COLORADO STATE UNIVERSITY

ROOTING OF CARNATION CUTTINGS

Cheever

THESIS

ROOTING OF CARNATION CUTTINGS

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER

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Abstract of Thesis

ROOTING OF CARNATION CUTTINGS

Procedures and materials for rooting carnation cuttings (Dianthus caryophyllus) with intermittent mist were evaluated. Five experiments in a series investigated pH and physical properties of media, medium temperature, mist quantity, foliar feeding, spacing of cuttings, and length of time in the medium. Data were taken on root quality, fresh and dry weight gains during propagation and recovery rate after planting.

Rooting ability was closely related to medium pH with an optimum near 7.0 but was not affected by water holding capacity or aeration of the medium tested. Cuttings rooted more rapidly in a 7-3 mixture of perlite and sphagnum peat limed to pH 7.0 and consistently showed greater fresh weight gains after planting when compared to horticultural perlite. Recovery rate was not affected by medium temperatures of 60, 70, and 80°F although the lowest temperature delayed rooting by 8 days. Dry weight gain was greatest for cuttings rooted in a medium temperature of 60°. This may have been a function of time or of reduced respiration. Conditioning of cuttings by providing no mist on the final day in the propagation bench reduced wilting for several days after planting but depressed fresh weight gains during the first month. Heavy mist (1 cm/hour) depressed recovery rate as well as rooting score at close spacings. A 2" spacing was found optimal for subsequent performance with a 7-8 g unrooted cutting. Adequate spacing shortened the time required for root development and was as effective as a conditioning period in the reduction

of wilting after planting. Foliar applications of complete nutrient solutions during the latter part of the rooting phase depressed top growth while rooting and had no effect on rooting score or recovery rate.

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CHAPTER I

INTRODUCTION

Vigorous performance of carnation planting stock is an important factor in maintaining optimum production levels. Procedures used by propagators may contribute to the subsequent performance and should be investigated. Research into the rooting phase of carnation propagation has never been done systematically. Most of the practices and environments used by propagators have been adopted by trial and error with little thought to the final performance of the plant. Experimental evidence is needed to determine the effects of alternative methods to produce superior planting stock for the grower.

In September 1965, a meeting of Colorado carnation propagators was held to discuss procedures that warranted study. As a result of this meeting, several major questions were selected for investigation. These questions concerned root inducing materials and their application, types of media, media temperatures, misting cycles, foliar feeding, and density of sticking.

Problem Analysis

Physiological factors such as root inducing substances and pH, aeration, and temperature of media were investigated first. Results from this research were incorporated with the remaining questions into factorial experiments designed to test for interactions. In this way, interrelationships of the factors in question were determined.

Experiment I - Media. This experiment was divided into two parts. Part I consisted of rooting cuttings in 12 unreplicated plots, some varying in particle size of the rooting media and others varying in percentages of peat and mineral components. Data were collected on medium aeration and pH for correlation with the rooting score obtained within each medium. Part II involved two replicated plots of six media derived from the trials in Part I. Cuttings were inserted in three groups at three day intervals though all were lifted and graded on the same day. In this way, the optimal time required for root development within a given medium could be determined. Cuttings from the three best media were planted and their fresh weight measured after one month of growth for a determination of the relative recovery rate.

Experiment II - Medium Temperature. Two questions were investigated in this experiment: 1. Does medium temperature have an effect on rate and quality of root development? 2. If higher temperatures accelerate root development, is this detrimental to recovery and subsequent growth of the cutting? Three temperatures, 60, 70, and 80^{o} were maintained in the media. Data were collected on: 1. average fresh and dry weight before and after rooting; 2. degree of rooting; 3. fresh weight one month after planting.

Experiment III - Foliar Feeding. With mist propagating there is a chance that nutrients become limiting within the cutting toward the end of the rooting period. This experiment investigated possible growth response, either during rooting or after benching, from foliar application of nutrient solutions. Two treatments, varying in ratios of N, P, and K, were applied. It was believed foliar feeding would provide rapid availability of nutrients while minimizing the accumulation of salts in the media.

