THE SHORT TERM EFFECT OF TEMPERATURE ON ROOT ELONGATION AND INITIATION

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ABSTRACT

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By

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Medium temperatures affect root initiation and elongation of callused cuttings. To study this effect, callused cuttings of Euphorbia pulcherrima, Hedera helix, and Taxus cuspidata were grown for 1, 3, or 5 days at medium temperatures ranging from 41° to 95°F. Pelargonium hortorium callused cuttings were grown at similar temperatures for 1, 2, or 3 days. After treatments, all cuttings were grown at 75° D.T. and 67° N.T. for 3 days to evaluate the residual effect of the temperature treatments.

Euphorbia pulcherrima had maximum root elongation and initiation from treatment at 77°F. This enhancement of root elongation and initiation remained 3 days after the 77° treatment. Cell number and the distance of the first observable xylem element from the tip were greater for roots from 5 day treatment at 77° than for roots at other medium temperatures. Hedera helix had maximum root elongation and initiation at a 77° soil medium temperature.

The residual effect of 68° and 77° treatments produced maximum root elongation and initiation. <u>Pelargonium hortorium</u> showed maximum root elongation and initiation from 86° treatment. Root elongation during a 3 day period after treatment at 59°, 68°, or 77° was greater than that from other treatments. Root initiation 3 days after 86° treatment continued to be maximum. <u>Taxus</u> <u>cuspidata</u> showed maximum root elongation after 77°-86° treatments. Root initiation during treatments and root elongation and initiation during 3 days after treatment showed no significant trends.

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By

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Appendix B is thesis research information condensed for publication in The Journal of the American Society for Horticultural Science.

INTRODUCTION

Medium temperature is a critical factor in root elongation and initiation. Some work has been done with the short term (10 days or less) effect of different soil temperatures on root growth (Loblolly pine [3], hop [20], cotton seedlings [32], and Silver maple [36]), but published work pertaining to floricultural crops is lacking. The only floricultural crop which has been studied for the effect of temperature on root growth is 'Better Times' roses, but this was done only after plants had been exposed for 130 days (38).

Carpenter and Rasmussen (10) found that irrigating with cold water (35° or 45°F) lowered greenhouse soil temperatures and rose and chrysanthemum turgidity. Warm water (85° or 95°) or the sun could cause an opposite effect. It is important to know what effect fluctuating soil temperatures have on floricultural crops.

LITERATURE REVIEW

Root Elongation

Studies of the effect of soil temperatures on root elongation have shown that the optimum temperature varies with plant species and in some cases with the study. The optimum soil temperature for most species is within the range of 68°F (20°C) to 86°F (30°C). The greater the temperature deviation, both higher and lower from the optimum, the less root elongation.

Several species exhibit optimal root growth at soil temperatures around 68°F (20°C). Young corn plants (*Zea may*) exhibit a rising optimum root temperature as plants develop from the 2 to the 6 leaf stage of corn plant development. Root growth was the greatest at 59°F soil temperatures during the 2 to 4 leaf stage and 68°F at the 4 to 6 leaf stage (4). One year old Stayman apple and Elberta peach trees were grown for 45 days at soil temperatures of 45° to 95°F. The maximum yield of roots occurred at 65°F based on fresh weight (33). Seedlings of Silver maple (*Acer saccharinum*) grown at soil temperatures ranging from 36°-86°F had maximum root elongation at 68°F (36).

Some species show optimal growth at a soil temperature close to 77°F (25°C). Lovell peach seedlings showed earlier growth and a greater amount of elongation after 25 days at 75°F than at higher or lower temperatures (34), while year old Elberta peach trees had optimal root growth at 65°F (33). Cotton seedlings (variety Super-Seven) grown for 14 days at different soil temperatures gave the longest tap roots at 75°F with shorter tap roots at higher and lower soil temperatures (1). Smoliak and Johnston determined that seven species of grasses gave the longest root growth at soil temperatures of 81°F. Five species preferred 64°F. No differences appeared after 16 days but were present 30 days after treatments began (39). During the period of active root growth 2 year old Ponderosa pine seedlings (Pinus ponderosa) showed a greater amount of lateral root elongation when grown at 77°F for 30 days than they did at lower temperatures (42).

Brouwer (5) found from data based on root weights that a broad optimum soil temperature exists for some plants. He stated that generally a soil temperature range of 180°F can be found where root growth does not differ greatly. The soil temperature range in °F for optimum root growth during 25 days exposure for each plant studied was as follows: strawberries 50°-77°, flax 59°-77°, broad beans 68°-86°, oats 68°-77°, rape 68°-77°, maize 77°- 86°, and red kidney beans 77°. Leitch (28) found beans to have two optimum soil temperatures for root growth, one at 79°F, and one at 86°F for average growth per 22½ hour period. No explanation for the difference was given and on repeating the treatments a peak of 86 F was found. Grobbelaar (18) found maize seedlings (Zea mays) to have optimum root growth at soil temperatures of 68°-86°F after 6 days of exposure. Brouwer's (5) maize seedlings did not have optimal growth at 68°F. He states a soil temperature of 95°F for all plant roots was extremely inhibiting except for maize. At 104°F there was very little root growth. He also reported a range of 4° or 5°F at high temperatures was all that was necessary to pass from favorable to harmful temperatures that gave complete inhibition to root growth. Douglas fir (Pseudotsuga menziesi) showed more root activity at 68°-77°F than at lower temperatures using seedlings with a root growth of 2.5 inches or longer (41). Barney (3) found Loblolly pine seedlings (Pinaccae taeda) grown for 5 days at soil temperatures from 41° to 95°F, had different optimum soil temperatures depending on where the seeds were collected. Seeds from North Carolina gave a peak of root growth at 77°F. The maximum growth for Louisiana collected seeds was 68°F with a slower growth rate than for North Carolina seeds.

Root recovery from exposure to temperatures other than the optimum varied with species and also with the extent of the deviation of the temperature from the optimum. Seedlings of Silver maple showed maximum root elongation at a soil temperature of 68°F (36). After 2 days exposure at 36°, 45°, or 50°F plants were returned to 68°F. Root elongation rate recovery was not complete 3 days later. Root elongation rate recovery was complete after exposure to 59°, 77°, or 86°F for 2 days. This residual effect was not shown in cotton seedlings (32). Two day old cotton seedlings were grown 4 days at soil temperatures of 54°, 64°, or 75°F in nutrient solutions. Little growth occurred during 4 days for roots of seedlings grown at 54°F. However, they resumed growth similar to seedlings grown at 75°F (optimum root growth temperature) upon changing temperatures from 54° to 75°F.

Richardson (36) explained the response of Silver maple to soil temperatures as the result of carbohydrate utilization. He believed the limited growth at temperatures below 68°F was the result of reduced respiration and utilization of carbohydrates. Above 68°F he thought there was a decreasing carbohydrate translocation with increasing temperatures or carbohydrates were present in an unusable form.

The effect of temperature is also tempered by the ability of roots to respond. Ponderosa pine (42), Douglas fir (41), ground-hemlock (*Taxus hunnewelliana*) (26), yew (*Taxus cuspidata* 'Nana'), and creeping juniper (*Juniperus horizontalis* 'Plumosa') (25) all showed this peak of more root activity during a certain period of the year. "Root-regenerating potential" (RRP) has been used as an expression of root activity. Lathrop (26) defines Stones and Schubert's

(42) RRP as the ability of a recently transplanted seedling to elongate existing lateral roots or initiate new lateral roots. Ponderosa pine, Douglas fir, and ground-hemlock generally show a similar period of RRP. The RRP is shown to have a seasonal cycle with a high in December through February followed by a low in July and August. The only exception is ground-hemlock with a low in mid-July. Yew showed more rooting in cuttings propagated from November to February, and creeping juniper November through April. Both had an unexpected peak in July (25).

Root Initiation

Soil temperature also affects root initiation with the optimum temperature varying with different species of plants. The most common temperatures are within the range of 65°-80°F. Plants and cuttings at higher or lower soil temperatures usually produce fewer new roots.

Some species show optimum root initiation near 68°F (20°C). One year old Stayman apple and Elberta peach trees showed maximum root initiation at soil temperatures of 65°F, this was the same temperature as previously stated for best root growth (33). Plum root stocks Myrobalan B, St. Julien A, and Clone 8-21 when rooted in the autumn showed most rooting at 66°F. When Myragalan B was rooted in the spring it showed a higher percentage of rooting at 70°F than at 66°F (23).

A soil temperature near 77°F (25°C) gave optimum root initiation for some plant species. Hops (*Humulus lupulus*) showed the highest percentage and most rapid rate of rooting after 3 weeks at soil temperatures of 70° to 75°F (43). It was reported that although temperatures of 85°-90°F inhibited hop root growth, root initiation was not adversely effected. Later work showed that hop plants developed roots in 4 days at a soil temperature of 81°F and in 6 days at 72°F. After 20 days the number of roots was slightly greater at 72°F (20). Basket willow cuttings (*Salix viminalis*) showed a significant increase in root number at soil temperatures of 77°F as compared to those at 72°F and there also was significantly more rooting at 16 days than at 10 days for all temperature treatments (13). Brompton and Pershore (difficult to root plum rootstocks) showed a small percentage of rooted cuttings at a soil temperatures of 75°-86°F and 75°F respectively when rooted in the autumn. At lower temperatures there were no cuttings rooted (23). Howard and Garner (22) found cuttings of M.26 apple showed the greatest number of rooted cuttings at 76°-81°F soil temperatures in 15 days. Howard (21) found soil temperatures of 70°-80°F gave the greatest per cent of M.26 rooted cuttings after 28 days. Both found the greatest number of roots on those cuttings at soil temperatures of 80° and 81°F. Crab C (apple root stock) had the greatest per cent of rooted cuttings after 28 days at soil temperatures of 70°F (21). Crab C cuttings at soil temperatures of 80°F had the largest number of roots per cutting as with M.26 (21,22). Two year old Ponderosa pine seedlings generally initiated more lateral roots December through May and at soil temperature of 68°F (42). Yew cuttings propagated in mid-November showed root growth earlier at 80°F than at lower temperatures and all cuttings at 80°F rooted (14).

Smoliak and Johnston (39) found grass seedlings showed a wide range of optimum temperatures of root initiation depending on the species. No increase in root number was seen after 16 days but was noted after 30 days of treatment. After 30 days of growth 6 species had the greatest number of roots at a soil temperature of 81°, 4 at 64°, 1 at 64° and 81°, and 1 at 55°F.

Few plants do not show some decreased root initiation at soil temperatures of 86°F (30°C). Soft tip cuttings of lemon-scented verbena (<u>Lippia citriodora</u>) gave similar rooting at soil temperatures of 80°-85°F as at 70°F. This was better than those with no bottom heat (43). Similar results have been previously mentioned for hop cuttings (43).

Domanski <u>et al.</u> (13) have stated a possible explanation of the effect of temperature on root initiation. They believed that their experiments with Basket willow cuttings suggested that its rooting was regulated by interactions of growth regulators and possible co-factors. As temperature increases toward optimum root initiation, the balance of internal growth regulators and possible co-factors may change to bring out the stimulatory effects of auxin on root initiation and overcome the inhibitory influences of cytokinins and gibberellins.

Morphology

The morphology of a root can be modified by the temperature of the soil in which grown. Roots of most plants tend to be white and fleshy in the optimum temperature range for root growth. At higher temperatures they become brown due to the suberization of the entire root.

Nightingale (33) observed that newly developed roots of both Stayman apple and Elberta peach were white, succulent, and of a larger diameter when grown at soil temperatures of 65°F. This, Nightengale felt, indicated the presence of an extensive zone of embryonic tissue. The amount of embryonic tissue decreased from 65° to 95°F while the external suberized tissue increased. Nightingale thought that with increasing temperature there was an increase in the rate of maturity and differentiation of primary tissue.

Lovell peach seedlings also showed these trends (34) but optimum elongation occurred at 77°F. Roots growing at the higher temperatures were fibrous and suberized close to the tips. Those roots at lower temperatures were thick, fleshy and white for several centimeters back from the tip.

Loblolly pine seedlings also showed that suberization apparently proceeds slower at lower than at higher temperatures. At 95°F pine roots were rather heavily suberized (3). Cotton tap roots at 94°F were white and turgid, but above 94°F they were brown and shrunken with 1 or 2 short brown and shrunken laterals (8).

Roots of certain species may be in a period of dormancy so they are not receptive to certain temperature changes within limits. Lathrop (26) reported that dormant roots of yew can be easily determined by the presence of dark red root tips whereas actively growing root tips appear a translucent white.

Cell Division and Elongation

The extent of root elongation is the result of the rate of cell division and amount cell elongation. Cell elongation and cell division combine to give the result of greater root growth at one optimum temperature or temperatures. The optimum temperature has been found to vary with different species of plants.

Burstrom (7) worked with wheat roots and Brown and Rickless (6) with excised root tips of field pumpkin (Cucurbita pepo). They found that roots were longest when grown at a soil temperature of 77°F. This longer root growth was due to longer cells as compared to roots grown at lower temperatures.

Pea (Pisum sativum) had optimum root growth at temperatures of 68° and 77°F but the rate of mitosis was most rapid at 77°-86°F (44). This indicates that cell length increased with temperatures to 68°F and then decreased. The optimum root growth at 68°F was the result of longer cells and at 77°F the result of more but shorter cells. Maize seedling roots may have shown this same result. Seedling roots grown at 77°F had both increased cell division and elongation as compared to those grown at 54°F (2).

Lopez-Saez et al. (29) and Lopez-Saez et al. (30) show a slightly different result from the effects of temperature on root elongation of onion (Allium cepa) bulbs. Maximum root elongation occurred at temperatures of 77°-86°F with no root growth at 32° or 104°F. Epidermal cell lengths between 10 and 20 mm. from the root tip remained constant as temperatures increased to 86°F, but at higher temperatures cell length decreased. The minimum mitotic cycle time occurred between temperatures of 86°-95°F. Root elongation is due to an increasing number of cells up to 86°F. Above this temperature there are more cells but they become much shorter in length.

Barney (3) found that root cells of Loblolly pine do not respond this way. He showed that there was very little difference in cell size in seedlings grown for 5 days at temperatures ranging from 41° to 86°F. Also, the amount of embryonic tissue and the number of mitotic figures appear about equal regardless of temperature. At 95°F no mitotic figures were observed and the region of elongation was short, so there was an abrupt increase in cell size from the region of cell division to that of maturation.

Gonzalez-Fernandez et al. (17) working with onion stated 2 hypothesis for cell elongation: (1) two hormones are produced, one in the region of the rootcap which causes geotropic reactions, and another in the quiescent center which controls the process of elongation; (2) one hormone is involved which causes the auxin level to rise or fall and can selectively effect cell elongation. Cell division would be regulated by a program present in the cell and not controlled by hormones out side the cell.

Esau (15) has found a correlation between the vascular elements and the root growth rate. She states that the exact distance between the meristem and the first mature vascular elements, especially zylem elements, varies in relation to the rate of growth of roots. In general, slow growing roots have mature vascular elements closer to the meristem than fast growing roots. This investigation was undertaken to determine the optimum soil temperature for root elongation and initiation of several woody and herbaceous horticultural crops.

