded plants when air temperature was 36° c and relative humidity 35% and soil temperature 18° c. If shaded, no wilting happened under such conditions. If the soil temperature was raised to 60° c under similar conditions wilting occurred and whitish areas appeared in the leaves. Cold root wilting was attributed to inadequacy of the root system to take up sufficient water to compensate for that lost through transpiration. High temperature resulted in death of root tissues, which probably lost ability to absorb water.

Vinokar, R. L. (78) studied lemons and soil temperatures of 33° and 12-14° c. He used plants at a state of shoot rest, (no actively growing young shoots) and found transpiration increases with increases in soil temperature. He concluded that increased soil temperature is not the cause of growth acceleration.

Bialoglowski, J. (9) studied the transpiration of rooted lemon cuttings, using an air temperature of 25° c. Transpiration during the period of darkness was unaffected by root temperature changes of 0° to 40° c. When air temperature is 25° c in light, the plants transpire most rapidly when the root temperature is over 35° c or below 25° c.

Cameron, S. H. (18) used Valencia orange trees and soil temperatures of 43° F, and 50 through 90 in 10 incriments. Plants showed evidence of moisture stress when soil temperature was 48° F or lower. Lowering the soil temperature from 90° to 45° F resulted in marked decrease in water loss. Under usual environmental conditions transpiration during day may be 10 times as great as at night.

Gray, G. F. (34) found that at soil temperature of 100° F, strawberry roots are severely injured and leaf scorch is due to inability to absorb water as rapidly as it is transpired, at soil temperature of 85° F, root development was normal.

Indications are that strawberry varieties susceptible to drouth and high temperature injury have a higher transpiration rate than resistant varieties. He concluded that the evaporative power of the air has a more direct effect upon transpiration rate than has the root temperature.

Clements, F. E. and Martin E. V. (21) studied transpiration of sunflowers (Helianthus annuus), using soil temperatures ranging from 34° F to 100° F. They found transpiration varies little with soil temperature between 55° and 100° F, drops rapidly below 55° F, is reduced by half at 38° F and approaches zero at 32° F. Stomata do not begin closing until the soil temperature is about 40° F, but are usually completely closed at 37° F. Plants recover rapidly from wilting when soil temperature is raised. The experiments were performed outdoors in summer in Santa Barbara, California.

Drobnik (27) studied respiration curves of samples of meadow soil and of compost at temperatures between 8° and 48° c. Within the range of 8° to 28° c, increased temperature is reflected only in an acceleration of the processes characterized by a $Q10 = 1.6 - 2.0$. Beginning at 38° c some anomalies occur, partial inhibition of respiration can be observed and maxima appear which resemble maxima found on adding substrata. These maxima are attributed to reactive oxidation of a part of the organic material of the soil released by higher temperature.

From the above statements, we knew that both low and high soil temperatures are unfavorable for plant growth as concerning with water absorption and transpiration. In the case of low soil temperature, water absorption is lowered due to the high viscosity of water, decreased permeability of cell wall, lowered protoplasm streaming; transpiration is lowered due to the closing of stomata. In the case of high soil temperatures, water absorption is lowered due to root damages, but transpiration has not been lowered, so wilting often occurs.

<u>Soil temperature and nutrients</u>. Many researches on soil temperature and nutrients have been done, but only those most pertinent to this study are reviewed here.

Sekioka, Hakobu (69) applied Sucrose C^{14} to the leaves of sweet potato plants with varying air and soil temperature. Regardless of temperature, the sucrose was translocated from leaf to roots and growing stem during 12 hours of darkness. Accumulation in the root increased with decreasing temperature, with a corresponding loss from leaves. When the root systems divided into halves and exposed to different temperature in darkness for 12 or 15 hours, the sucrose C^{14} moved more rapidly from the leaves to 30° c than to 40° c roots more rapidly; to 30° c than 20° c roots, and more rapidly to 20° c than to 10° c roots.

Vinokur, R. L. (78) used soil temperature of 33° c and 12° - 14° c with lemon plants at state of shoot rest. He found the increased plant growth upon an increase in root temperature is not related to the simultaneous increase in intensity of nitrate nitrogen absorption. Increase in root temperature does not affect amino acid composition qualitatively, but it does affect it quantitatively, indicating that different mutabolic activities are affected differently by temperature.

Gukova, M. M. (36) used pea, lupine and bean as experimental materials. The root zone of the control plants was kept at a temperature of 20° c, while that of experiment plants were kept at 32° c. He found the plants grew equally well and assimilated nitrogen in the root zone at both temperatures. The weight of green matter of the plant and the total intake of nitrogen were somewhat greater at a substrate temperature of 32° than 20°. However, the phosphorus content in the experimental plants was always much lower at the high temperature, this reduction reached 20 - 25% of the quantity of phosphorus in the control plant. Still greater differences were observed in the absorption of phosphorus in later growth period of the plant. The process of exosmosis of phosphorus increases when a high temperature exists in the root zone and causes a decrease on phosphorus in the whole plant.