Experiment IV - Mist Delivery, Media, Spacing. This experiment investigated the effects of, and interactions between, three mist levels, two media, and four spacings. All the cuttings were lifted the same day and data were collected as in Experiment II. Touring growers rated the treatment at weekly invervals during the one month recovery period.

Definition of Terms

1. Intermittent mist - A mist propagation system that delivers water mist at regular intervals, sufficient to maintain a thin water film on all leaf tissue during daylight hours.
2. Mist interval - The length of time elapsing between the beginning of two consecutive "on" periods.
3. Mist duration - The length of time of each "on" period.
4. Mist delivery - The measured amount of water that falls per hour or per day on the cuttings under an intermittent mist system.
5. Rooting score - A measurement of root quality obtained in response to a given treatment during propagation. The mechanics of the measurement are explained under the heading, "Evaluation of Cuttings," General Methods and Materials, Chapter III.
6. Recovery rate - A measurement of growth during the first month after planting obtained in response to a given propagation treatment. Gain in fresh weight between planting and harvest is used as the criterion.

Delimitations

1. All temperatures are expressed in degrees Fahrenheit.
2. Cuttings of commonly grown Sim varieties were used. There are no reports by propagators, or in the literature, suggesting appreciable differences in rooting response between these varieties.
3. Established commercial propagating procedures are followed during all experiments. Such procedures include the use of intermittent mist, treatment with root inducing substances, watering-in of cuttings after sticking, maintenance of a medium temperature near 70°, use of a spacing board, and storage of unrooted or rooted cuttings for several weeks duration.
4. Gain in fresh weight the first month after benching of the cuttings is used as an evaluation of recovery and performance. Previous research at Colorado State University has consistently shown that plants ahead at this stage of growth remain ahead throughout the early history of the crop (1, 68).

CHAPTER II

LITERATURE REVIEW

Section 1. Mist Propagation

Historical Background. An excellent review on the mist propagation technique was prepared in 1957 by Knight et al. (71). They claimed that Dutch propagators, for many years, had been using an overhead sprinkling technique to keep water on the leaves of cuttings. In the 1930's, cacao cuttings were rooted under mist in Trinidad. An interesting point from this work was the fact that continuous mist, in full sunlight, resulted in serious leaching. The cacao cuttings could be rooted successfully, however, with intermittent mist in full sunlight or with constant mist under lath protection. In 1938, Woycicki (146) found that sprinkling carnation cuttings four times per day resulted in quicker rooting than if done only two times per day.

As early as 1941, Fisher (44) described the use of mist for propagating poinsettias, lantana, and other difficult to root cuttings in a sunny greenhouse. He noticed that cuttings rooted under mist had heavier root systems. They also put on a large amount of top growth, and became stronger plants. Stoutemyer (118), in 1942, reported that the ability to use slightly immature wood, on leafy cuttings of many species, definitely aided rooting. He demonstrated how this type of material could be used if protected from desiccation. Stoutemyer provided "mechanical humidification" with an atomized fog dispersed by a gentle fan. He cautioned that loss of turgor pressure within the cutting reduced its ability to root. He also pointed out that a "bell jar" atmosphere was not the answer. It was not adapted to commercial production, increased foliage disease, and favored an aphid population. Also, rapid temperature change could lower the humidity and desiccate the cuttings.

Theory and Physiological Aspects. Hess and Snyder, of Cornell University, were given the credit by Knight et al. (71) for pointing out the differences between mist propagation and humidification. HUMIDIFICATION refers to filling the air surrounding the cuttings with very fine water particles in order to maintain high relative humidity and reduce transpiration. Wetting of leaves is incidental with humidification. With MIST, the propagator deliberately wets the leaves. This cools them and reduces the vapor pressure within, resulting in lower transpiration loss.