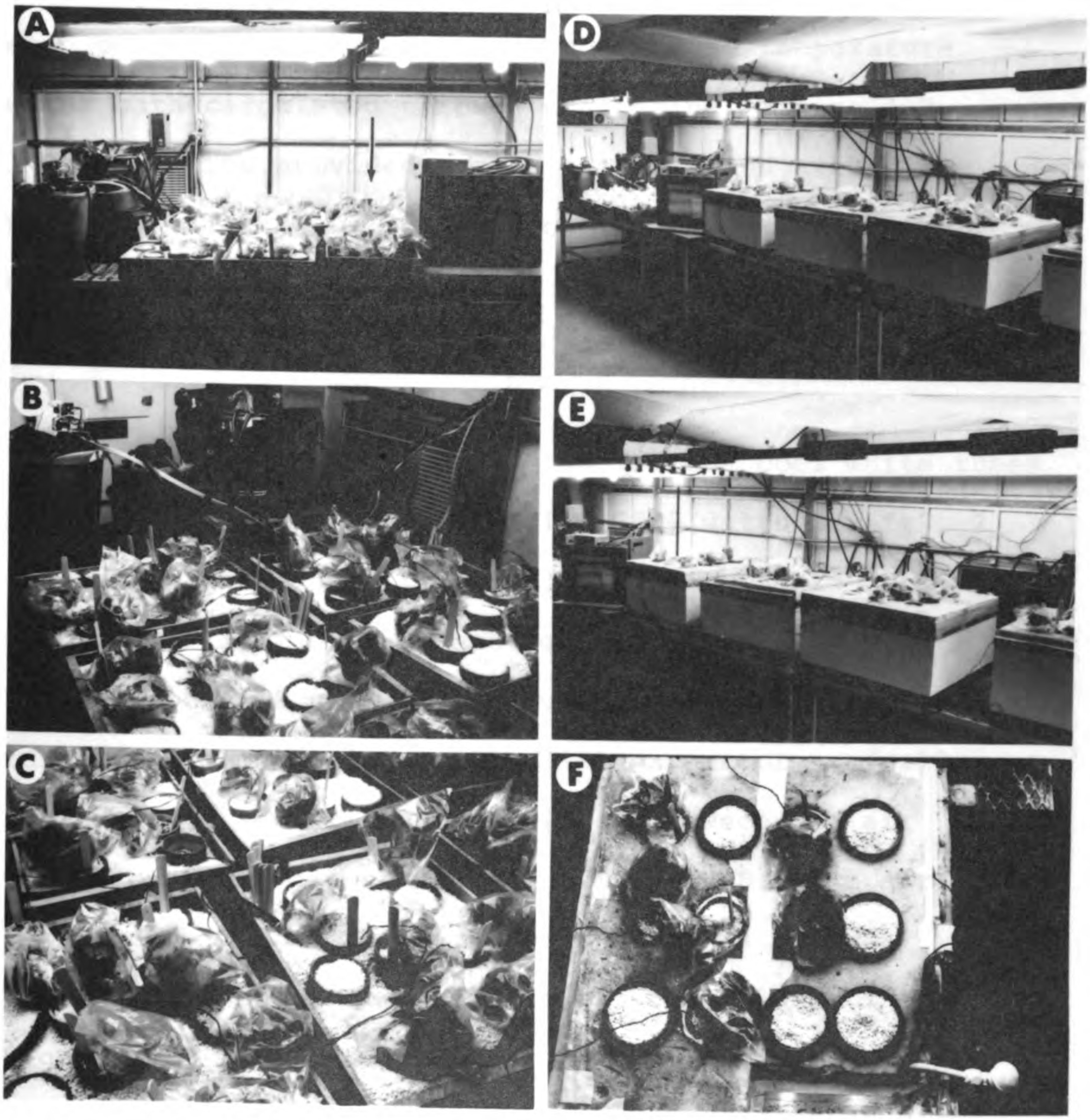
METHODS AND MATERIALS

Growth and Data Collection

Rooted cuttings of *Euphorbia pulcherrima* (poinsettia, cultivar D-3) from Paul Ecke Inc., *Hedera helix* (English ivy, juvenile), and *Taxus cuspidata* (yew) were grown for 1, 3, or 5 days at 1 of 7 different soil temperatures 41°F (5°C), 50°F (10°C), 59°F (15°C), 68°F (20°C), 77°F (25°C), 86°F (30°C), or 95°F (35°C). *Pelargonium hortorum* (geranium, cultivar Irene) rooted cuttings were grown at similar temperatures but only for 1, 2, or 3 days. The cuttings were maintained in a medium consisting of a 1:1 mixture of peat and Turface in 3-inch clay pots. Figure 1 shows the experimental equipment for refrigeration and heating to maintain each temperature.

The refrigeration system consisted of 4 refrigerated containers (figure 1-E) each with an inside measurement of 2 ft. X 2 ft. Tubes, circulating Freon, were around the inside perimeter to maintain a desired air temperature. The top of each chamber was a 2 ft. styrafoam lid which had twelve pots suspended in the chamber (figure 1-F). By controlling the temperature of the air surrounding the pots, the desired soil temperature was maintained at 41°, 50°, 59°, or 68°F. Grade #2 Perlite (Grace's

Figure 1.--Experimental equipment for maintaining medium temperatures: (1) A, B, and C show the system for maintaining the warm medium temperatures, (2) D, E, and F show the refrigeration system for maintaining cool medium temperatures. Arrow in A indicates plants being grown during the 3 day period after treatment.


A
B
C
D
E
F

Horticultural Perlite 'Perl-gro') insulated the soil and allowed the shoots to project into the room environment.

In order to maintain the warm soil temperatures (77°, 86°, or 95°F) flat-sided rubber tubing encircled each pot and warm water from a controlled temperature water bath circulated through the tubing (figure 1-B, 1-C). Perlite provided adequate insulation around the pot and soil surface. Following the temperature treatments, plants were grown for 3 additional days under 75°F D.T. and 67°F N.T. air and soil temperatures (figure 1-A).

Light was supplied by 9 fluorescent cool white tubes and 3 incandescent lamps yielding 33.8 watts per ft^2, 2 feet above the plants (figure 1-D). All plants received 9 hours of light during each replication.

The entire system was housed in a constant temperature room to maintain similar air temperatures of all treatments. A partition was placed between the air conditioner and plants shown in figure 1-B. The air temperature 15 cm. above the cold chambers was not altered by the operation of the air conditioner in figure 1-E.

Thermocouples of 24-gauge copper-constantan wire were placed approximately 1.5 cm. in from the side of the pot. Soil temperatures were recorded for half an hour 4 times per 24 hours on a 24-point recording potentiometer. The thermocouples were at the same depth as the cutting's base to give accurate temperature recordings. The air temperature in the controlled temperature room was maintained at 75°F D.T. and 67°F N.T. with a + or - 2°F fluctuation for all replications. The root zone temperature fluctuation per day for each replication and species used are given in Appendix Table 1.

The cuttings were started in mist propagation benches from March through September 1970, with the exception of the yew cuttings which were started in mid-December 1969. When sufficient cuttings for 1 replication had 3 or more roots, the cuttings were gently removed, placed on moist newspaper in flats and transported to the treatment area from the propagation benches. The propagation media was removed from each cutting by gently washing the roots and lower stem in a beaker of water at room temperature. Each cutting was then placed in a large metal tray filled with water at room temperature to prevent desiccation of the roots until measured. The procedure for measuring the roots was similar for all cuttings. Only cuttings with 3 to 6 roots were used. If more than 6 roots were present, 6 uniform roots were randomly selected and the remainder removed with tweezers. A cutting was selected at random. It was inverted and measured from the base of the root to the tip with a 15 cm. ruler. The root was pressed gently against the ruler to keep it as straight as possible for accuracy. A reference point was noted on each cutting so that the roots were measured in the same manner and order during all measurements.

After measuring, each cutting was transferred to a pot in which the medium had been previously watered thoroughly. Each cutting was placed about 1.5 cm. from the side of the pot to compensate for the slight rise in temperature from the side of the pot to the center. Immediately after the cutting was potted, it was watered thoroughly with a 200 ppm concentration of completely soluble 20-20-20 fertilizer solution. Perlite, acting as an insulator, was placed around each cutting filling the pot to the rim.

All plants which were to be remeasured on the same day were measured as 1 group. These were then placed in their respective temperature treatments. The next set of plants was then measured and this process repeated with the last set. Each set of plants was located in its respective temperature treatment within fifteen minutes from the first to the last. The soil in the pots had been cooled to desired temperatures prior to potting the cuttings. The 95°F treatment took 1 hour and 45 minutes to reach the desired temperature after treatments began. Within this period the 41°F treatment reached 44° and an additional ½ hour was required to reach 41°. All other treatments reached the desired temperatures within 1 hour and 15 minutes. Watering with 65° water brought the medium at 41°F to 47° and the medium at 95°F to 87°. The 95°F treatment required 1 hour and 20 minutes to return and the 41°F treatment 1 hour and 40 minutes to return after watering. As in the planting the less extreme temperature treatments were affected to a lesser degree. The plants at the higher temperatures (86°-95°) required watering once or twice a day. The cooler temperature treatments (41°, 50°, and 59°) required watering only once every 3 to 5 days. Watering was not necessary until plants had been in treatments for 1 day. After treatment for 1, 3, or 5 days each pot in a treatment was removed from its temperature bath in the same order. Each cutting was removed by inverting the pot and gently tapping the top of the pot on the table.

The roots were remeasured following the same order and method as previously described. When cuttings were repotted, the insulation covering of Perlite was not replaced. After tops and roots had remained at room temperature (75° D.T. and 67°F N.T.) for 3 additional days, the cuttings again were removed and remeasured to determine the residual effect of the temperature treatment. Each time cuttings were removed and measured the total number of new roots initiated by the cuttings was counted.

All species had the same temperature treatments. Poinsettias, because of wilting during a preliminary run at low soil temperatures, had their tops covered during the experiment with plastic sandwich bags.

Two replications of poinsettias were grown for 1, 3, or 5 days at the 7 temperatures but not removed from their pots for root measurements prior to the 3 days growth at 75° D.T. and 67°F N.T. (poinsettie #2). This procedure was used to determine the effect, if any, of removing the cuttings after the temperature treatments and repotting. The cuttings therefore grew for a total of 4, 6, or 8 days between measurements. Numbers of new roots initiated were also counted. One replication of poinsettia was grown for 6, 12, or 24 hours to determine if a residual effect of temperature occurred after less than 1 day of treatment.

A split plot design (40) was used with 3 subtreatments per replication for the statistical analysis of root elongation (Appendix Table 2) and root initiation (Appendix Table 3). Because of the high variability and low number of roots initiated among cuttings at similar temperatures .5 was added to the average number of roots initiated at each temperature per replication and the square root was taken of this value (40). This final number was the value used on the split plot design for root initiation. The total number of replications varied with plant species and were as follows: poinsettia -5, poinsettia #2 -2, geranium -3, ivy -4, and taxus -2. The total root length and number of roots initiated during temperature treatments and the 3 day residual effects were determined for each species used. Because of the random response of root initiation in yew to temperature, the numbers of roots initiated were not analyzed statistically.

Histological Technique

Representative roots of 1 replication of poinsettia were collected at random after temperature treatments and also after 3 days of additional growth. These were dehydrated, infiltrated, and embedded in tissuemat following Feder's *et al.* (16) procedure. Specimens remained at each step for 24 hours. For Feder's monomer mixture 2 changes of tert-butyl alcohol (TBA) used. Specimens were placed in 3 changes of tissuemat, embedded and then sectioned. While the roots were in TBA prior to embedding each root was inspected using a Spencer A and O dissection microscope. All soil particles were carefully removed.

Specimens were sectioned with a rotary microtome at 10 microns. Selected sections of ribbon were mounted on slides with Haupt's adhesive (24) and allowed to dry at room temperature for 24 hours.

Two staining procedures were used for this study: A general histological stain, Chlorozol Black E, was used for preliminary study of sections and Safranin-Fast Green as a stain for xylem elements. The Chlorozol Black E schedule was a modification of Darrow's (12).

Sections were brought down to 70 per cent alcohol from xylene.

1.	70 per cent alcohol	5 minutes
2.	1 per cent Chlorozol Black E in 70 per cent alcohol	5 minutes
3.	70 per cent alcohol	differentiate 2-3 minutes

Sections were taken from 70 per cent alcohol to xylene and then permatized. The Safranin-Fast Green was a modification of Sass's procedure (37).

Sections were brought down from xylene to 50 per cent alcohol.

1.	50 per cent alcohol	5 minutes
2.	1 per cent Safranin in 50 per cent alcohol	2 hours
3.	50 per cent alcohol	2 (rince and 5 minutes)
4.	70 per cent slcohol	2 (rince and 5 minutes)
5.	95 per cent alcohol	5 minutes
6.	0.1 per cent Fast Green in 95 per cent alcohol	10 seconds
7.	Absolute ethyl alcohol	5 minutes

Sections were brought from absolute ethyl alcohol to xylene and then permatized.

The stained slides were permatized with a 60 per cent Harleco resin solution in zylene. Weights were placed on the cover slips of the slides and were dried on a 109°F warming table for 24 hours. Final drying was in a 136° paraffin oven for 3 to 5 days.

Histological Observations

Observations and photomicrography were made with a Carl Zeiss GFL microscope. Roots which had grown for 5 days under each temperature treatment and 3 additional days at 75°F D.T. were found to be the most desirable for study. Roots which had grown for 1 or 3 days at 41°F and 3 additional days at 75° D.T. and 67° N.T. were also studied. Measurements and counts of the numbers of cells were made for each root section from the root tip to the first visible xylem element identified (Table 1). The root section with the shortest distance was considered as having the earliest xylem development. Cell counts were made on all root sections unless the root appeared to bend. If this occurred, using the central cylinder as a guide, another root section was used which appeared to contain the desired area. When it was impossible to ascertain cell boundries for vascular cells beyond the meristematic region, cortex cells were counted. The cell numbers given in Table 4 are means of 4 counts within the space of 0.4 mm. Two counts were made on each side of the central cylinder.

Photomicrographs (Figures 7 and 8) show where the first xylem element appeared for the roots studied.

Tissue Analysis

Cuttings of poinsettia, cultivar D-3, were taken in late December 1970 and rooted by early January 1971. While in the propagation bench the cuttings were watered with 200 ppm concentration or completely soluble 20-20-20 fertilizer solution. After rooting, 3 cuttings were grown for 5 days at each of the following temperatures: 41°, 68°, or 95°F. Cuttings taken from the propagation bench were used as a control. Plants were washed with distilled water. The 3 cuttings at each treatment were combined into 1 sample. Tissue analysis was run on entire cuttings minus the callus and roots to eliminate any soil particles (Table 2). The method of tissue analysis was as follows: N by the Kjeldhl method, K by flame photometer, and P, Na, Ca, Mg, Mn, Fe, Cu, B, Zn, and Al spectrographically.