Proebsting, E. L. (60) grew two varieties of strawberries in the greenhouse, tops exposed to greenhouse temperatures during March through June 1. Medium temperatures were 45°, 55°, 65°, 75°, 85°, and 90° F. He found growth sharply reduced at extreme temperatures, greatest increase in dry weight at 75° F, and fruiting only at lower temperatures. Greatest runner production was at 75° F. There was limited variation in nitrogen content due to treatments, but potassium in the roots was found to drop sharply with increasing temperature (about 55° F) while phosphorus content of plants was highest at 65° F.

Bange, G. G. J. et al (5) studied the time course of NH_4 absorption by cut discs of potato tuber tissue at 0° c and 20° c. The results point to the existence of a difference of NH_4 concentration inside the absorbing tissue during steady absorption at 20° c.

Batjer, L. C. et al (7) used York Imperial apple trees and root temperatures of 42° and 45° F, found low root temperature caused a decrease in transpiration and earlier closing of stomata, it thus appears that reduced water was at least partially responsible for reduced growth of treated plants. Low root temperature (40° F) resulted in little if any root growth. A root temperature of 40° F also appeared to interfere with translocation of nitrogen reserves.

Shtrausberg, D. V. (72) used tomatoes, maize, cabbage, oats, and found that phosphorus uptake in plants fertilized through the roots decreased to much greater extent if the temperature around the roots is decreased than if air temperature is lowered. (used temperatures of 21° c and 7° c). At low soil temperatures, nutrition by foliar application is more practical, because uptake occurs more readily by this method of application than by root feeding. He concluded "when the temperature dropped to 11° - 12° c, the assimilation of phosphorus was impeded, whereas that of nitrogen was not. A drop in temperature from 11° to 7° c noticeably reduced nitrogen uptake in the plants, but only slightly affected the uptake of phosphorus. A further drop in temperature to 5° - 1° c most noticeably impeded the assimilation of nitrogen and to a somewhat lesser extent the uptake of phosphorus and least that of calcium and sulphur, at low soil temperatures potassium was the most readily assimilated of these elements." "A drop in temperature to 11° c somewhat hampered nitrogen uptake in tomato plants, but did not impede protein synthesis, at the same time, the ratio of nitrogen protein to non-protein nitrogen increased slightly."

Wallace, A. (81) used both ammonium and nitrate forms of nitrogen on citrus cuttings, found sufficient nitrogen is absorbed by citrus roots at a temperature of 48° F to increase nitrogen in the plant. This temperature is considerably below that for root elongation in citrus. Greatest absorption coeficient were found with a root temperature of between 58° - 74° F, above 74° F it leveled off and dropped off above 90° F. Uniform air temperature were used for all treatments.

Smith, R. L. and A. Wallace (73) using citrus and other plant species to study the absorption of calcium and potassium, found the uptake of cation changes only slightly with temperature while uptake of anions generally increases considerably with increasing temperature.

Wilcox et al (84) used tomato plants to study the effect of root zone temperature and phosphorus concentration in the soil on tomato growth and phosphorus uptake, constant root temperatures of 56°, 58° and 60° F were used. 60° F and 58° F caused increased dry weight production as compared to 56° F. Both temperature and phosphorus treatment significantly influenced the uptake of phosphorus at the zero phosphorus level the uptake of phosphorus at the 3 temperatures was similar. At 50 and 100 ppm phosphorus the uptake at 58° and 60° F was several fold greater than that at 56° F. Data showed no phosphorus temperature interaction and the increased application of phosphorus in the root zone of tomato did not overcome the effect of low temperature.

Lingle, J. C. (54) reported that growth of tomatoes sharply reduced at soil temperature of 50° - 55° F contrasted to 60° - 65° or 70° - 75° F. Greatest concentration of phosphorus in the plant occurred at soil temperature in the 60° - 65° F range, (85% over non-fertilized plant) contrasted to 59% in 50° - 55° region and 45% in the 70° - 75° range with only 23% in the 80° - 88° F range. The increased absorption of phosphorus and increased growth at higher soil temperature attributed to: (1) greater respiratory activity at higher temperatures. (2) favorable effect of higher soil temperature on rate of root growth, hence increased absorption surface. (3) increased water absorption at higher soil temperatures.

Lacascio, S. J. et al (51) reported that root temperature near 50° F reduce tomato growth sharply, also reported tomato response to phosphorus was greater at low soil temperature than at high soil temperature, and that the difference in response at low temperature was not a direct effect of phosphorus availability at low temperature. The soil temperatures used were 55°, 70°, 85° F.

Apple, S. B. Jr. et al (2) used pole beans in a greenhouse study of the effect of soil temperature, and found applied phosphorus more effective at 63° F than at 82° F. 63° F and 82° F were the soil temperatures used, air temperature were 55° - 60° F at night, 65° - 75° F during the day.