Light that strikes the leaf is largely converted to heat. Warm leaves lose moisture to cooler air by both transpiration and evaporation. Shade can reduce leaf temperature but may also limit light below that necessary for the health of the cutting. A mist film on leaves keeps them cooler than the surrounding air, even in strong light. If the leaf remains lower in temperature, both the leaf and the air can be warm, even hot. Therefore, cuttings under mist can be kept much warmer, speeding up physiological processes and root development. The propagator gains the advantage of maintaining maximum speed and growth (12). Langhans (74) demonstrated how the use of mist provides rapid unchecked growth and makes possible propagation in full sunlight for optimum manufacture of carbohydrates and endogenous growth substances. Rooting speed is much greater with mist (66). Reducing any excessive water loss by portions of cuttings above the medium is the most important factor in rooting cuttings (5, 66).

Breazeale et al. (13) showed that tomato plants will grow to maturity, flowering and producing fruit, with the only available water being absorbed through leaves exposed to fog or a saturated atmosphere. These tomato plants were able to absorb moisture from this saturated atmosphere and build up soil moisture to or above field capacity. Although these plants lost water to the soil, they obtained sufficient nutrients in return from the soil for normal growth. Growing in a saturated atmosphere or fog, leaves became a more important means of plant water absorption than roots. Water absorbed through the leaves developed greater pressure than that from roots. The absorption is faster and the total quantity greater from a fog, when abundant free moisture is maintained on leaf surfaces, than from a 100% humid atmosphere.

<u>Constant Vs. Intermittent Mist</u>. Many of the earlier mist propagating systems ran continuously during daylight hours (49, 50, 66, 71). In some cases, mist was employed 24 hours per day (50, 69). Hartmann and Hansen (50) observed that misting only during daylight resulted in better rooting and prevented the excessive growth of algae upon the vermiculite medium. Kemmerer and Kamp (69) produced superior cuttings of chrysanthemum and carnation with 24-hour constant mist on outdoor beds during summer. These cuttings had heavier stems, more vigorous growth, and better root systems than those from the greenhouse. There was no soft growth in the outdoor rooted cuttings, though evidence of chlorosis appeared by the time they were lifted. The chlorotic cuttings recovered well after planting in soil.

The more water delivered by a mist system the more temperature reduction results. Constant mist can reduce leaf temperature by 20°F in midsummer (66). The temperature of plant tissue may be reduced below the optimum for best rooting (103). Snyder observed that leaf temperatures of cuttings were 10-20^{o}F warmer under intermittent mist than under a constant system (71). Intermittent mist is recommended in winter as it avoids creating adversely cool temperature conditions. Attempts to heat the water were found impractical (66). Intermittent mist, just enough to keep the leaves wet, is usually superior to constant mist (49, 71).

The disadvantages of constant mist are summarized by Knight et al. (71): 1. causes leaching, 2. wasteful of water, 3. saturates the medium, 4. cools the medium excessively, 5. serious leaching of plant material may cause death before roots form, and 6. the cooling effect is operative beyond necessity. They pointed out that an intermittent system must provide a constant film of moisture on all leaf tissue. Properly regulated, an intermittent system promotes more rapid root formation due to a higher medium temperature.

Technical Considerations. Environmental factors influence the mist schedule requirements. Transpiration is increased by increasing light intensity and increasing temperature. Evaporation from cuttings is dependent on air circulation and humidity conditions; also skill of the propagator will be required for necessary adjustments unless suitable electronic light intensity controls are used. Under some conditions, a large amount of damage can result if cuttings dry out for only a few minutes (66). Excessive air temperature, insufficient bottom heat, and uneven mist coverage are all interrelated conditions that cause uneven rooting of carnation cuttings (58).

An intermittent mist system requires control devices, though it can be operated manually (71). An "electronic leaf" can be used to insure adequate coverage. This device allows for passage of an electric current across a film of water between two points. Whenever the film dries, halting the electric flow, the device activates a solenoid valve. The mist remains on until the current connecting the two points is reestablished (22, 71). The "electronic leaf," though a valuable step toward automation, is subject to salt accumulation problems (60, 66). Challenger (22) reported that the "electronic leaf" and a manually controlled system produced the same results. The manual system came on at regular intervals, but had to be turned on in the morning and off in the evening.