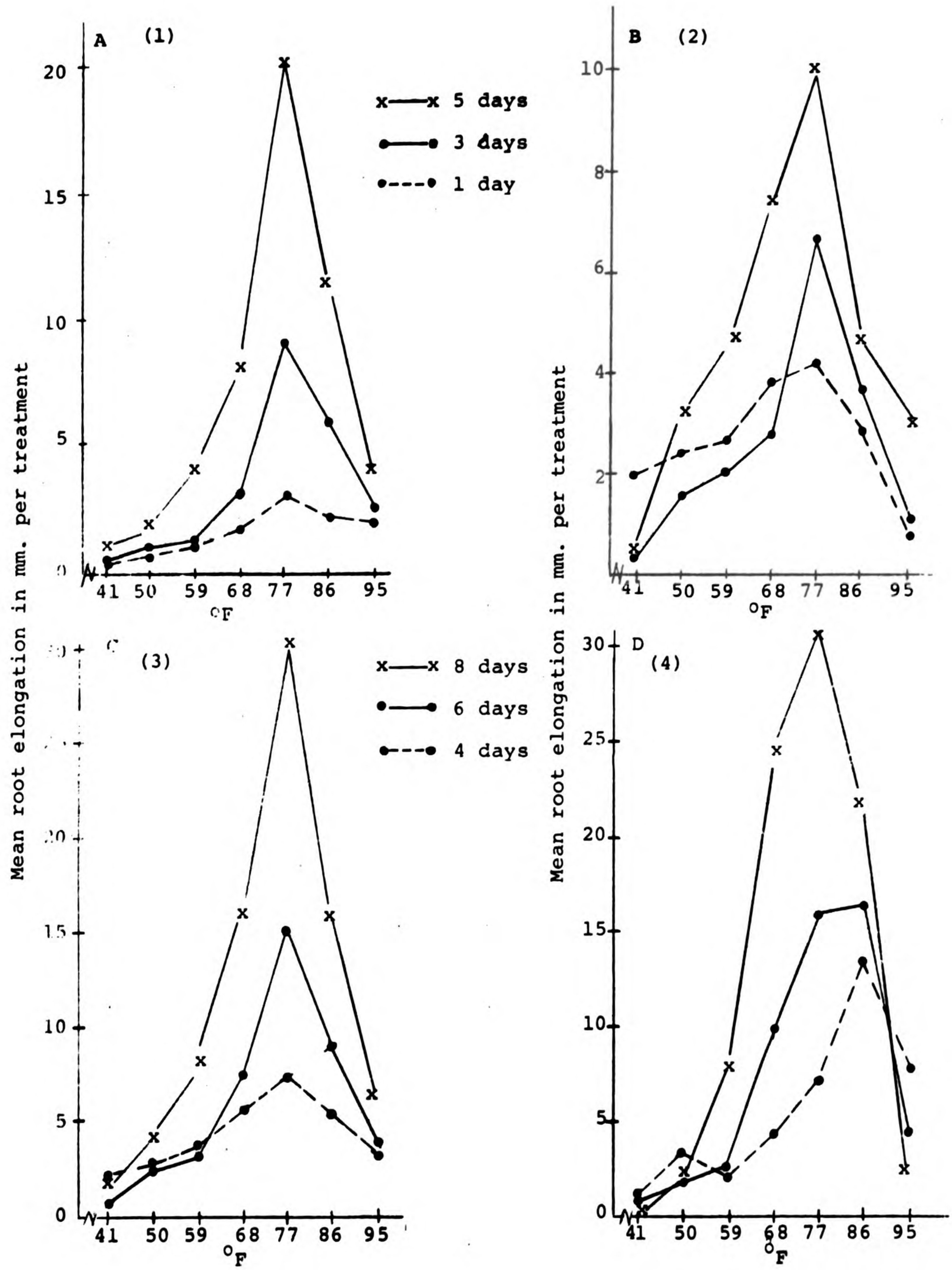
RESULTS

Root Elongation

Poinsettia

The amount of poinsettia root elongation during exposure for 1, 3, or 5 days at temperatures ranging from 41° to 95°F was significant at $P<0.001$ (Appendix Table 2-column A). The effects of time and of the time-temperature interaction also were significant ($P<0.001$). A progressive increase in root elongation resulted as temperatures increased from 41° to 77° and length of exposures was extended from 1 to 5 days. As temperatures increased above 77° there was decreased root elongation. The only significant results for roots grown at 1 temperature but at different lengths of exposure were: 68° for 5 days, 77° for 1, 3, or 5 days, and 86° for 1, 3, or 5 days ($LSD\alpha 0.05 = 0.274$). The extraction and significance of the linear, quadratic, and cubic components of the graph (1, 3, or 5 days of treatment) in Figure 2-A are given in Appendix Table 2-column A. It showed treatment for 1 day had no significant effect on root elongation at any of the temperatures used, but root elongation during 3 or 5 days of treatment varied significantly with the soil temperature.

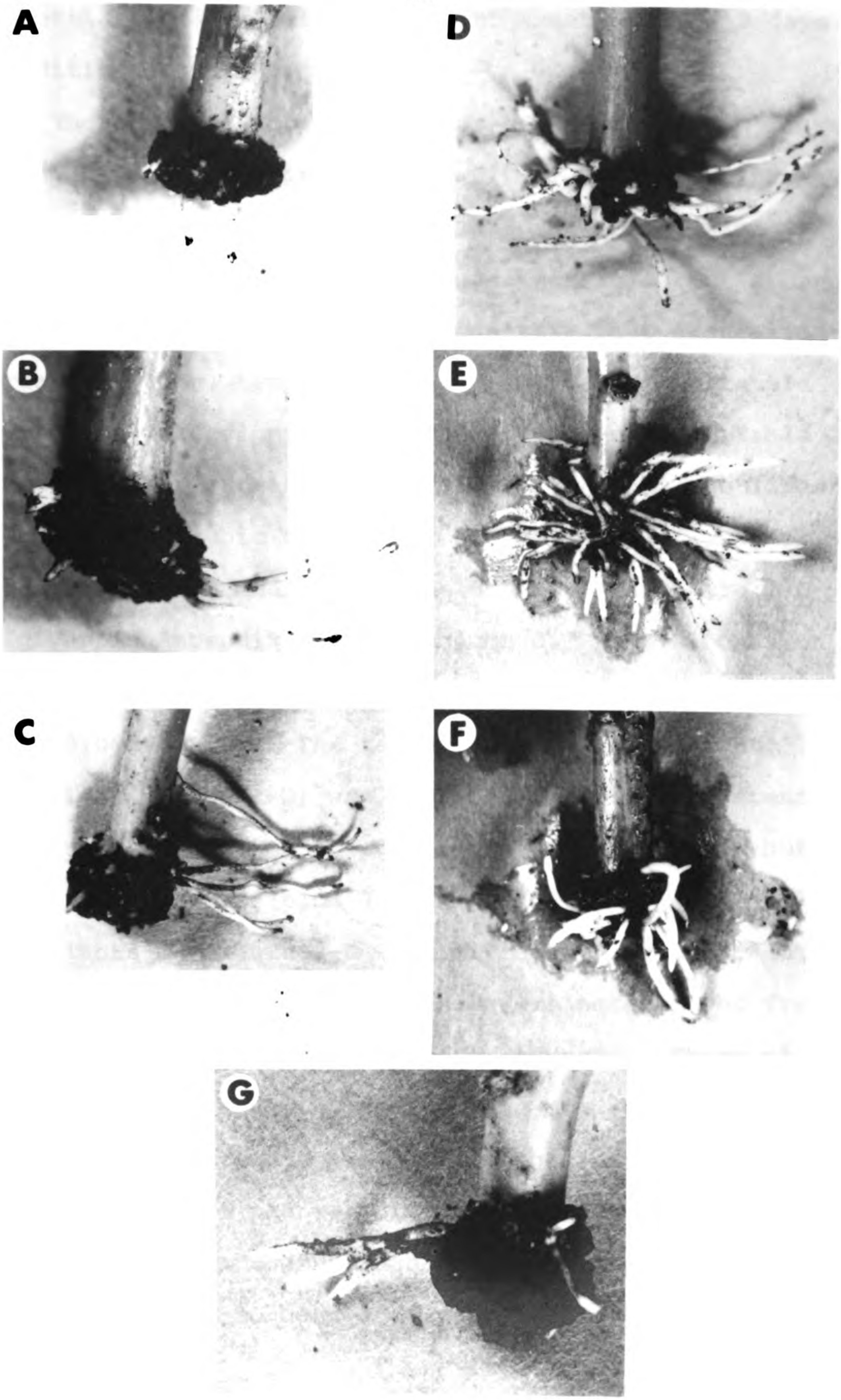
Figure 2.--Mean poinsettia root elongation: (1) during treatment, (2) during 3 day period after treatment, (3) combined elongation of A and B, (4) cuttings not removed prior to 3 day growth period.



A
(1)
x——x 5 days
●——● 3 days
●- - -● 1 day
B
(2)
C
(3)
x——x 8 days
●——● 6 days
●- - -● 4 days
D
(4)
Mean root elongation in mm. per treatment
Mean root elongation in mm. per treatment
41 50 59 68 77 86 95
°F

After removal from the temperature treatments and 3 days of growth at 75° D.T. and 67°F N.T., poinsettia roots (figure 2-B) still showed the same general trends as seen during temperature treatments (figure 2-A). The effects of temperature and of time were significant at $P<0.001$ (Appendix Table 2-column B), but the time-temperature interaction was not. Roots at 77° for 5 days had the most elongation during treatment and also during a 3 day period (75° D.T. and 67° N.T.) after treatment. The length of exposure time at each temperature resulted in non-significant differences except for the treatments of 5 days at 68° and 77° ($LSD\alpha 0.05 = 0.267$). The extraction and significance of the linear, quadratic, and cubic components of the graphs (root growth for 1, 3, or 5 days of treatment and 3 days at 75° D.T. after treatment) in figure 2-B are given in Appendix Table 2-column B. Root elongation which showed no significant trends after 1 day of treatment does after 3 additional days (75° D.T. and 67° N.T.) of growth (Appendix Table 2-column B) by showing a significant quadratic trend. The quadratic curve shown for 3 and 5 days of temperature treatments was significant at $P<0.01$ and $P<0.001$ respectively. As previously seen, as temperatures increased to 77° there was increased root elongation, but further increases in temperature resulted in decreased root elongation. Figure 3 shows the average response of

Figure 3.--Average rooting response of callused poinsettia cuttings given 3 days of treatment at: (A) 41°, (B) 50°, (C) 59°, (D) 68°, (E) 77°, (F) 86°, or (G) 95°F followed by 3 days at 75°F.


A
B
C
D
E
F
G

poinsettia cuttings after 3 days of treatment and 3 days of additional growth.

The combined root elongation of poinsettia in figures 2-A and 2-B is shown in figure 2-C. From 59° to 77°F as temperatures and lengths of exposure increased (plus 3 days at 75° D.T. and 67° N.T.) there was increased root elongation. Above this temperature poinsettia root elongation decreased. Time, temperature, and the time-temperature interaction were significant at $P<0.001$ (Appendix Table 2-column C). The extraction and significance of the linear, quadratic, and cubic components of the graphs (1, 3, or 5 days of treatment and 3 days at 75° D.T.) in figure 2-C are given in Appendix Table 2-column C. Root elongation at similar temperatures but different exposure times has an $LSD\alpha 0.05 = 0.110$. The temperature effect on root elongation (figure 2-C) was not significantly different after 1 day of treatment (plus 3 days at 75° D.T.), but was for 3 or 5 days (plus 3 days at 75° D.T.) ($P<0.001$).

Plants in figure 2-D were given similar treatments as those in figure 2-C except they were not removed from their pots following temperature treatments. These plants (figure 2-D) are a check (plants were not removed from their pots between treatments and 3 additional days of growth at 75° D.T.) on those plants which were removed (figure 2-C). The effects of temperature and the time-temperature interaction were shown to be significant at $P<0.001$ (Appendix

Table 2-column D). Below 59°F there were no significant differences among treatments for the various lengths of exposure (LSDα0.05 = 0.187). Optimum root elongation occurred at lower temperatures (from 86° to 77°) with increasing lengths of treatments from 1 to 5 days (plus 3 additional days of growth). After 4 days (1 day treatment and 3 days at 75° D.T.) of growth there was a linear trend ($P<0.05$). The linear components for the graphs of 6 and 8 days of growth (3 or 5 days of treatment plus 3 days at 75° D.T.) are significant at $P<0.01$ and $P<0.001$ respectively (Appendix Table 2-column D).

Figures 2-C and 2-D show similar trends but different peaks depending on the length of exposure during treatment. Plants (figure 2-C) removed following temperature treatment (plus 3 days at 75° D.T.) had the most root elongation at 77°F for all 3 exposure times. Plants (figure 2-D) had the most root elongation at 86° for 1 day of growth (plus 3 days at 75° D.T.) and at 77° for 5 days of growth (plus 3 days at 75° D.T.). Root elongation (figure 2-D) at 86° and 77° was approximately the same after 3 days of growth (plus 3 days at 75° D.T.).

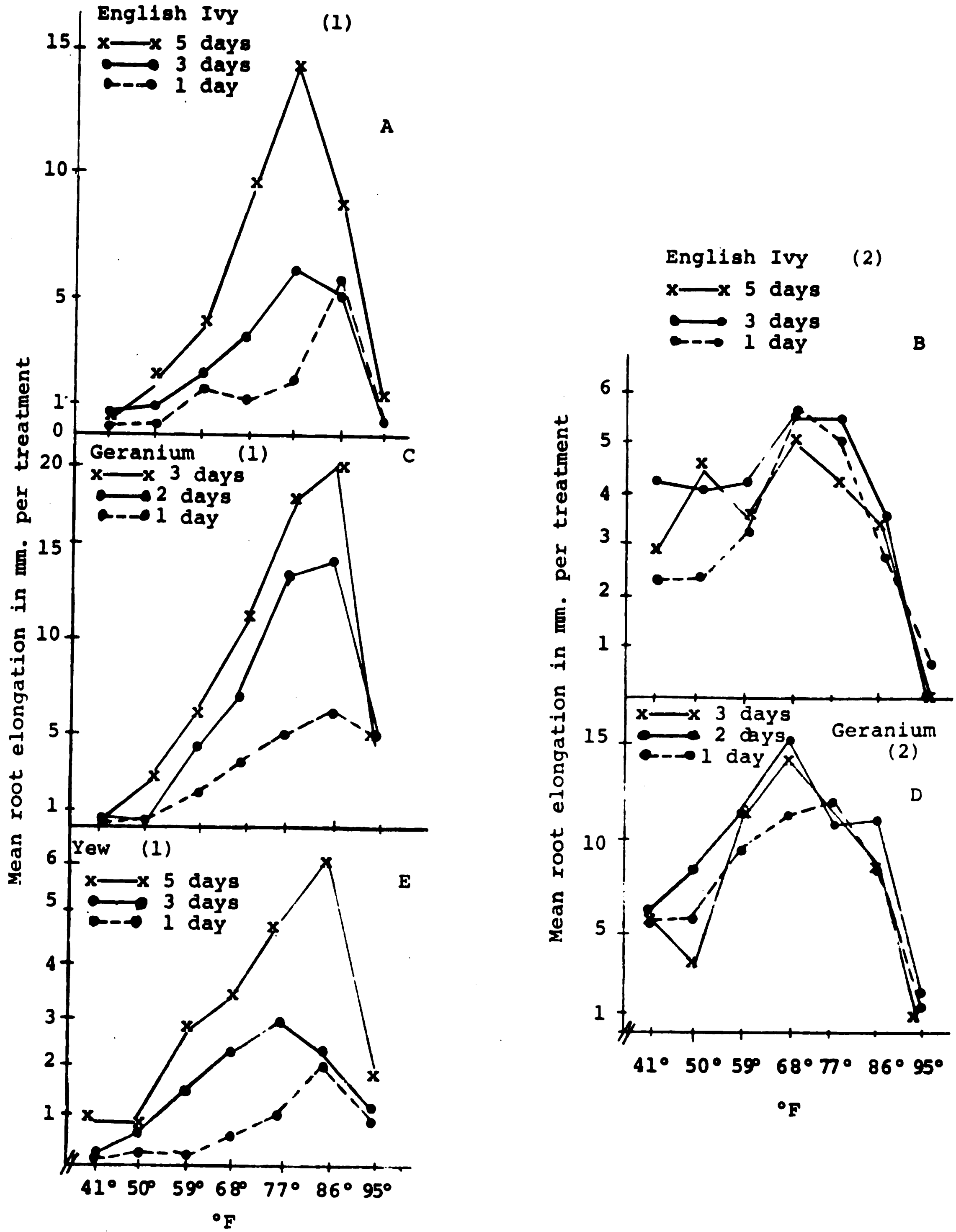
Poinsettia cuttings exposed to each temperature for 6 or 12 hours showed the greatest root elongation at 77°F, with less root elongation occurring both at higher and lower temperatures. Following 3 days of additional growth by each cutting at 75° D.T. the residual effect of temperature treatment for 6 or 12 hours was lost except for those plants exposed to 95°. The 95° residual effect was similar to that observed during a 3 day period after treatments of 1, 3, or 5 days.