Robinson, R. R. (66) suggested the more rapid uptake of phosphorus in clover at higher temperatures is associated with the coefficient of absorption rather than increased phosphorus in the soil solution. As temperature increases, plants are able to absorb more phosphorus from the soil solution. Since banding of phosphorus fertilizer increases the concentration of the soil solution, temperature then becomes less important to phosphorus uptake.

Robinson, R. R. (65) grew Ladino clover in Dekalb soil, maintained optimum moisture content for 2 months, used soil temperature 15°, 20°, 25°,35°, 40°, 45° c, and 3° c, with phosphorus incubation or with no incubation treatment. He found 15° - 45° c resulted in very poor plant growth, compared to 3° c with incubation or with no incubation treatment. He concluded poor growth resulting from incubation at high temperature was due to a decrease in available phosphorus.

From the review above it is clear that soil temperature has some effects on the absorption and translocation of nutrients in plants. Generally speaking, a higher soil temperature is more favorable for absorption of nutrients by plants.

OPTIMUM SOIL AND AIR TEMPERATURE FOR ECONOMIC PLANTS

PLANT	ORIGIN	KIND	OPTIMUM SOIL TEMPER-ATURE	OPTIMUM AIR TEMPER-ATURE	REFERENCE
Apple	Temperate	Tree	64.4°F		7
Barley	Temperate	Biennial	68.0°F		41
Beans	Temperate	Annual	71-78.8°F		15
Bermuda grass	Sub-tropical	Perennial	100.24°F	100.24°F	74
Blueberry	Temperate	Shrub	70°-90°F		4
Blueberry cutting	Temperate	Shrub	69.8°-71°F		68
Bluegrass	Temperate	Perennial	59°F		13
Calendula	Temperate	Annual	60°-72°F	50°F	1
Canada bluegrass	Temperate	Perennial	50°F	50°F	13
Colonial bentgrass	Temperate	Perennial	60°F		77
Coffee tree	Tropical	Shrub	78.8°F day 68°F night	78.8°F day 68°F night	32
Coniferous hardwood cutting	Temperate	Tree	50°-55.4°F		53
Corn	Temperate	Annual	74.6°-81.6°F		26
East Malling rootstock	Temperate	Tree	55°F		55
Eureka lemon	Sub-tropical	Tree	61°-81°F		78

PLANT	ORIGIN	KIND	OPTIMUM SOIL TEMPER-ATURE	OPTIMUM AIR TEMPER-ATURE	REFERENCE
Field pea Canadian	Temperate	Annual	below 80°F		43
Freesia	warm	Corm	60°F (most flowers) 70°F (early growth)		1
Gardenia Veitchii	Warm	Shrub	66°F		24
Gladiolus	Warm	Corm	77°F		30
Guayule plant	Tropical	Tree	79.8°-83.6°F		8
Grapefruit	Sub-tropical	Tree	78.8°F		38
Grapefruit (Marsh)	Sub-tropical	Tree	61°-81°F		38
Hemp	Warm	Annual	80°F	59°F	56
Holly cutting	Temperate	Shrub	64.4°-74.6°F		53
Mesquite (prospis verotina)	Temperate dry	Succu-lents	95°F		20
Ocotillo (Fouguieria Splendens)	Temperate dry	Succu-lents	95°F		20
Kentucky bluegrass	Temperate	Perennial	50°F	50°F	14
Onion, Red Globe	Warm	bulb	below 68°F (root) 68°F and above (top)		79
Onion, Yellow Bermuda	Warm	bulb	68°F (root) 77°F (top)		79

PLANT	ORIGIN	KIND	OPTIMUM SOIL TEMPER-ATURE	OPTIMUM AIR TEMPER-ATURE	REFERENCE
Onion, White Portugal	Warm	Bulb	68°F (root) 71.6°F (bulbing)		80
Onion, Crystal wax Bermuda	Warm	Bulb	68°F(root) 71.6°F (bulbing)		80
Orchard grass	Temperate	Perennial	69.8°F	69.8°F	13
Pea	Temperate	Annual	71.6°F		11
Peach	Temperate	Tree	64.4°F	69.8°- 60.8°F	57
Pine, loblolly	Temperate	Tree	68°-77°F		6
Pine, white	Temperate	Tree	81.8°F		6
Pine, ponderosa	Temperate	Tree	77°F		76
Pineapple	Sub-tropical	Perennial	83.6°F		82
Poa praetensis	Temperate	Perennial	59°F		23
Poinsettia	Tropical	Shrub	50°-80°F	60°F	46
Potato	Warm	Tuber	65°F 68°F	68°F	16
Prickly pear (opuntia versicolor)	Temperate dry	Succulent	95°F		20
Redwood seedling	Temperate	Tree	64.4°F	74.6°F	40
Rose	Temperate	Shrub	60°-65°F	58°F (night)	31