<u>English Ivy</u>

The effects of time, temperature, and time-temperature interaction of English ivy during exposure for 1, 3, or 5 days at temperatures ranging from 41° to 95°F were significant at $P<0.001$ (Appendix Table 2-column E). Root elongation at 41°, 50°, 59°, or 95° was not significantly different for the 3 lengths of exposure ($LSD\alpha 0.05 = 0.322$). For 1 day of exposure the greatest root elongation occurred at 86° (figure 4-A) but the amounts of elongation at different temperatures were non-significant (Appendix Table 2-column E). Longer periods (3 or 5 days) of exposure brought the peak of root elongation to 77°. The differences were significant after 3 days of exposure ($P<0.05$) and after 5 days of exposure ($P<0.01$).

The residual effect of each temperature treatment on later root growth during a 3 day period at 75° D.T. and 67°F N.T. was significant at $P<0.01$ (Appendix Table 2-column F). There was no significant effect of time or time-temperature interaction on root elongation. The maximum root elongation occurred at 68° (figure 4-B) and showed a quadratic trend at $P<0.01$ after 3 or 5 days of treatment

Figure 4.--Means of English ivy, geranium, and yew root elongation: (1) during treatment, (2) during 3 day growth period after treatment.


English Ivy (1)
x——x 5 days
●——● 3 days
●---● 1 day
A
Geranium (1)
x——x 3 days
●——● 2 days
●---● 1 day
C
Yew (1)
x——x 5 days
●——● 3 days
●---● 1 day
E
Mean root elongation in mm. per treatment
41° 50° 59° 68° 77° 86° 95°
°F
English Ivy (2)
x——x 5 days
●——● 3 days
●---● 1 day
B
x——x 3 days
●——● 2 days
●---● 1 day
Geranium (2)
D
Mean root elongation in mm. per treatment
41° 50° 59° 68° 77° 86° 95°
°F

(plus 3 days at 75° D.T.) (Appendix Table 2-column F) and at $P<0.001$ for 1 day (plus 3 days at 75° D.T.). The lengths of exposure at each temperature resulted in non-significant differences among the treatments (LSDα0.05 = 0.201). Root elongation during a 3 day period after exposure at 95° for 5 days was less than for any other exposure period for English ivy (figure 4-B).

Geranium

Geraniums had maximum root elongation from treatment for 1, 2, or 3 days at 86°F (figure 4-C). Above or below 86° there was less root elongation. The peak at 86° was significant at $P<0.001$ for each length of exposure (Appendix Table 2-column G). The time, temperature, and time-temperature interaction all were significant at $P<0.001$ (Appendix Table 2-column G). The longer the exposure time the greater the amount of root elongation recorded at each temperature from 59° to 86°. Root elongation from different lengths of exposure (1, 2, or 3 days) at 41°, 50°, or 95° was non-significant (LSDα0.05 = 0.351).

Geranium roots previously exposed for 1 day (77°F), or 2 or 3 days (68°F) to treatments and 3 days of additional growth (75° D.T. and 67° N.T.) made maximum elongation (figure 4-D). The effects of the prior temperature treatment was significant at $P<0.001$ (Appendix Table 2-column H). The time and time-temperature interaction were not significant. The residual effect of length of exposure at 68° and 77° (after 3 days at 75° D.T.) were non-significant (LSDα0.05 = 0.588). The 3 growth curves showed the importance of previous temperatures on root elongation ($P<0.001$).

Yew

Yew roots had increased elongation as temperatures increased from 59° to 86°F and length of exposure increased from 1 to 3, or 5 days (figure 4-E). Very limited root elongation resulted from exposure to 41°, 50°, or 95° for 1 to 5 days and increases in root length were non-significantly different (LSDα0.05 = 0.155). The effects of time, temperature, and time-temperature interaction were $P<0.01$, $P<0.001$, and $P<0.05$ respectively (Appendix Table 2-column I). Maximum root elongation occurred at 77° after 3 days of exposure and after 1 or 5 days of exposure at 86°. Appendix Table 2-column I shows the extraction and significance of the linear, quadratic, and cubic components of the graphs (1, 3, or 5 days of treatment) in figure 4-E. Those values which were small and non-significant have been pooled in their respective residual value. There was a significant linear trend ($P<0.05$) after 1 day of exposure. The significant linear trend and complexity of the growth response increased with longer periods of exposure. Yew had no significant residual effect from treatment during a 3 day growth period following exposure.

Root Initiation from Base of Cutting

Each replication and each subsample at the same temperature showed a great deal of variability for the number of roots initiated at the base of the cutting. This applied to all plants studied.

Poinsettia

The number of roots initiated by poinsettia cuttings during treatment at different temperatures for 1, 3, or 5 days is shown in figure 5-A. The effect of time, temperature, and time-temperature interaction were all significant at $P<0.001$ (Appendix Table 3-column A). The largest number of roots were initiated at 86°F during 1 or 3 days of exposure and at 77° during 5 days of exposure. Few roots were initiated at temperature treatments below 59° or at 95°.

The number of poinsettia roots initiated during temperature treatments and an additional 3 days at 75°F D.T. are shown in figure 5-B. Above 50° the number of roots initiated increased with the period of exposure, except for treatments at 95°. Peak root initiation occurred at a lower temperature (figure 5-B) during 1 and 3 days of treatment and 3 days of additional growth than for root initiation during treatments (figure 5-A). After 3 days of additional growth the cuttings exposed to 77° for 5 days continued to have maximum root initiation (figure 5-B). The effects of time, temperature, and time-temperature interaction were significant at $P<0.001$ (Appendix Table 3-column B).

Figure 5.--Mean root initiation: (1) during treatment, (2) during treatment plus 3 day growth period after treatment, (3) during treatment but not removed prior to 3 day growth period after treatment.

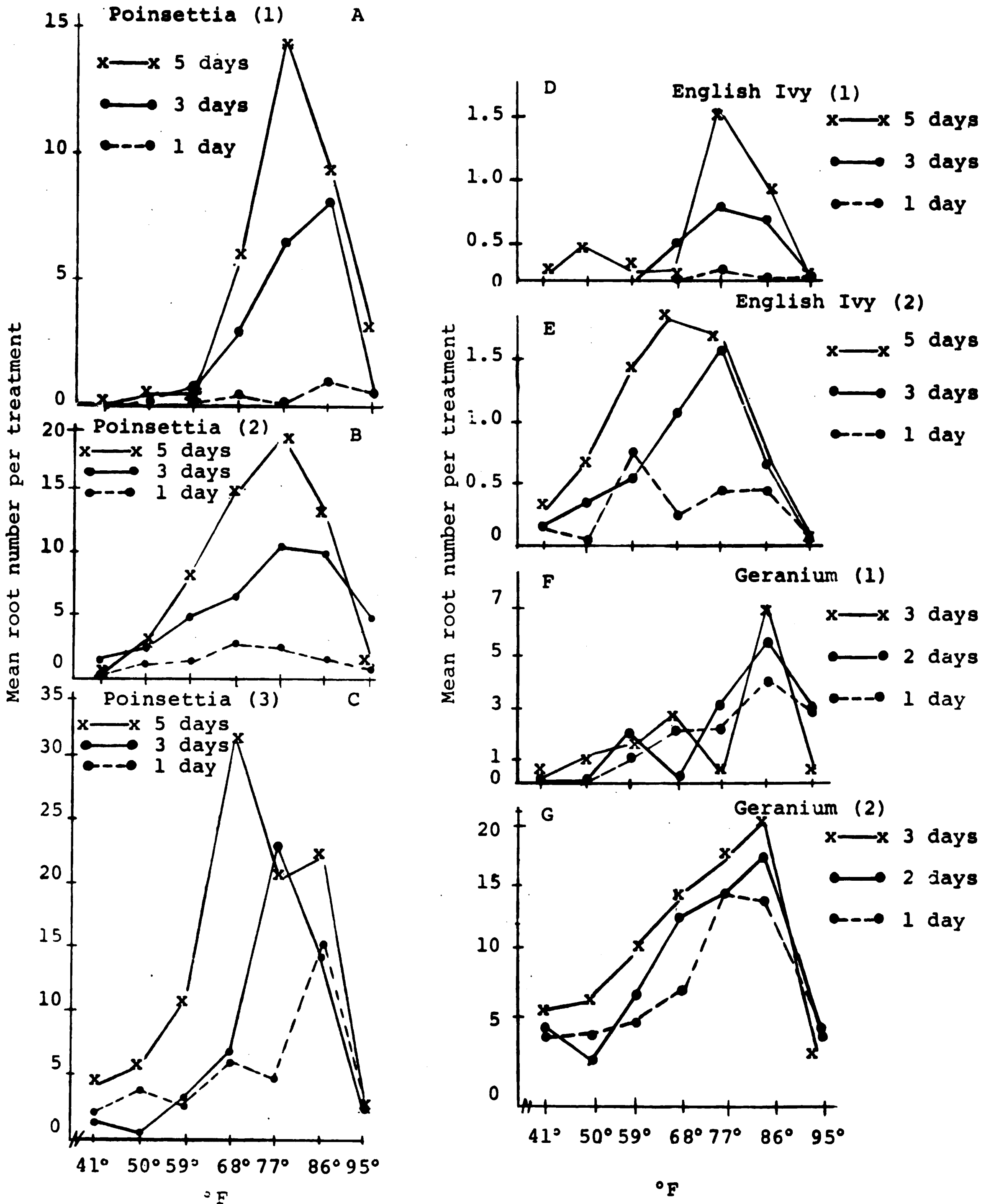

Poinsettia (1)
A
x—x 5 days
●—● 3 days
●---● 1 day
Poinsettia (2)
B
x—x 5 days
●—● 3 days
●---● 1 day
Poinsettia (3)
C
x—x 5 days
●—● 3 days
●---● 1 day
Mean root number per treatment
41° 50° 59° 68° 77° 86° 95°
°F
D
English Ivy (1)
x—x 5 days
●—● 3 days
●---● 1 day
English Ivy (2)
E
x—x 5 days
●—● 3 days
●---● 1 day
F
Geranium (1)
x—x 3 days
●—● 2 days
●---● 1 day
G
Geranium (2)
x—x 3 days
●—● 2 days
●---● 1 day
Mean root number per treatment
41° 50° 59° 68° 77° 86° 95°
°F

Figure 5-C shows the number of roots initiated by poinsettia cuttings kept at the various temperatures for 1, 3, or 5 days but not removed prior to 3 days of growth at 75° D.T. and 67°F N.T. The level of significance was: temperature $P<0.01$, time $P<0.001$, and time-temperature interaction $P<0.05$ (Appendix Table 3-column C). As the period of growth increased, the optimal temperature decreased from 86° for 4 days to 68° for 8 days (1 or 5 days of treatment and 3 days at 75° D.T.). The trends for roots initiated as shown in figure 5-C are similar to those observed in figure 5-B, although the total number of roots initiated are not. The graph of figure 5-C does not exhibit a smooth trend from 51° to 95° for any of the 3 treatments. Callused poinsettia cuttings did not show any trends of root initiation during 6 or 12 hours of temperature treatments, or with 3 days of additional growth at 75° D.T.

<u>English Ivy</u>

English ivy showed the effect of temperature ($P<0.01$) on root initiation while exposed to different temperatures for 1, 3, or 5 days (Appendix Table 3-column D). The effects of time and time-temperature interaction were non-significant. Most root initiation occurred at 77°F for all 3 exposure times (figure 5-D). The overall response of root initiation at all temperatures was slow during the short time periods used.

Figure 5-E shows the varied response of root initiation by cuttings of English ivy 3 days after temperature treatment. The response of cuttings to the effect of temperature was significant at $P<0.05$ (Appendix Table 3-column E). Time and time-temperature again were non-significant. Peak root initiation occurred at 59° after 4 days, 77° after 6 days, and 68° after 8 days (1, 3, or 5 days of treatment and 3 days at 75° D.T.) of total growth.

Geranium

Geraniums showed a significant effect of temperature ($P<0.001$) on root initiation (Appendix Table 3-column F) with the length of exposure and time-temperature interaction having no significant effect. Maximum root initiation occurred after 1, 2, or 3 days of exposure to 86°F (figure 5-F).

Root initiation during and 3 days after temperature treatments for geraniums showed similar levels of significance to that which occurred during treatments (Appendix Table 3-column G). Peak root initiation occurred 3 days after 1 day of exposure at 77° and after 2 and 3 days exposure at 86°F (figure 5-G). The residual effect of 95°was similar to that experienced during treatment.

Yew

Root initiation in cuttings showed only a random response regardless of temperature and length of exposure.

This was also true for cuttings which were grown for 3 additional days.

Root Anatomy

At treatments of 77°F or below, the roots of most cuttings did not appear to be more suberized than prior to the treatment. Roots of some cuttings grown at 86° for 3 or 5 days had brown root tips but this varied with cuttings. No geranium roots appeared to have brown tips after exposure to 86°. Roots of many cuttings after exposure to 95° for 3 or 5 days were either brown or black. In some cases the measurements were less after treatment than prior to 95° treatment. Root diameter varied more due to individual cuttings than to treatments.

Histological Observations

The distance of the first xylem element from the root tip varied with the treatment as shown in Table 1. The longer the exposure to 41°F the closer the first xylem element was to the root tip. The distance from the tip of the root to the first xylem element progressively increased for temperature treatments from 41° to 77°, except for the root exposed to 50°. This distance again decreased as treatment temperatures rose from 77° to 86° and 95°F. Figure 7 shows the first observable xylem element for roots grown at 41° for 1, 3, or 5 days plus 3 days additional growth at 75° D.T. and 67° N.T. The first

TABLE 1.--Histological measurements of poinsettia roots 3 days after treatment.

		Cell No. Within 0.4 mm. Back From					
		Vascular	Cortex				
Temp. of Treatment (No) days	mm. to 1st Xylem Element	Meristem	Meristem	0.5 mm. From Meristem	1st Xylem Element	2.0 mm. From Root Top	4.0 mm. From Root Top
41°F (1)	1.5		25	9	5	5	9
41°F (3)	0.8	26	29	11	13	10	7
41°F (5)	0.7	26	25	11	25	8	6
50°F (5)	0.5	18	24	12	17	10	7
59°F (5)	1.3	26	27	13	9	7	6
68°F (5)	2.1	24	30	8	11	9	11
77°F (5)	2.5	27	33	14	6	7	7
86°F (5)	2.0	24	29	8	6	5	5
95°F (5)	0.3	21	13	5	7	6	7

Figure 6.--Comparison of position of first xylem element in poinsettia roots at different temperatures or exposure times as shown in figures 7 and 8.

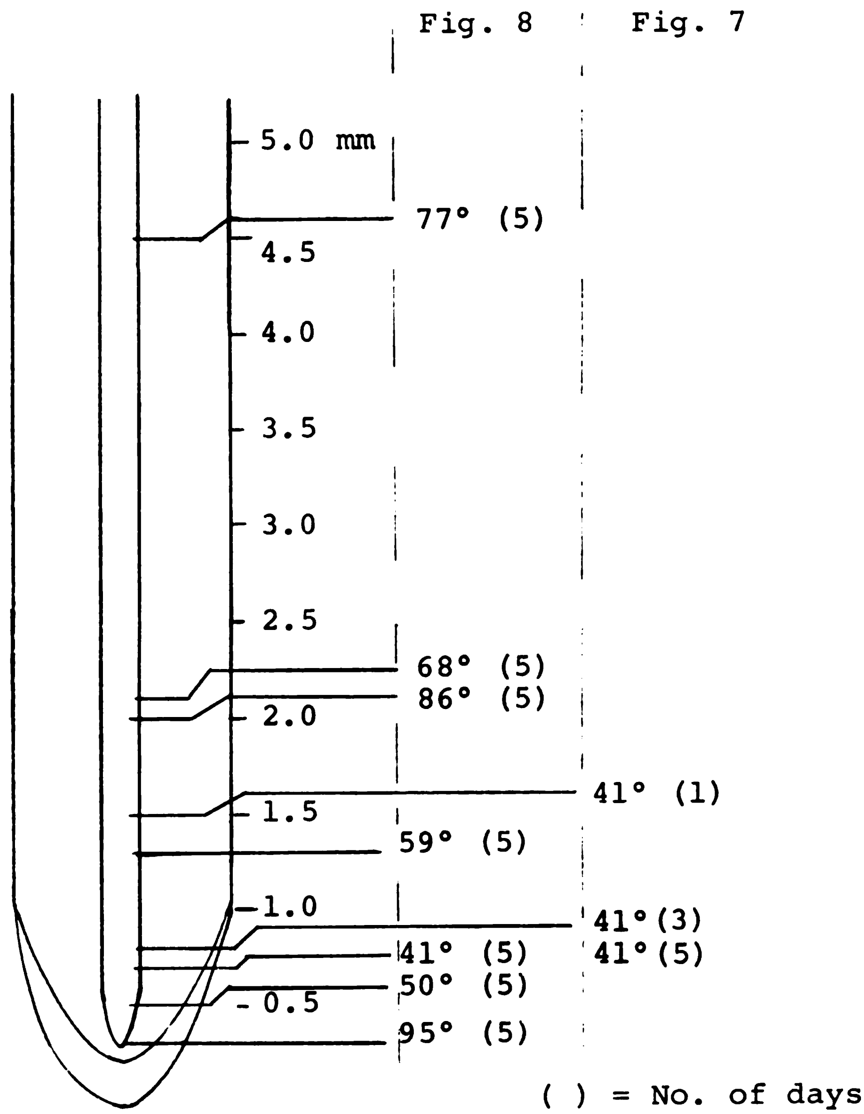
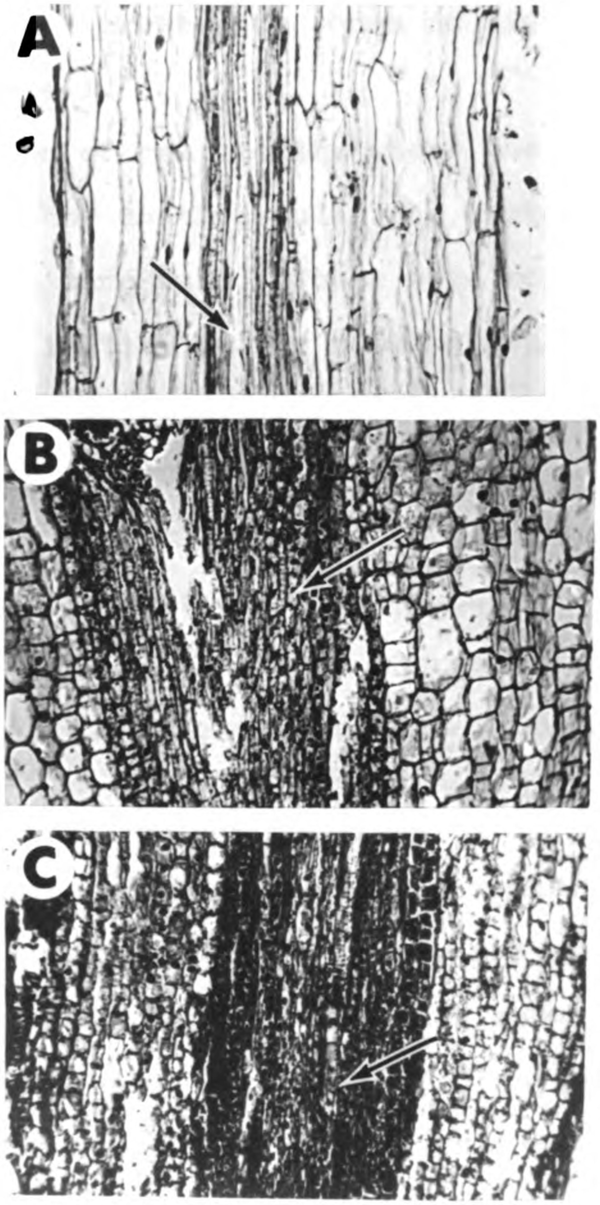


Fig. 8
Fig. 7
5.0 mm
77° (5)
4.5
4.0
3.5
3.0
2.5
68° (5)
86° (5)
2.0
41° (1)
1.5
59° (5)
1.0
41°(3)
41° (5)
41°(5)
50° (5)
0.5
95° (5)
( ) = No. of days

Figure 7.--A comparison of the length of treatment at 41°F on the position of the first xylem element in poinsettia roots. Plants were grown at 41°F for (A) 1 day, (B) 3 days, and (C) 5 days plus 3 days at 75° D.T. and 67° N.T. before sections were taken.


A
B
C

xylem element for roots grown for 5 days at 41° through 95° plus 3 days additional growth (75° D.T.) are shown in figure 8. Cell number counts for the roots from the various temperature treatments shown in figures 7 and 8 are given in Table 1.

A comparison of cell counts where the first xylem element appears show that vascular and cortex cells do not mature at the same rate. There were more cortex cells in the region of initiation for roots grown at 77°F than at higher or lower temperatures. Cortex cell size 2 mm. from the root tip show no discernable trend due to temperature. The number of cortex cells 4 mm. back were related more to general root diameter than to treatments. Treatment of 95° caused an abrupt increase in cortex cell size due to a very short region of elongation.

Tissue Analysis

The 3 cuttings (minus callus and roots) form each treatment were combined for the tissue analysis (Table 2). The cuttings from the propagation bench showed less of those elements tested except for Ca, Mn, and B as compared to cuttings from treatments. A comparison of this analysis with poinsettias to one by Criley and Carlson (11) (Criley and Carlson used the most recently mature, fully expanded leaves--no stems) was done. It was found that the amounts of all elements except Na, Ca,

Figure 8.--Comparison of the effect of different 5 day medium temperatures on the position of the first xylem element in poinsettia roots. Plants were grown at (A) 41°, (B) 50°, (C) 59°, (D) 68°, (E) 77°, (F) 86°, or (G) 95° for 5 days plus 3 days at 75° D.T. and 67° N.T. before sections were taken.

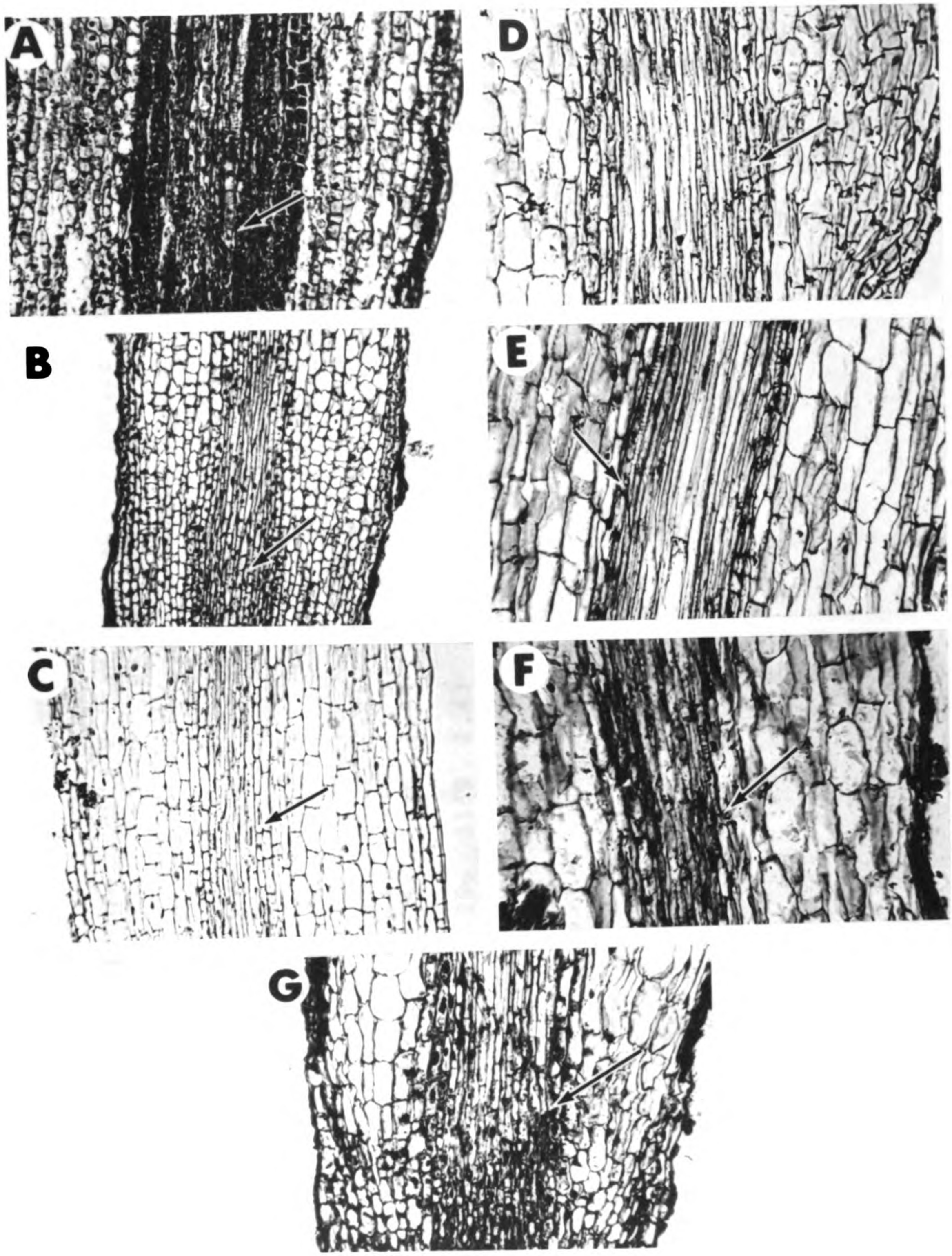

A
B
C
D
E
F
G

TABLE 2.--Tissue analysis (mean of 3 foliar samples) of entire poinsettia cutting without callus and roots.

Sample (No) days	N %	K %	P %	Na ppm	Ca %	Mg %	Mn ppm	Fe ppm	Cu ppm	B ppm	Zn ppm	Al ppm
41°F (5)	2.28	1.56	.308	1216	1.36	.36	51	124	11.4	12.9	95	21
68°F (5)	2.76	1.98	.447	1682	2.07	.50	70	200	15.6	19.1	119	36
95°F (5)	2.36	1.62	.357	1216	1.33	.36	56	153	11.4	15.7	95	24
Pro. Bench	1.94	1.42	.286	1169	1.43	.33	62	124	10.7	15.7	84	21

Cu, and Zn were below those values given by Criley and Carlson. Work done by Carlson and Bergman (9) with 'Better Times' rose plants illustrated that N, P, K, Ca, Mg, Mn, Fe, Cu, and B are in larger concentrations in the upper leaves than upper stems. For this reason the low values (as compared to the analysis by Criely and Carlson) found in this study for N, K, P, Mg, Mn, Fe, B, and Al are believed to be caused by a dilution effect which resulted from the stem tissue being analyzed with the leaves. Also, at most only 1 leaf per cutting was fully mature. The poor growth at the extreme temperatures (41° and 95°F) for the short period of time of this study was not due to a measurable deficiency of the analyzed elements present in the plant tissue.

DISCUSSION

Poinsettia

There is no stated recommended optimum soil temperature or temperature range for poinsettia root elongation or initiation. Poinsettia medium temperature recommendations have been confined to plant propagation. Miller (31) stated that previous to 1960 a medium temperature of 65°F was recommended for propagation. Later, however, medium temperatures of 70°F have been recommended (27, 31). The Paul Ecke Poinsettia Co. is recommending for 1971 that cvs. Eckespoint C-1 Red and Pink be directly rooted in 6 inch pots at 75° night and 80° day greenhouse air temperatures. The results of this study indicated that as medium temperatures increase above 70° there is increased root elongation and initiation. The literature indicates only a few plants have maximum root elongation or initiation at temperatures below 70° (4, 23, 33, 36).

Poinsettias in this study had maximum root elongation after 5 days at soil temperatures of 77°F (Table 3). After 6 hours at 77° an increase of root growth was seen as compared to higher (95°) or lower (50°, 59°, or 68°) temperatures. The root elongation after 5 days at 77° was significantly greater than that for a comparable

TABLE 3.--Optimum medium temperatures in °F for root elongation and root number of callused cuttings of poinsettia, English ivy, geranium, and yew.