PLANT	ORIGIN	KIND	OPTIMUM SOIL TEMPER-ATURE	OPTIMUM AIR TEMPER-ATURE	REFERENCE
Rose cutting	Temperate	Shrub	69.8°F		52
Rice, caloro	Temperate	Annual	79.8°F		29
Rice, Japanese	Temperate	Annual	83.6°F		29
Strawberry	Temperate	Perennial	65°-75°F	50°-60°F 60°-65°F	60
Snapdragon	Temperate	Annual	60°-72°F	50°F	1
Sugarbeet	Temperate	Biennial	above 69.8°F		58
Soybean	Temperate	Annual	71°-79.8°F		28
Stock, column	Temperate	Annual	60°-72°F	50°F	1
Tobacco, white burley	Warm	Annual	72.8°-74.6°F		42
Tobacco Connecticut Havana	Warm	Annual	78.8°-83.4°F		42
Tomato	Warm	Annual	56°-57°F	52°-58°F (night)	17
Tomato	Warm	Annual	74.6°-81.8°F (shoot) 85.0°F (Stem and Fruit)		63
Wheat, Spring	Temperate	Annual	60.8°-68.8°F		85
Wheat, winter	Temperate	Biennial	53.6°-60.8°F		85

MATERIALS AND METHODS

Three kinds of flowering plants were used in this experiment, namely, carnation (Dianthus caryophyllus), Easter lily (Lilium longiflorum) and Geranium (Pelargonium hortorum).

Well rooted cuttings of uniform size of carnation, cv. Improved White Sim were selected and potted into 5 inch pots on April 9, 1963 in steam sterilized greenhouse potting soil. There were 8 replications within each soil temperature treatments.

Easter lily cv. King were used. Seven cm. diameter bulbs were chosen and potted into 6 inch pots on March 28, 1963, with steam sterilized potting soil, with 5 replications within each treatment. The bulbs had been in 40° F cold storage November 1, 1962 to the potting date.

Geranium cv. Pink Cloud, uniform well-rooted cuttings having three leaves, were potted into 5 inch pots in steamed potting soil on April 2, 1963. There were 8 replications within each treatment.

Three soil temperatures were used in this experiment; 80° F, 60° F and 40° F. These soil temperatures were constantly maintained by placing pots in cans in separate water tanks at the appropriate temperature.

These water tanks loaned by Soil Science Department, and have been used successfully since 1957. They were milk cooling tanks of dimensions of 34 inches in width, 52.5 inches in length, and 28 inches in depth, with 3.5 inch wall and bottom which were insulated inside. Equipments were added such as:

(1) Suspension float board for placing plant pots in cans, and can be adjusted to any desired depth.

(2) Over flow drainage, by which a constant water level can be maintained.

(3) Circulation pump, made the water circulated in the tank constantly to maintain an even water temperature over the entire tank.

Additional equipment was regulating the water temperature. In the 80° degree tank, an electrical thermostat and a heater bathed in the water tank were used. The heater warmed the water, and thermostat controlled the temperature. In both 60° degree and 40° degree tanks, thermostat and refrigeration compressor were used to maintain the desired temperature.

In operation the first step was putting the cans on the board and adjusting the depth of board so each was two-thirds submerged. In order to maintain the same water level throughout the entire experimental period, water was added now and then to compensate for the loss from evaporation. The thermostats were adjusted to maintain the appropriate temperatures. Usually the temperatures became stabilized within 48 hours.

The air temperature was maintained at about 68°F at night through the entire experimental period except for a few nights. During the day time, air temperature was between 70° F and 100° F, and above 100° F sometimes on hot days. The soil temperature remained constant and did not show any change through the entire experimental period. Previous work with this equipment had revealed variations of 2° F. Plants were watered as required, and fertilized with half strength Plant Marvel (12 - 31 - 14, one-half teaspoon per two gallons of water) once every fourteen days. Weekly records were taken on the growth of plants, height of carnation and lily, number of leaves of geranium.

In case of carnation, the experiment terminated as the flower fully bloomed, measurements were taken on (1) days to bloom, (2) length of stem (in cm.), (3) flower size, (4) number and length of side shoots, (5) dry weight of the top (in gm.), and, (6) dry weight of the roots (in gm.).

In case of Easter lily, the experiment terminated when the first flower fully opened, growth was measured as (1) days to emergence, (2) days to bloom, (3) length of stem (in cm), (4) number of leaves, (5) number of flowers, (6) flower length (in cm).

For geranium, growth was measured as (1) days to first bloom, (2) number of leaves, (3) leaf areas, (4) number of flowers, (5) number of florets, (6) length of flower stem, (7) dry weight of the top and roots. The experiment was terminated on July 7, 1963.

As the plants were healthy through the entire period, no pest control had been used.