Temperature	Poinsettia			English Ivy			Geranium			Yew	
	Days	Root Length	Root No.	Days	Root Length	Root No.	Days	Root Length	Root No.	Days	Root Length
During	1	77°	86°	1	86°	77°	1	86°	86°	1	86°
treatment	3	77°	86°	3	77°	77°	2	86°	86°	3	77°
	5	77°	77°	5	77°	77°	3	86°	86°	5	86°
Effect of	1	77°	68°	1	68°-77°	59°	1	77°	77°-86°		
treatment 3	3	77°	77°-86°	3	68°-77°	77°	2	68°	86°		
days later	5	77°	77°	5	68°	68°-77°	3	68°	86°		

period at 68° and 86°. Poinsettia root elongation at 77° treatment was significantly greater with increased length of exposure (1, 3, or 5 days). Although from 1 day at 77° more root elongation occurred than at other 1 day treatments the differences were non-significant. Also, root elongation differences from increased length of exposure (1, 3, or 5 days) at 41°, 50°, 59°, or 95° and 3 days at 68° were not significantly greater than 1 day at 77°. These results were unexpected for temperatures of 59°, 68°, and 95° but not for 41° and 50°. Poinsettia roots given 50° or below made no elongation after 6 or 12 hours.

Poinsettia roots remained white and fleshy from treatments at 41°, 50°, 59°, 68°, and 77°F, while root tips in treatments of 86° and 95° became suberized. These trends have been reported before, but they vary with the temperature that gives optimum root growth (3, 33, 34). Many roots at 95° soil temperatures became dark brown or black. Black roots generally appeared to be dead.

Poinsettia root initiation also was greatest after 5 days at 77°F soil temperatures (Table 3). Treatment for 1 or 3 days at 86° gave good root initiation, and differences between 86° and 77° were small. The treatments showed variability based on the ability of individual cuttings to initiate roots. As was seen in root elongation, length of exposure (1, 3, or 5 days) at unfavorable temperatures of 41°, 50°, 59°, or 95° does not increase root initiation except for a few of the more vigorous cuttings. Unlike root elongation, treatments of 77° or 86° for less than 1 day (6 or 12 hours) had no effect on root initiation.

A residual after treatment effect of temperature on root elongation was found for treatments for 1 day or longer at all soil temperatures (41°-95°F). This was unlike Silver maple which showed a residual effect 3 days after exposure to soil temperatures of only 50° or below (36). The trends established for root elongation during treatments for 1, 3, or 5 days continued during a 3 day period when all plants had been growing at 75° (Table 3). Treatments of less than 1 day had no residual effect except at 95°. This will be discussed later. The root elongation from 5 days at 77° was significantly greater than for 5 days at 68° and 86°, or 3 days at 77°. Root growth during 3 days after 1 day at 77° was significantly greater than other temperature treatments of 1 day. Three days after treatment the only 5 day treatments which had significantly more root elongation than 3 day treatments at similar temperatures were 68° and 77°.

Treatment at 95°F for 6 or 12 hours caused reduced root growth which continued during a 3 day period at 75° following treatment. Both the 50° and 95° treatments for 6 or 12 hours reduced root growth, but unlike the 95°

treatment there was no reduction during 3 days following 6 hours at the 50° treatment. The number of dead from the 95° treatment, varied with individual cuttings. Exposures to 95° for 6 hours may have disrupted the process of root elongation. The decrease in cell numbers seems to explain this. Microscopic examination showed roots grown for 5 days at 95° had a very short region of elongation when compared with roots at the other temperatures. This also has been reported for Loblolly pine (3). A possible answer is that temperatures of 95° retarded the "pre-ordained intercellular program" for cell division (17) or accelerated processes controlling cell elongation (17). Mineral element deficiency is not an answer.

Callused poinsettia cuttings during a 3 day period at 75° after 1 or 3 days of treatment continued not to show the same optimum temperature for root initiation as the 5 day treatments. Differences in the mean numbers of roots initiated during a 3 day period after 1 day of treatment at 68°, 77°, or 86° was at most 1.5 roots per cutting. During a comparable period of time for 3 day treatments of 77° or 86° the difference was less than a mean of 1 root per cutting. The 3 day period after the 5 day treatment showed cuttings which had been exposed to 59° or 68° averaged 8 new roots per cutting as compared to an average of only 4 new roots by cuttings which had been exposed to 77° or 86°. The total number of roots initiated during the 8 day growth period (5 days of treatment and 3 days 75°) was greatest for the 77° treatments. Treatments of 50° to 95° for less than 1 day (6 or 12 hours) showed no trends of enhanced root initiation 3 days later.

Length of exposure (1, 3, or 5 days) at 59° did not increase the number of roots initiated. There was a direct correlation between length of exposure and the number of roots initiated during the 3 day period of additional growth. This indicates that a fluctuating temperature of 1 day at 59° and then 75° is more harmful than longer exposures at 59° and raised to 75°.

It appeared that the peak elongation of 5 days at 77°F is the optimum temperature for utilization of stored carbohydrates as suggested by Richardson (36). A stimulating effect in the roots was present 3 days after treatments of 77°. The amount of elongation was significantly greater 3 days after the 5 day treatment at 68° or 77° than after a comparable 3 day treatment. The resulting longer roots from 77° treatment were caused by an increase in cell number. This resembles the temperature treatment response of onion bulb roots (29, 30). Mineral element content was not measurably changed during 5 days of 41°, 68°, or 95° treatment. The distance of the first observable xylem element indicates that roots at 77° were growing at a more rapid rate (15). Root initiation was more rapid 3 days after treatment at 68° than at 77°. However, total initiation during and after treatment was greatest for 77°. A soil temperature of 77° gave maximum root elongation and initiation during 5 days of treatment and 3 days additional growth. This effect on elongation was present after only 6 hours of treatment, but had no residual after effect.

Soil temperature effect on root initiation may be the combined interaction of growth regulators, inhibitors, and co-factors (13). The interaction of growth regulators, co-factors, and temperatures have not been studied for poinsettias or any of the other plant species in this study. Richardson (36) alone has acknowledged the residual after effect of temperature on plant root growth.

A comparison of root elongation was made using callused poinsettia cuttings. Some were removed from their pots after treatment, measured, and repotted while others remained undisturbed during the entire growth period. Cuttings grown for 5 days at treatments of 41° to 95° and 3 days at 75° whether removed or not showed the same trends. In both cases plants which had received the 77° treatments had significantly more root elongation than 5 days at 68° and 86° or 3 days at 77°. Maximum root elongation during the 1 and 3 day treatments did not show the same peaks (86° for plants not removed and 77° for plants removed). It is believed that the variability among cuttings caused this difference. The mean of removed cuttings was lowered by several poor replications whereas the mean for cuttings not removed was not. The cuttings not removed consisted of the mean of only 2 replications, while those removed had 5 replications.

Root initiation was also compared for cuttings either removed or not prior to the 3 day period (75°) after treatment. The interpretation of the root count indicated that plant removal had damaged roots and gave a lowered root number. By comparing the response of each 5 day treatment replication for cuttings removed or not it was shown that this wasn't the case. The 68° treatment, for cuttings not removed, (consisting of 2 replications) was distorted when 1 replication made an unusually large response. The other replication at 68° and those at 77° or 86° were not larger than the responses recorded for cuttings at similar temperatures which were removed. The mean of removed cuttings (consisting of 5 replications) again was lowered by several poor replications whereas the mean for cuttings not removed wasn't lowered.

English Ivy

There are no optimum soil temperatures for the propagation of English ivy reported in the literature. A bottom heat between 65 to 75 F (19) is commonly recommended. This study indicates that an increase in bottom heat gives improved root elongation and initiation.

English ivy had significantly more root growth after 5 days at 77°F (Table 3) than 5 days at 68° or 86°. Root elongation was significantly greater with increased length of exposure (1, 3, or 5 days) to 77° treatments. As with poinsettias, elongation was not significantly increased by the length of exposure (1, 3, or 5 days) at 51°, 50°, 59° or 95° and 1 or 3 days at 68°. The effect of 1 day treatment was distorted when 1 replication from the 86° treatment made an unusually large response. Without this 1 replication the results for 77° and 86° would be similar. However, the amount of elongation at any temperature treatment for 1 day was not significantly different from any other. Five days at 41°, 50°, 59°, or 95° does not significantly increase the amount of root growth over that of 1 day at 77° or 86°.

Root initiation from callused English ivy cuttings was most rapid during treatments of 77°F for 5 days (Table 3) as for poinsettias. The length of exposure was not significant but effect of temperature was. The root initiation response was slow. The maximum root initiation was after 5 days at 77° but averaged only a little more than 1 new root per cutting. Treatments of 41° or 95° produced no new roots on any replication even after 5 days. Treatments of 50°, 59°, and 68° varied in response depending on the vigor of individual cuttings, and produced few new roots.

The effect of temperature on ivy root elongation was not lost after 3 days (during which all plants were at 75°) though 68°F treatments had slightly more elongation than the 77° treatment. The difference was less than a mean of 1 mm. total root elongation per cutting. The length of treatment did not significantly change root elongation during the 3 day growth period after treatment. Root elongation during 3 days after treatments at 68° or 77° was significantly larger than at higher (86° and 95°) or lower (41°, 50°, and 59°) temperatures. The harmful after-effect of 95° treatment was present to a greater degree than for poinsettias. Though English ivy cuttings had fewer dead roots than poinsettia cuttings, few ivy roots showed any growth. Many roots turned a dark brown while a few were black and appeared dead. This response varied among individual cuttings. Roots remained white and fleshy until soil temperatures of 77° were exceeded then roots became completely suberized. Complete suberization did not occur frequently after 1 day of exposure to a soil temperature of 95° but did after 3 days (75°) additional growth. Three days after 5 day treatment at 95° mean total root length decreased. The death and shrinking of some roots combined with no growth by other roots caused this. The roots from treatments of 41° to 77° were not changed noticably in appearance 3 days after treatments.

Maximum root initiation occurred during 3 days at 75° after 5 days of 68°F treatment (Table 3). The effect of temperature treatment for 3 or 5 days was not lost. The root number for cuttings grown for 8 days (5 days of treatment and 3 days after at 75°) was very small (averaging less than 2 roots per cutting). The length of exposure during treatment did not significantly increase the number of roots initiated during a 3 day period after treatment, but temperature of the treatment did. This was expected since treatments for 1 or 5 days did not significantly increase the number of roots initiated but the temperature of the treatment did.

During the study of English ivy root growth, there were some secondary roots initiated, but the number was not counted. Possibly the "root-regenerating potential" (26, 42) would have given a clearer indication of English ivy root activity. A soil temperature of 77°F gave significantly greater English ivy root elongation and initiation than higher (86°-95°) or lower (41°-68°) temperatures. This could be the ideal temperature for utilization of carbohydrates (36) and other internal processes (17) for root growth. Root initiation though significantly increased at soil temperatures of 77° was not rapid. Residual temperature effects on the third day after treatments of 68° or 77° gave approximately the same response for root elongation and initiation. Higher (86°-95°) and lower (41°-59°) temperatures gave a decreased response.

Geranium

Callused geranium cuttings had significantly more growth after 1, 2, or 3 days at soil temperatures of 86°F than corresponding lengths of exposure at higher (95°) or lower (41°-77°) temperatures (Table 3). The more rapid response of geranium cuttings than poinsettia and ivy necessitated the use of 1, 2, or 3 day periods of treatment instead of 1, 3, or 5 days. Length of exposure (1, 2, or 3 days) at 41°, 50°, and 95 did not significantly increase the amount of root growth, but did after 68°, 77°, and 86° treatments.

Treatment of callused geranium cuttings at 86°F for 1, 2, or 3 days also gave maximum root initiation. The length of exposure was not significant at any temperature.

Three days after treatment (during which all plants were at 75°F) geraniums showed a residual temperature effect. Roots which had been exposed to 77° for 1 day or 68° for 2 or 3 days had maximum root elongation as compared to other roots exposed for a comparable period of time. It was observed that on the third day after the 5 day treatment of 68° root elongation was significantly increased compared to 5 day treatments of 59° or 77°.

The inhibitory residual temperature after effect of 95°F was seen clearly with geranium cuttings. As with English ivy, 3 days after treatment geranium roots exposed

95° showed less growth than roots exposed to other temperatures (41°-86°). Some roots given 95° temperatures appeared dark brown or black and dead, but the number discolored was less than that observed on poinsettia cuttings. Here an increase in 9°F separated optimum root growth from a level causing the death of the root or greatly reduced growth. Brouwer (5) also observed at high temperatures a narrow range between a favorable and harmful temperature. Generally, roots were white and fleshy for treatments of 41° to 86° for 1, 2, and 3 days.

Root initiation during and 3 days after treatment (during which all plants were grown at 75°F) had the same trend as during treatment. Length of treatment was not significant. It is observed by comparing figures 5-F and 5-G that during the 3 day period (75°) of additional growth treatments of 68° to 86° for 2 or 3 days initiated roots at a similar rate and were only continuing the already established trend. Root initiation was maximum over the 6 day growth period (3 days of treatment and 3 days at 75°) by cuttings from the 86° treatment. There was great variability between cuttings in their ability to initiate roots regardless of temperature and length of exposure.

A bottom heat of 65° to 75°F has been recommended to hasten propagation of geranium cuttings (35). Both root elongation and initiation were significantly increased with a rise in temperature for 1 day. Possibly the optimum temperature of 86° for geraniums is due to larger quantity of carbohydrates as compared to poinsettias or is optimum for processes in geraniums. The nature of this response is unknown. It also is not known if medium temperatures of 86° were continued for longer periods if the optimal temperature for geranium root elongation and initiation would be the same. It would be assumed that under normal conditions the leaves would continue to make carbohydrates available to root meristemes to continue this trend. After 5 days at treatments of 77° and 86° roots were too numerous to obtain an accurate number without removing them as they were counted. Few plants have been reported as having maximum root elongation and initiation at as high a soil temperature as 86° (5, 28, 43).

Yew

It has been reported that yew had earlier root growth when exposed to 80°F than lower soil temperatures (9). Yew cuttings had significantly greater root growth after exposure to optimum medium temperature of 77° and 86° (Table 3). The overall response of yew cuttings was very small regardless of temperature. After February, coniferous root activity begins to decrease (15, 16, 26, 27). These tests were conducted in mid and late April which could in part explain the small response. No yew roots developed a red tip during or 3 days (75°) after treatments. This has been reported as being characteristic of dormant *Taxus cuspidata* roots (27).

There were no significant trends of root elongation 3 days (75°F) after treatments. Primary root initiation showed no significant trends during or after treatment. This seemed to result from the slow response of yew roots. A soil temperature of 86° increased root elongation but had no effect on root initiation during the 8 day period (5 days of treatment and 3 days at 75°) used in this study.

SUMMARY AND CONCLUSION

Callused poinsettia cuttings had maximum root elongation and initiation after exposure to 77°F soil temperatures. The 77° treatment had significantly more root elongation than the other temperature treatments after only 6 hours. Root initiation was not changed after 6 or 12 hours at any temperature. Length of exposure (1, 3, or 5 days) at 41°, 50°, 59°, or 95° did not significantly increase the amount of root elongation and initiation. The reduced growth at 51° or 95° as compared to 68° was not due to a measurable mineral element deficiency.

Poinsettia cuttings exposed to 77° during treatment continued to show maximum root elongation and initiation on the third day after treatment. The longer roots at 77° treatments were the result of an increase in cell numbers. No residual effects on root elongation and initiation were found from soil temperature treatments of 41° to 86° for 6 or 12 hours. The residual effect of all 95° treatments (6 or 12 hours and 1, 3, or 5 days) caused a complete suberization of root tips and killing of some roots.