RESULTS

GENERAL OBSERVATION

Generally speaking, lily plants in this experiment appeared normal except one lily plant in 80° F treatment produced one flower of 4 petals and 4 anthers, this might be the result of long storage period which causing decline of vitality (75). Geranium plants in 40° F treatments had plain leaves in contrast to those in 60° F and 80° F treatment with crinkled leaves. The leaf color was the same. No marked differences in appearance were observed in carnation plants.

The underground portions of the plants appeared to be more influenced by soil temperature than the tops of the plants.

The roots of carnation showed marked differences due to treatment. Those in 40° F pots were short, slender, numerous and filled the upper half of the pot, those in 60° F and 80° F pots were longer, tougher, fewer in number and were distributed throughout the soil.

Because the lilies in 40° F treatment had not flowered by the end of this experiment, only plants of 60° and 80° soil temperatures were observed. The roots in 60° F pot were numerous, longer, both in stem roots and basal roots; those in 80° F pots were shorter and fewer.

The root system of Geranium showed great difference among soil temperature treatments. Those in 40° pots were slender, short, white in color, numerous, not differentiated into branch and side roots, and only filled the upper part of the pot. Those in 60° F pots were several large half-suberized branched roots, brown in color, each bore many side roots. Those in 80° pots had several suberized branched roots brown in color, and bore a few or no side roots. Roots at both 60° and 80° filled all the pots. This phenomena was found to be identical with those of Lovell peach seedlings, within a soil temperature range of 7.2 - 35° c, "the tendency towards thicker fleshy roots at low temperature and towards fibrous suberized roots at the higher temperature was apparent." (Proebsting 1943) (59).

Similar situation occurred in rose, (Shanks and Laurie 70), the roots with the largest diameter at 62° F, and root hairs few or absent at 72° F. In case of cotton, (Arndt 3) the roots had the greatest total length at 30° c and were most numerous at 27° c. Nelson, S. H. and Tukey, H. B. (56) worked with East Malling rootstock, found the roots were thick, pearly white and nonbranched at 44° F, while at 77° F, they were slender, much branched, more or less discolored, concluded that raising the root temperature increases root cell maturation.

CARNATION

Table I indicated that there were no significant differences in growth characters which may be attributed to the effect of soil temperature, such as days to bloom, number of nodes, height of flower and root dry weight.

The significant differences found were (1) the number of side shoots was lower in plants grown in 40° F soil treatment than those in 60° F treatment; (2) the total growth and average length of side shoots of plants in 40° F treatment was inferior to those grown in 80° F and 60° F treatment; (3) the flower diameter of 40° F treated plants was also inferior to those in both 80° F and 60° F treatment; (4) the stem length of plants in 40° F treatments was shorter than those in 60° and 80° F treatments; (5) the total dry weight of plants in 40° F treatments was smaller than that in 60° F treatment; (6) the top dry weight of plants in 40° F treatment was smaller than those in 60° F and 80° F treatments.

TABLE I

GROWTH OF CARNATION AS RELATED TO SOIL TEMPERATURE

MEASUREMENT (Mean of 8 Plants)	SOIL TEMPERATURE °F				SIGNIFICANCE OF DIFFERENCE BETWEEN			
	80	60	40	Temp	80/60	80/40	60/40	D
Days to bloom	53.75	51.75	53.75	NS				
Stem length (cm)	55.06	55.13	45.31	1%	NS	5%	5%	1.535
No. of nodes	11.00	11.12	10.38	NS				
No. of side shoots	3.50	5.00	1.88	1%	NS	NS	5%	2.054
Mean length of side shoots (cm)	15.61	13.90	6.71	1%	NS	5%	5%	4.284
Total growth of side shoots (cm)	55.17	68.92	14.06	1%	NS	5%	5%	23.366
Diameter of flower (cm)	6.68	6.43	5.87	1%	NS	5%	5%	0.4533
Height of flower (cm)	5.12	4.68	4.75	NS				
Total dry weight (gm)	5.950	7.212	4.637	5%	NS	NS	5%	1.8921
Top dry weight (gm)	5.33	6.32	3.81	1%	NS	5%	5%	0.9539
Root dry weight (gm)	0.638	0.912	0.700	NS				

NS - Non significant

D = QS = (See Snedecor, F. W.: Statistical Methods, 1957 P. 251)

EASTER LILY

Table II indicated obviously that 40° F soil temperature is not favorable to Easter lily growth as shown by the significant difference in the days to emergence. As they did not bloom when this experiment ended, it was impossible to have more data. So only two soil temperatures were used for comparing other items.

The data showed that there was no significant difference between 80° and 60° at the 1% level in the items such as days to emergence, stem length, number of leaves, number of flowers, top dry weight, root dry weight and flower length. The only differences were (1) significance of difference in days to bloom occurred at 1% level, and (2) significant difference in total dry weight at 5% level. The former favored plants in 80° F treatment, flowered 6.6 days earlier than 60° F plants, the latter favored plants in 60° F treatment.

TABLE II

GROWTH OF EASTER LILY AS RELATED TO SOIL TEMPERATURE

MEASUREMENT (Mean of 5 plants)	SOIL TEMPERATURE °F				SIGNIFICANCE OF DIFFERENCE BETWEEN			
	80	60	40	Temp	80/60	80/40	60/40	D3
Days to emergence	21.4	21.8	65.2	1%	NS[2]	5%	5%	1.447
Days to bloom	76.0	82.6	-	1%				
Stem length (cm)	28.9	31.0	-	NS				
Number of leaves	62.2	64.2	-	NS				
Number of flowers	1.2	1.4	-	NS				
Length of flower (cm)	15.6	15.4	-	NS				
Total dry weight (g)	5.46	9.56	-	5%				
Top dry weight (g)	4.06	6.52	-	NS				
Root dry weight (g)	1.04	3.04	-	NS				

1) As plants in 40° F were remained vegetative when this experiment terminated, no more data could be taken.

2) NS - non significant

3) D = QS x (see Snedecor, G. W.: Statistical Methods 1957, p. 251)

GERANIUM

Table III showed that there were no significance of difference in days to first bloom concerning these soil temperatures. As for other items, there were significant differences. Plants in 40° F treatment were inferior to those in 80°, and 60° treatment in number of leaves, leaf areas and total dry weight; were inferior to plants in 80° treatment in top dry weight, were inferior to those in 60° in number of flower clusters. As for the leaf area, plants in 80° treatment had the largest, plants in 60° F the second, and those in 40° F the third. As far as root dry weight was concerned, plants in 60° F ranked the first, those in 80° F the second, and those in 40° F the third.

TABLE III

GROWTH OF GERANIUM AS RELATED TO SOIL TEMPERATURE

MEASUREMENT (Mean of 8 plants)	SOIL TEMPERATURE °F				SIGNIFICANCE OF DIFFERENCE BETWEEN			
	80	60	40	Temp	80/60	80/40	60/40	D
Days to first bloom	53.50	49.50	55.37	NS				
No. of leaves	30.25	31.50	20.62	1%	NS	5%	5%	4.85
Leaf area $(cm)^2$	893.12	583.75	348.75	1%	5%	5%	5%	151.263
Flower stem length (cm)	15.16	14.50	11.62	1%	NS	5%	5%	2.316
No. of flower clusters	3.5	4.0	2.9	5%	NS	NS	5%	1.006
Florets per cluster	43.26	43.34	34.75	5%	NS	5%	5%	2.786
Top dry weight (gm)	22.35	19.68	14.72	5%	NS	5%	NS	6.29
Root dry weight (gm)	3.96	5.26	2.38	1%	5%	5%	5%	1.034
Total dry weight (gm)	26.43	25.07	17.10	1%	NS	5%	5%	6.47

NS = Non significant

D= QS x (see Snedecor, F. W.: Statistical Methods, 1957, p. 251)

DISCUSSION

By observing the above mentioned facts, it was clear that soil temperature played an active role upon plant growth.

In case of carnation, a perennial from temperate region, no significant difference occurred among the flowering date of three soil temperature treatments. In other words, plants in 40° F could bloom at about the same time as those in 60° F and 80° F treatments, though the flower diameter was smaller and stem length shorter. Significant differences were found that the number, total growth and average length of side shoots was smaller; total and top dry weight was smaller, too. This meant plants in 40° F treatment were unable to produce more branches for further flowering beyond the first bloom. As the plants were all well rooted at the beginning and no significant differences were found among the root dry weight afterwards, then it could be assumed that it was the activity of roots which caused the difference. Forty degree soil apparently lowered the activity of roots with regard to absorption of water and nutrients, but sufficient growth was attained to support the first flower. The cause of low activity of roots under low soil temperatures has been explained as due to high viscosity of water, decreased permeability of cell wall, and lowered protoplasm streaming by Kramer (49).

In case of strawberry plants, Robert, S. N. and Kenworthy, A. L. (64) found also that no significant difference in dry weight of roots among all root temperatures (45° F, 55° F, 65° F, 75° F).

No significant difference was found between 60° and 80° treatment. As it was easier to maintain a soil temperature of 60° than 80°, so 60° F could be considered as the ideal soil temperature for carnation.

As there was great variation in the measurement of characters, the original data are listed as Appendix I.

The same situation existed in geranium, a perennial from sub-tropics. No differences were found among different soil temperature treatments with regard to days to first bloom. Plants in 40° F bloomed in about the same number of days as those in 60° and 80°, but the number of flower clusters, number of florets per flower, and length of flower stem were smaller as also was the vegetative growth such as number of leaves, leaf area and dry weight. These may be explained as the result of low activity of roots caused by low soil temperature.