English ivy callused cuttings had maximum root elongation and initiation after exposure to 77°F medium temperatures, although this trend was not significant until 3 days of treatment. Root initiation was slow even at 77° treatments. Medium temperatures of 68° and 77° had the least residual effect on root elongation and initiation 3 days after treatment. Three days after 1, 3, or 5 days of 95° treatment many roots showed no growth and some died. No root initiation occurred during or after 95° treatments.

A medium temperature of 86° gave optimum callused geranium cutting root elongation and initiation. Root elongation was greatest 3 days after 1, 2, or 3 days of 59°, 68°, or 77° treatments. The harmful residual effect of 95° treatment was present after all exposure times (1, 2, or 3 days). Treatments of 86° produced the maximum number of roots for the total length of the study (during and after treatment).

Considerable variability in root elongation and initiation resulted when callused yew cuttings were given the various temperature treatments. Optimum root elongation occurred after 77° and 86° treatments, but there was no optimum temperature range for root initiation because of cutting variability. The effect of temperature did not have significant trends on root elongation and initiation on the third day after treatment. It is believed that the slow response in this study was due in part to the inactive condition of the yew roots.

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APPENDICES

APPENDIX A

Appendix Table 1.--Mean 24-hour medium temperatures.[1]

	Treatments						
Days	41°F	50°F	59°F	68°F	77°F	86°F	95°F
Poinsettia							
1	40° (-1+4)[2]	59° (-1+1)	59° (-2+1)	67° (-2+1)	77° (-1+2)	86° (-1+1)	95° (-1)
2	40° (-2+1)	50° (-2+1)	58° (-1+2)	66° (-1+2)	77° (-1+1)	86° (-1+1)	95° (0)
3	40° (-2+4)	49° (-2+1)	58° (+1)	66° (-3+2)	77° (-2+2)	86° (+1)	95° (-2)
4	40° (-2+1)	49° (-1+1)	59° (+1)	66° (+1)	78° (-3+1)	86° (-1+1)	94° (-2+1)
5	40° (-1+1)	49° (-1+2)	59° (-1+1)	67° (-2+3)	78° (-2+3)	86 (-1+1)	94° (-1+1)
Poinsettia #2[3]							
1	38° (0)	49° (1)	58 (0)	68° (-2+1)	77° (-1+1)	86° (-1)	94° (-2+1)
2	39° (-1+1)	50° (-1)	60 (-1)	68° (-1+1)	78 (-1+1)	87° (-1)	96° (0)
3	40° (-1)	49 (-1+1)	59° (-1)	67 (0)	81° (-2+2)	87° (-1)	97° (-1)
4	40° (0)	51° (-1)	60 (-1)	69 (-1+1)	80 (-1+1)	87° (0)	96° (0)
5	41° (0)	51 (-1)	60 (-1+1)	70 (-2+1)	79 (-2+2)	87 (0)	98 (-2+1)
English ivy							
1	40 (-1+1)	50 (-1)	59 (-1)	67 (-1+1)	77 (+1)	86 (0)	96 (-2+1)
2	39 (-1+1)	50 (-1)	59 (-1+1)	67 (-1+2)	77 (-1+1)	86 (-1+1)	95 (-1+1)
3	39 (-1+1)	50 (-1+1)	59 (-1+1)	68 (-3)	78 (-1)	86 (-1)	95 (+1)
4	40 (-2)	50 (-1)	59 (+1)	68 (-2)	77 (+1)	86 (0)	95 (-1)
5	39 (-1+1)	49 (-2+2)	59 (-1)	66 (-1+2)	77 (-1+2)	86 (-1+1)	95 (-1)
Geranium							
1	40 (-1+1)	49 (-1)	59 (-1+1)	66 (-1+1)	77 (-1+2)	85 (+1)	95 (+1)
2	40 (-2+1)	50 (-1)	58 (-1+2)	67 (-3+3)	78 (-1+3)	86 (-1+1)	95 (+1)
3	39 (+1)	49 (+1)	58 (-1+1)	66° (+1)	77° (+1)	86° (0)	95° (+1)
Taxus							
1	39° (-2+1)	50 (-1)	59° (-1+1)	67 (-1)	79° (-2+2)	88° (-1)	95° (-1)
2	40° (-1)	49° (-2+1)	58° (-1+1)	66° (-1)	79° (-2+1)	87° (-1)	95° (0)
3	40° (0)	50° (-1)	60° (-1)	66° (0)	79° (-1+1)	87° (-1)	95° (0)
4	40° (-1)	51° (-1)	59° (-1)	65° (-1+1)	77° (-1)	86° (0)	94° (-2+1)
5	42° (-3+2)	51° (-1+1)	60 (-1)	67° (-2+1)	79° (0)	86° (0)	93° (-2+2)

[1]The mean 24-hour medium temperatures were calculated from the mean 24-hour temperature for each replication.

[2]The number in parenthesis represent the maximum temperature deviation from the mean per replication.

[3]Poinsettia #2 plants were grown for 1, 3, or 5 days at the 7 different medium temperatures but not removed from their pots prior to the 3 days growth at 75° D.T. and 67°F N.T.

Appendix Table 2.--Mean squares from table of variance for root elongation.

Source	df	Poinsettia A	Poinsettia B	Poinsettia C	df	Poinsettia D	df	English Ivy E	English Ivy F	df	Geranium G	Geranium H	df	Yew I
		(1)	(2)	(3)		(4)		(1)	(2)		(1)	(2)		(1)
Temp.	6	1.991^{xxx}	0.650^{xxx}	4.634^{xxx}	6	3.195^{xx}	6	1.087^{xxx}	0.327^{xx}	6	2.182^{xxx}	1.435^{xxx}	6	0.079^{xx}
Blocks	4	0.206	0.112	0.667	1	0.295	3	0.850	0.465	2	0.730	0.240	1	0.061
Error A	24	0.145	0.062	0.312	6	0.215	18	0.132	0.063	12	0.080	0.107	6	0.005
Time	2	2.753^{xxx}	0.554^{xxx}	5.225^{xxx}	2	1.956^{xxx}	2	1.202^{xxx}	0.027	2	1.566^{xxx}	0.086	2	0.167^{xxx}
Time x temp.	12	0.478^{xxx}	0.082	0.844^{xxx}	12	0.659^{xx}	12	0.221^{xxx}	0.013	12	0.233^{xxx}	0.035	12	0.013
Q_1 linear	1	0.174	0.003	0.247	1	1.484^{x}	1	0.234	0.013	1	0.883^{xxx}	0.003	1	0.036^{x}
Q_1 quad.	1	0.046	0.298^{x}	0.488	1	0.001	1	0.083	0.495^{xxx}	1	0.025	1.660^{xxx}		
Q_1 cubic	1	0.030	0.083	0.224	1	0.229	1	0.231	0.085	1	0.089	0.321		
Q_1 resid.	3	0.007	0.005	0.017	3	0.151	3	0.146	0.025	3	0.002	0.016	5	0.004
Q_2 linear	1	1.024^{xxx}	0.209^{x}	2.029^{xxx}	1	1.984^{xx}	1	0.214	0.199^{x}	1	2.585^{xxx}	0.105	1	0.062^{xx}
Q_2 quad.	1	0.482^{x}	0.586^{xx}	2.392^{xxx}	1	1.150^{x}	1	0.590^{x}	0.414^{xx}	1	0.994^{xxx}	2.837^{xxx}	1	0.050^{x}
Q_2 cubic	1	0.929^{xxx}	0.291^{x}	1.996^{xxx}	1	1.961^{x}	1	0.521^{x}	0.158^{x}	1	1.743^{xxx}	0.235		
Q_2 resid.	3	0.161	0.092	0.320	3	0.065	3	0.013	0.004	3	0.064	0.105	4	0.003
Q_3 linear	1	3.862^{xxx}	0.507^{xx}	6.771^{xxx}	1	3.501^{xxx}	1	0.899^{xx}	0.142^{x}	1	3.384^{xxx}	0.116	1	0.170^{xxx}
Q_3 quad.	1	3.808^{xxx}	1.890^{xxx}	11.813^{xxx}	1	10.124^{xxx}	1	3.677^{xxx}	0.420^{xx}	1	2.689^{xxx}	2.958^{xxx}	1	0.106^{xx}
Q_3 cubic	1	4.655^{xxx}	0.205^{x}	7.099^{xxx}	1	5.504^{xxx}	1	1.950^{xxx}	0.044	1	2.836^{xxx}	0.275	1	0.137^{xxx}
Q_3 resid.	3	0.720^{xx}	0.175	1.287^{xx}	3	0.163	3	0.037	0.018	3	0.153	0.587^{x}	3	0.012
Error B	56	0.048	0.064	0.114	14	0.152	42	0.053	0.021	28	0.045	0.074	14	0.005

Level of significance--x=0.05, xx=0.01, xxx=0.001. (1) During treatment. (2) During 3 period after treatment. (3) Combined elongation of A and B. (4) Cuttings not removed prior to 3 day growth period.

Appendix Table 3.--Mean squares from table of variance for root initiation.

	Poinsettia					English Ivy			Geranium		
Source	df	A	B	df	C	df	D	E	df	F	G
		(1)	(2)		(3)		(1)	(2)		(1)	(2)
Temp.	6	6.483^{xxx}	7.836^{xxx}	6	7.655^{xx}	6	0.151^{xx}	0.418^{x}	6	2.816^{xxx}	9.436^{xxx}
Blocks	4	2.751	7.390	1	1.869	3	0.006	0.243	2	2.400	10.570
Error A	24	0.581	0.965	6	0.805	18	0.027	0.138	12	0.265	0.423
Time	2	8.268^{xxx}	16.072^{xxx}	2	6.955^{xxx}	2	0.126	0.391	2	0.690	1.596
Time x temp.	12	1.609^{xxx}	1.512^{xxx}	12	1.242^{x}	12	0.038	0.067	12	0.438	0.440
Error B	56	0.382	0.381	14	0.445	42	0.044	0.134	28	0.315	0.557

Level of significance--x=0.05, xx=0.01, xxx=0.001. (1) During treatment. (2) During treatment plus 3 days after treatment. (3) During treatment but not removed prior to 3 day growth period after treatment.

APPENDIX B

TEMPERATURES' SHORT TERM EFFECT ON ROOT ELONGATION AND INITIATION

Abstract. The medium temperatures' effect was measured on root elongation and initiation of callused *Euphorbia pulcherrima* L. (poinsettia) and *Hedera helix* L. cuttings during and after 1, 3, or 5 days at 5° to 35°C, and *Pelargonium hortorium* Bailey (geranium) cuttings for 1, 2, or 3 days. After treatment, cuttings were grown at 24°C day temperature (D.T.) and 19°C night temperature (N.T.) for 3 days to evaluate the after effect of each temperature.

Poinsettia cuttings had maximum root elongation and initiation during treatment at 25°C and this continued during the 3 day period after treatment. Cell number and the distance of the first observable xylem element from the root tip were greater for roots having a 5 day, 25°C treatment than for roots kept 5 days at other medium temperatures. English ivy also had maximum root elongation and initiation at a 25°C medium temperature which continued during a 3 day period at 20° and 25°C after treatment. Maximum geranium root elongation and initiation was 30°C, but the greatest root elongation during the 3 day period after treatment occurred at 15°, 20°, and 25°C with more roots initiating at 25°C.

* * * *

Most previous research studies measuring the effect of various medium temperatures on plant root growth have been conducted for periods exceeding 10 days. Optimum root growth for Loblolly pine seedlings occurred at 20° and 25°C and 20°C for silver maple during 2 to 5 days of treatment (1, 9). Hop plants initiated the most roots at medium temperatures of 22° and 27°C during 4 to 6 day periods (5). Optimum temperatures for cell division and elongation vary among plants. Maximum root elongation of onions occurs at 25° and 30°C with cell lengths remaining constant up to 25°C while the rate of cell division continually increases to 30°C (7). Loblolly pine seedling roots have similar cell size at medium temperatures from 5° to 30°C (1), but at 35°C cell size increases. Esau (4) found slower growing roots have the 1st zylem element closer to the meristem than faster growing roots. The purpose of this study was to determine the effect of various medium temperatures on the root growth of several herbaceous and woody horticultural crops.

Materials and Methods

Euphorbia pulcherrima L. (poinsettia, cultivar D-3) and *Hedera helix* L. (English ivy, juvenile) cuttings with 3 to 6 roots were grown for 1, 3, or 5 days, and *Pelargonium hortorium* Bailey (geranium, cutlivar Irene) for 1, 2, or 3 days at 7 different medium temperatures from 5° to 35°C. Mechanically refrigerated containers constantly maintained medium temperatures at 5°, 10°, 15°, or 20°C. Temperatures of 25°, 30°, and 35°C were maintained by pumping water from controlled temperature water baths through flat-sided rubber tubing encircling each pot. Perlite provided insulation around the pot and medium surfaces. Cuttings were maintained in a medium consisting of a 1:1 mixture of peat and Turface in 3-inch clay pots. The tops of all plants were maintained at 24°C day temperature (D.T.) and 19°C night temperature (N.T.) with a ± 1°C fluctuation. Medium temperatures also had a ± 1°C fluctuation. Thermocouples of 24-guage copper-constantan wire on a 24-point portable potentiometer recorded the medium temperatures for 4 half hour periods daily. Cuttings were grown for 3 additional days at 24°C D.T. and 19°C N.T. to determine if there was a temperature effect after treatment. Total root length was measured 3 times: (a) prior to treatment, (b) immediately after treatment, and (c) 3 days after treatment. Root counts were made immediately after treatment, and again 3 days later. The root elongation and number of roots initiated during each period were analized by a split plot design (11). Prior to statistical analysis the number of roots initiated were transformed by $\sqrt{0.5 + N}$ (N = the number of roots initiated by each cutting) (2). Cuttings were fertilized at each watering with a 200 ppm nitrogen concentration of a water soluble 20-20-20 fertilizer. Nine hours of light were supplied daily at 33.8 lamp watts per ft^2.

Roots were collected from poinsettia cuttings at all temperatures immediately after treatment and 3 days later. Longitudinal sections of representative roots were stained with Safranin-Fast Green (10). The number of cortex cells within 0.4 mm. at different distances from the root tip was counted and the distance of the first observable xylem element from the root tip measured in mm.

Results

Poinsettia: Callused cuttings showed an increase in root elongation (Table 1-A) as medium temperatures increased from 5° to 25°C. Further increases in medium temperatures (30° to 35°C) gave reduced root elongation. Cuttings at 25°C for 5 days had significantly more elongation than those at 20° or 30°C. Root elongation was significantly increased with longer lengths of exposure (1, 3, or 5 days) at treatments of 20°, 25°, and 30°C. Root initiation also was maximum after the 25°C treatment (Table 2-A).

Post treatment observations indicated that 25°C treated cuttings continued to have more root elongation than those at other treatments (Table 1-B). Increased

TABLE 1.--The effect of soil temperature on poinsettia root elongation comparing response during and after treatment. Figures represent means (mm.) per 15 cuttings.