The only significant difference between 60° and 80° treatments was in leaf area and root dry weight. Plants in 60° F had the larger root dry weight and plants in 80° F had the larger leaf area. As the flowering characteristics were almost the same between plants in 60° and 80°, and from aesthetic point of view it would be better to have less foliage for the same amount of flowers, so it was more reasonable to think 60° was more suitable to culture of geraniums. Another consideration is the cost of fuel, it is less for 60° soil temperature than 80° F. As there was great variation in the measurement of character, the original data are listed as Appendix II.

As for Easter lily, a bulbous plant from a warm region, among these soil temperatures, 40° F delayed their emergence and growth. No significant differences were found between 60° F and 80° F in days to emergence. However, significant differences existed between plants in 60° F and 80° F in days to bloom, plants in 80° F soil bloomed 6.6 days prior to those in 60° F. The total dry weight, however, was greater in the plants grown in 60° F soil. As the lily plants were not well rooted when they were planted, it may be assumed that 40° F was not favorable for emergence and root formation of lilies, but 60° F and 80° F were both favorable. As the roots were formed, the root activity appeared greater in 80° plants than 60° plants because the plants in 80° bloomed 6.6 days earlier. This could be explained by Q10 = 1.2 - 1.3, the physiological process increases 1.2 - 1.3 fold by each increase of 10° c (18° F), and this could be brought into practical use by raising soil temperature to hasten lily flowers.

As there was great variation in the measurement of characters, the original data are listed as Appendix III.

SUMMARY

The effect of soil temperature upon the growth of carnation (*Dianthus caryophyllus*, L.), Easter lily (*Lilium longiflorus*, Thumb) and Geranium (*Pelargonium hortorum*, Bailey) was studied. These plants were grown on pots in greenhouse potting soil, put into separate water tanks maintaining soil temperatures of 80°, 60° and 40° F. Air temperature maintained 68° F at night in the greenhouse.

Growth was measured as dry weight, days to bloom, and number of leaves for all plants. Additional measurement was made of number and total growth of side shoots, and size of flower in carnation; days to emergence, size of flower, number of flower in Easter lily; and leaf area, number of flower cluster, number of floret per flower in Geranium.

Significant differences were found in carnation plants concerning the number and total growth of side shoots, and total and top dry weight. Plants in 40° F pots were inferior to those in 60° and 80° treatments. No significant difference existed between 60° and 80° F treatments. As for other items, no significant differences existed among the treatments.

In Easter lilies, plants in 40° F treatment were delayed in emergence, and had not flowered when this experiment terminated. No significant difference was found between 60°

and 80° treatment in days to emergence, but plants in 80° F treatment were flowered 6.6 days earlier than 60° F treatment. No significant differences were found among other items.

In Geranium, plants in 40° F treatment were inferior to those in other treatments in respect to leaf area, number of flowers, florets per flower and dry weight. No significant difference existed between 60° and 80° treatments.

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APPENDIX I

CARNATION ROOT TEMPERATURE STUDY

APPENDIX I

CARNATION ROOT TEMPERATURE STUDY (Original Data)

Pots	Days to bloom	Stem Length (cm)	Number of Nodes	Side Shoot Number	Side Shoot Mean Length	Side Shoot Total Length	Flower (cm) Diam.	Flower (cm) Height	Dry Weight (g) Total	Dry Weight (g) Top	Dry Weight (g) Root
80°F											
1	56	58.5	11	3	13	39.00	7	5.5	5.6	5.1	0.5
2	54	54	12	6	18	108.00	6.5	5.5	7.8	6.8	1.0
3	54	58.5	11	4	15.5	62.00	7	5	7.2	6.2	1.0
4	57	49.5	11	4	18.5	74.00	6.5	5	6.3	5.8	0.5
5	54	52.5	10	4	12.75	51.00	7	5.5	5.6	5.0	0.6
6	54	59.5	12	3	13.3	39.90	7	5.5	5.6	5.2	0.4
7	50	55.5	10	2	11	22.00	6.5	4.5	5.2	4.8	0.6
8	51	52.5	11	2	22.75	45.50	6	4.5	4.3	3.8	0.5
Mean	53.75	55.06	11	3.5	15.61	55.17	6.68	5.12	5.95	5.33	0.638
60°F											
1	56	56.5	11	6	14.25	85.50	7	5	8.2	6.7	1.5
2	49	54.5	12	4	15.5	62.00	7	4.5	7.4	6.4	1.0
3	54	54	11	6	9.99	59.94	6.5	5	6.4	6	0.4
4	50	55.5	11	6	14.41	86.46	6	5	8	6.5	1.5
5	49	59	11	4	16	64.00	6	4	7	6.5	0.5
6	50	51.5	11	4	14.12	56.48	6	4.5	6	5.4	0.6
7	51	55	11	4	12.5	50.00	6	4.5	5.7	5.0	0.7
8	55	55	11	6	14.5	87.00	7	5	9.2	8.1	1.1
Mean	51.75	55.13	11.12	5	13.90	68.92	6.43	4.68	7.212	6.32	0.912
40°F											
1	58	46	10	2	4	8	6	5	4.1	3.9	0.2
2	52	46	11	5	9.7		6	5	6.5	4.6	0.9
3	51	38	10	1	1	1	5.5	4.5	3.5	3.2	0.3
4	54	44.5	10	1	3	3	6	4.5	3.9	3.4	0.5
5	54	56	11	2	6.5	13	5.5	4.5	5	3.9	1.1
6	52	46.5	11	1	5	5	6	4.5	3.7	3.2	0.5
7	57	49	10	1	15	15	6	5	5	4.3	0.7
8	52	36.5	10	2	9.5	19	6	5	5.4	4	1.4
Mean	53.75	45.31	10.38	1.88	6.71	14.06	5.87	4.75	4.637	3.81	0.70

APPENDIX II

GERANIUM ROOT TEMPERATURE STUDY

APPENDIX II

GERANIUM ROOT TEMPERATURE STUDY (Original Data)

Pots	Days to first bloom	Number of Leaves	Leaf Area (cm^2)	Flower stem Length (cm)	Number of flower cluster	Florets per Cluster	Dry weight (g) Total	Dry weight (g) Top	Dry weight (g) Root
					80°F				
1	67	34	1270	14.88	4	48.75	33.9	28.4	5.5
2	52	32	1060	16.63	4	44.00	27.2	22.3	3.9
3	38	27	880	16.38	4	42.50	25.0	20.7	4.3
4	49	33	975	16.60	3	46.00	14.5	10.2	4.3
5	41	24	410	13.33	3	36.33	28.4	24.5	3.0
6	73	32	880	15.00	3	42.50	27.5	25.0	3.4
7	73	30	880	12.00	3	39.00	29.0	24.5	4.5
8	35	30	790	17.13	4	47.00	26.0	23.2	2.8
Mean	53.50	30.25	893.12	15.16	3.5	43.26	26.43	22.35	3.96
					60°F				
1	59	33	520	15.17	3	41.66	25.5	18.5	6.0
2	63	36	520	14.48	4	46.25	29.0	22.5	6.5
3	63	29	255	15.00	3	42.33	20.0	16.2	4.0
4	38	33	710	14.70	5	44.00	27.7	23.2	4.5
5	38	27	480	15.70	5	43.00	23.0	17.8	5.2
6	38	34	1000	14.00	4	41.50	28.0	22.0	6.0
7	45	28	455	11.50	4	43.25	22.5	18.1	4.4
8	52	32	730	15.50	4	34.75	24.7	19.2	5.5
Mean	49.50	31.5	583.75	14.50	4	43.34	25.07	19.68	5.26
					40°F				
1	45	30	360	14.0	4	45.0	30.5	22.0	1.0
2	52	11	150	10.50	1	25.0	23.0	27.5	3.0
3	45	20	300	12.17	3	39.0	14.6	13.0	1.6
4	28	19	275	7.25	2	22.5	10.0	8.0	2.0
5	56	21	475	15.00	2	34.0	11.5	9.5	2.0
6	52	16	240	13.13	4	39.0	11.2	8.5	2.7
7	87	23	480	11.67	3	44.50	16.5	12.8	3.7
8	28	25	510	9.25	4	29.0	19.5	16.5	3.0
Mean	55.37	20.62	348.75	11.60	2.9	34.75	17.10	14.72	2.38

APPENDIX III

EASTER LILY ROOT TEMPERATURE STUDY

APPENDIX III

EASTER LILY ROOT TEMPERATURE STUDY (Original Data)

Pots	Days to Emergence	Days to Bloom	Stem Length (cm)	Number of Leaves	Number of Flowers	Length of Flower (cm)	Total dry Weight (g)	Top dry Weight (g)	Root Dry Weight (g)
				80°F					
1	21	72	39	66	1	16	8.1	5.1	3.0
2	21	74	14.5	62	1	16	1.1	0.9	0.2
3	21	77	32.5	55	1	16	6.5	4.3	2.2
4	22	77	29	64	2	16	6.2	5.0	1.2
5	22	80	30	64	1	14	5.4	5.0	0.4
Mean	21.4	76	28.9	62.2	1.2	15.6	5.46	4.06	1.40
				60°F					
1	21	80	26	61	1	15	13.0	9.2	3.8
2	21	82	31	60	2	15	6.5	4.1	2.4
3	22	83	27	69	1	15	5.0	3.5	1.5
4	22	84	36	69	1	16	12.4	8.8	3.6
5	23	84	35	62	2	16	10.9	7.0	3.9
Mean	21.8	82.6	31	64.2	1.4	15.4	9.56	6.52	3.04
				40°F					
1	36	121	19	51	1	-	-	-	-
2	57	127	18	62	2	-	-	-	-
3	68	130	16	57	1	-	-	-	-
4	77	139	17	62	1	-	-	-	-
5	88	149	19	64	1	-	-	-	-
Mean	65.2	133	17.8	59.2	1.2	-	-	-	-