		Temperature (°C)							
	Days of Growth	5°	10°	15°	20°	25°	30°	35°	Days H.S.D. 5%
A During Treatment	1	0.23	0.47	1.05	1.74	2.98	2.05	1.83	1.26
	3	0.40	1.01	1.24	3.08	9.07	5.87	2.55	1.26
	5	0.69	1.32	3.46	7.94	20.24	11.37	3.89	1.26
Temp. H.S.D. 5%		7.73	7.73	7.73	7.73	7.73	7.73	7.73	
B Post Treatment	3	2.00	2.40	2.70	3.87	4.21	2.82	0.77	1.23
	3	0.30	1.69	2.90	2.89	6.74	3.69	1.03	1.23
	3	0.50	3.13	4.55	7.36	10.45	4.75	3.09	1.23
Temp. H.S.D. 5%		5.06	5.06	5.06	5.06	5.06	5.06	5.06	
C Total (A+B)	4	2.23	2.87	3.75	5.61	7.19	4.87	2.60	1.94
	6	0.71	2.70	3.33	5.97	15.81	9.56	3.58	1.94
	8	1.22	4.45	8.01	15.30	30.69	16.12	6.98	1.94
Temp. H.S.D. 5%		11.34	11.34	11.34	11.34	11.34	11.34	11.34	

TABLE 2.--The effect of soil temperature on poinsettia root initiation comparing response during and after treatment. Figures represent means (no.) per 15 cuttings.

	Days of Growth	Temperature (°C) 5°	10°	15°	20°	25°	30°	35°
A During Treat-ment	1	0.0^{ax}[1]	0.0^{ax}	0.0^{ax}	0.5^{ax}	0.1^{ax}	1.0^{ax}	0.5^{ax}
	3	0.0^{ax}	0.4^{ax}	0.7^{ax}	2.9^{abxy}	6.5^{aby}	8.2^{by}	2.9^{abx}
	5	0.0^{ax}	0.3^{ax}	0.4^{ax}	5.8^{aby}	14.6^{bz}	9.3^{by}	0.7^{ax}
B Post Treat-ment	3	0.4^{ax}	1.1^{ax}	1.5^{ax}	2.4^{ax}	2.4^{ax}	0.7^{ax}	0.4^{ax}
	3	1.4^{ax}	2.0^{ax}	4.1^{ax}	3.7^{ax}	4.0^{ax}	2.1^{ax}	2.1^{ax}
	3	0.3^{ax}	2.5^{ax}	7.9^{ax}	8.8^{ax}	4.3^{ax}	3.6^{ax}	1.0^{ax}
C Total (A+B)	4	0.4^{ax}	1.1^{ax}	1.5^{ax}	2.9^{ax}	2.5^{ax}	1.7^{ax}	0.9^{ax}
	6	1.4^{ax}	2.4^{ax}	4.8^{axy}	6.6^{ax}	10.5^{ay}	10.3^{ay}	5.0^{ax}
	8	0.3^{ax}	2.8^{abx}	8.3^{aby}	14.6^{by}	18.9^{bz}	12.9^{by}	1.7^{axy}

[1]Means having letters in common (a, b for temp. and x, y, z for days) are not significantly different at the H.S.D. 5% level. Numbers are the means of actual roots present. Statistical analysis was performed on transformed data.

length of treatment (1, 3, or 5 days) at 25°C gave significantly longer roots. The number of roots initiated after 10° to 35°C was not significantly different (Table 2-B).

Total root elongation (during and after treatment) was greatest for the 25°C treatment (Table 1-C). This was significant for cuttings treated 5 days. Total root number also was greatest for cuttings exposed to 25°C (Table 2-C). Increased length of exposure (1, 3, or 5 days) at 25°C gave significantly more roots.

Poinsettia roots were white and fleshy for all cuttings during treatments of 5° to 25°C, but appeared highly suberized at higher temperatures. Roots after 35°C treatment for 5 days were either dead, damaged, or actively growing. Roots of cuttings at 25°C had more cortex cells in the meristematic region than roots at higher (30°-35°C) or lower (5°-20°C) temperatures (Table 3). Roots in the 35°C treatment had an abrupt increase in cortex cell size due to a very short region of elongation. All other treatments did not produce noticeable changes in root anatomy and cell appearance. The distance from the root tip to the first observable xylem element progressively increased for temperature treatments from 5° to 25°C and then decreased to 35°C.

English Ivy: Callused cuttings at 25°C generally had maximum root elongation (Table 4-A), while increased length of treatment (1, 3, or 5 days) at 20° and 25°C gave

TABLE 3.--Histological measurements of poinsettia roots 3 days after treatment.

Temp. of Treatment (No.) days	mm. to 1st Xylem Element	Mean Cortex Cell No.	
		From Meristem to 0.4 mm.	0.5 mm. to 0.9 mm. from Meristem
5°C (5)	0.7	25	11
10°C (5)	0.5	24	12
15°C (5)	1.3	27	13
20°C (5)	2.1	30	8
25°C (5)	2.5	33	14
30°C (5)	2.0	29	8
35°C (5)	0.3	13	5

TABLE 4.--The effect of soil temperature on English ivy root elongation comparing response during and after treatment. Figures represent means (mm.) per 12 cuttings.

	Days of Growth	Temperature (°C) 5°	10°	15°	20°	25°	30°	35°	Days H.S.D. 5%
A During Treatment	1	0.25	0.31	1.74	1.37	2.17	6.06	0.54	1.50
	3	0.75	1.04	2.26	3.84	6.42	5.46	0.49	1.50
	5	0.57	1.91	4.13	9.74	14.46	8.93	1.23	1.50
Temp. H.S.D. 5%		8.48	8.48	8.48	8.48	8.48	8.48	8.48	
B Post Treatment	3	2.44	2.62	3.44	5.62	5.11	2.82	0.73	0.94
	3	4.13	3.99	4.13	5.48	5.38	3.56	0.07	0.94
	3	2.80	4.32	3.57	4.98	4.21	3.35	-0.09	0.94
Temp. H.S.D. 5%		5.86	5.86	5.86	5.86	5.86	5.86	5.86	
C Total (A+B)	4	2.69	2.93	5.18	6.99	7.28	8.88	1.27	1.95
	6	4.88	5.03	6.39	9.32	11.80	9.02	0.56	1.95
	8	3.37	6.23	7.70	14.72	18.67	12.28	1.14	1.95
Temp. H.S.D. 5%		9.28	9.28	9.28	9.28	9.28	9.28	9.28	

TABLE 5.--The effect of soil temperature on English ivy root initiation comparing response during and after treatment. Figures represent means (no.) per 12 cuttings.

	Days of Growth	Temperature (°C) 5°	10°	15°	20°	25°	30°	35°
A During Treatment	1	0.0^{ax}[1]	0.0^{ax}	0.0^{ax}	0.0^{ax}	0.2^{ax}	0.0^{ax}	0.0^{ax}
	3	0.0^{ax}	0.0^{ax}	0.0^{ax}	0.4^{ax}	0.6^{axy}	0.5^{ax}	0.0^{ax}
	5	0.0^{ax}	0.3^{ax}	0.1^{abx}	0.1^{abx}	1.2^{ay}	0.6^{abx}	0.0^{ax}
B Post Treatment	3	0.1^{ax}	0.0^{ax}	0.7^{ax}	0.2^{ax}	0.2^{ax}	0.4^{ax}	0.0^{ax}
	3	0.1^{ax}	0.3^{ax}	0.5^{ax}	0.6^{ax}	0.9^{ax}	0.1^{ax}	0.0^{ax}
	3	0.2^{ax}	0.3^{ax}	1.2^{ax}	1.7^{ax}	0.5^{ax}	0.0^{ax}	0.0^{ax}
C Total (A+B)	4	0.1^{ax}	0.0^{ax}	0.7^{ax}	0.2^{ax}	0.4^{ax}	0.4^{ax}	0.0^{ax}
	6	0.1^{ax}	0.3^{ax}	0.5^{ax}	1.0^{ax}	1.5^{ax}	0.6^{ax}	0.0^{ax}
	8	0.2^{ax}	0.6^{ax}	1.3^{ax}	1.8^{ax}	1.7^{ax}	0.6^{ax}	0.0^{ax}

[1]Means having letters in common (a, b, for temp. and x, y for days) are not significantly different at the 5% level. Numbers are the means of actual roots present. Statistical analysis was performed on transformed data.

significantly more root elongation (Table 4-A). Root initiation was greatest during the 25°C treatment for all lengths of exposure (Table 5-A).

Cuttings exposed to 20°C had maximum elongation during post treatment observations although the amount was not significantly greater than other treatments (Table 4-B). The number of initiated roots was still small with no significant differences among treatments (Table 5-B).

Total cutting root elongation was similar at 20°, 25°, and 30°C although greatest elongation resulted from 25°C treatment (Table 4-C). Increased length of exposure at 25°C gave significantly longer roots. Largest numbers of roots were initiated at 20° and 25°C treatments without significant differences between them (Table 5-C). Cuttings exposed to 35°C did not initiated roots during the study. Ivy root appearance was similar to that described for poinsettia. Root shriveling and necrosis was noted 3 days after 35°C treatment.

Geranium: Similar root elongation rates occurred when callused cuttings were grown at 25° or 30°C (Table 6-A). Length of treatment (1, 2, or 3 days) at 25° and 30°C did not significantly increase the amount of elongation. Largest numbers of roots were initiated during the 5 day 30°C treatment but differences with increased length of exposure were non significant (Table 7-A).

TABLE 6.--The effect of soil temperature on geranium root elongation comparing response during and after treatment. Figures represent means (mm.) per 9 cuttings.

	Days of Growth	Temperature (°C) 5°	10°	15°	20°	25°	30°	35°	Days H.S.D. 5%
A During Treatment	1	0.36	0.66	1.94	3.54	5.19	6.33	5.03	8.36
	2	0.84	0.55	4.36	7.15	13.48	14.28	5.02	8.36
	3	0.68	2.53	6.04	10.91	17.14	19.18	4.61	8.36
Temp. H.S.D. 5%		8.08	8.08	8.08	8.08	8.08	8.08	8.08	
B Post Treatment	3	5.66	5.85	9.58	11.24	11.93	8.48	2.61	2.07
	3	6.19	8.49	11.31	15.12	10.82	11.01	1.37	2.07
	3	5.96	3.49	11.30	14.26	11.54	8.88	0.96	2.07
Temp. H.S.D. 5%		9.35	9.35	9.35	9.35	9.35	9.35	9.35	
C Total (A+B)	4	6.02	6.51	11.52	14.78	17.12	14.81	7.64	3.49
	5	7.03	9.04	11.67	22.27	24.30	25.29	6.39	3.49
	6	6.64	6.02	17.34	25.17	28.68	28.06	5.57	3.49
Temp. H.S.D. 5%		10.92	10.92	10.92	10.92	10.92	10.92	10.92	

TABLE 7.--The effect of soil temperature on geranium root initiation comparing response during and after treatment. Figures represent means (no.) per 9 cuttings.

	Days of Growth	Temperature (°C) 5°	10°	15°	20°	25°	30°	35°
A During Treatment	1	0.0^{ax} [1]	0.0^{ax}	1.0^{ax}	2.1^{ax}	2.3^{ax}	4.2^{ax}	3.3^{ax}
	2	0.0^{ax}	0.0^{ax}	2.0^{ax}	0.2^{ax}	3.0^{ax}	5.6^{ax}	2.8^{ax}
	3	0.2^{ax}	1.2^{abcx}	1.6^{abcx}	2.8^{abcx}	0.3^{acx}	7.1^{cx}	0.4^{abx}
B Post Treatment	3	3.4^{ax}	3.1^{ax}	3.2^{ax}	4.6^{ax}	11.8^{ax}	9.5^{ax}	0.2^{ax}
	3	3.7^{ax}	1.3^{ax}	4.4^{ax}	12.0^{ax}	11.2^{ax}	11.4^{ax}	0.2^{ax}
	3	4.9^{ax}	5.0^{ax}	8.1^{ax}	11.1^{ax}	16.4^{ax}	12.7^{ax}	1.8^{ax}
C Total (A+B)	4	3.4^{ax}	3.1^{ax}	4.2^{ax}	6.7^{ax}	14.1^{ax}	13.7^{ax}	3.5^{ax}
	5	3.7^{ax}	1.3^{ax}	6.4^{ax}	12.2^{ax}	14.2^{ax}	17.0^{ax}	3.0^{ax}
	6	5.1^{ax}	6.2^{ax}	9.7^{ax}	13.9^{ax}	16.7^{ax}	19.8^{ax}	2.2^{ax}

[1] Means having letters in common (a, b, c, for temp. and x, y for days) are not significantly different at the 5% level. Numbers are the means of actual roots present. Statistical analysis was performed on transformed data.

During post treatment observations root elongation and initiation was not significantly greater at any one temperature (Table 6-B and 7-B). However, total root elongation was greatest at 20°, 25°, and 30°C (Table 6-C). Maximum total root initiation also occurred at 20°, 25°, and 30°C treatments, but differences were non significant (Table 7-C). Geranium roots appeared white and fleshy at all temperatures except 35°C. Their appearance after treatment was similar to that observed in ivy.

Discussion

Maximum poinsettia root elongation and initiation occurred during exposure to the 25°C medium temperature. This was observed to continue during post treatment for root elongation but not initiation. Total root elongation and initiation was greatest at 25°C. This indicates that previously recommended medium temperatures of 21°C (6) for poinsettia propagation should be raised to 25°C. Although 5° to 25°C treated roots had a different general appearance from 30°C treated roots, anatomical observations revealed no difference in cell appearance.

English ivy as with poinsettia had maximum root elongation and initiation at the 25°C medium temperature but they were not significantly different from the 20° and 30°C treatments. The data indicates that for propagation of English ivy medium temperatures should be 20° to 30°C.

The rooting response of ivy cuttings as compared to poinsettia was slower. Few new roots were initiated after cuttings from the 20°, 25°, and 30°C medium temperatures had grown for 8 days.

Geranium root elongation and initiation also was high over a wide temperature range and occurred more rapidly than for poinsettia or English ivy. Root elongation was greatest after 3 days at 25° and 30°C medium temperatures. The data indicates that previous recommendations of 18° to 24°C (8) for geranium propagation are slightly low and that enhanced rooting will occur at 20° to 30°C.

All crops showed the same trend of increased root elongation and initiation with a raise in medium temperatures from 5° to 25°C. A 5°C increase from 30° to 35°C have resulted in decreased root elongation and initiation. Three days after 35° treatments were terminated many roots appeared to be necrotic. The 35°C treated poinsettia roots had an abrupt increase in cortex cell size as a consequence of a very short region of elongation.

One day of different medium temperatures produced no significant differences for poinsettia, English ivy, and geranium root elongation and initiation. After 3 days for poinsettia and English ivy, and 2 days for geranium there were significant differences for root elongation but not for initiation. This difference was still present

3 days later for poinsettia. Poinsettia and English ivy after 5 days and geraniums after 3 days had significant differences for root elongation. Again only poinsettia had a significant residual effect from temperature treatments. This indicates that more than 1 day of different medium temperatures is necessary to significantly affect root elongation and initiation within the temperature range of 5° to 35°C.

This study was designed to determine at what medium temperatures maximum root elongation and initiation occurred for several horticultural crops. No attempt was made to correlate enzymatic or biochemical processes and the observed anatomical and morphological changes in the roots.

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