Kamp (66) observed that an intermittent system, delivering 4 seconds of mist each minute, reduced water usage to 7 percent of that required for a constant system. For outdoor beds in Illinois, he considered "off" periods of 8 minutes too risky. Tinga et al. (126), rooting large cuttings of Pyracantha in a 60° greenhouse, used 1 minute of mist every 10 minutes during daylight hours. Many growers adjust intervals to the season of the year and even to compensate for daily weather fluctuations (58).

Fine nozzles require filters for most water supplies. These fine nozzles are also greatly affected by air movements and may require high pressure lines. Heavy fogging or deflection nozzles deliver more water but operate at low pressure on most all water supplies (66). Bradley (12) reported that high capacity nozzles are necessary to keep leaf surfaces wet. These nozzles provide better distribution so a shorter "on" time and less total water is used.

<u>Advantages and Disadvantages</u>. Dickey and Sheehan (32) found interrupted or constant mist superior to any hand watering technique for rooting ornamentals. Challenger (22) considers a mist system as a labor saver in that it replaces the need for hand watering. He believes this feature will pay for the system. Mist allows a rapid turnover of easily rooted cuttings. Moore and Ink (88) demonstrated how plants propagated in full sunlight grew significantly more than shaded controls. Provided with adequate mist, superior cuttings can be produced in outdoor beds in full sunlight (49, 50, 66).

For most plant species, the rooting percentage is increased through mist propagation (22). Sharpe (115) rooted muscadine grape cuttings in 30-45 days if succulent tips with immature leaves were used. Prior to the use of mist, cutting propagation of this valuable species was impossible. Mist has extended the period over which many ornamental cuttings can be collected for successful rooting (23, 31). Large 18" cuttings of <u>Pyracantha</u> could be rooted as easily as 6" cuttings and grown into saleable 24" container plants in one season. This eliminated the need for overwintering the containers. The <u>Pyracantha</u> flowers were successfully pollinated under the mist (126).

Langhans (74) showed that contrary to what might be expected, mist propagation does not encourage or aggravate foliage disease. Spores, requiring thin moisture films for germination, thrived under the sweat box and shaded conditions required before the advent of mist. Apparently, many of these spores are not effective pathologically under mist, due to the slow and constant washing of the foliage (66).

Under mist, there is a danger of upsetting the nutrient and chemical composition of a cutting which is so essential for rooting. Natural inhibitors and promoters of rooting may also be leached, possibly resulting in some of the responses of cuttings under mist (128). Chlorosis of cuttings has occurred under mist (63, 69). Carnation cuttings propagated with the mist technique had a lower sugar content after two weeks in the medium. Four weeks after planting in soil the misted group showed a higher sugar content (58). Langhans (74) predicted the mist technique would alter the mineral nutrition of cuttings. He believed the more rapid growth would create a requirement for more fertilizer.

Good and Tukey (46) reported that deficiencies in softwood and herbaceous cuttings caused by mist propagation are a result of dilution through growth. Because the cuttings gain in both fresh and dry weight while rooting, the original nutrient supply is diluted as growth proceeds. They measured 0.28 g of dry weight added per cutting of White Sim carnation while rooting. By propagating in acid-washed sand with a distilled water mist, they showed that this dry weight gain was entirely in organic assimilates. In this study, no measurable losses of nutrients or metabolites, including soluble carbohydrates, were detected from chrysanthemum and White Sim carnation cuttings. However, significant amounts of N, P, K, Ca, and Mg were leached from hardwood ornamental cuttings.

Hardening-off of Cuttings. Soft cuttings continue their top growth under mist while producing roots. This soft growth is drastically checked upon planting in an open environment (71). Moving cuttings from moist conditions to a drier environment is a real problem and demands care (22, 51). Pokorny (103) defined hardening-off as the gradual transfer of mist-rooted cuttings to less humid conditions. He states that cuttings should be removed from mist conditions to avoid soft succulent growth, once root systems have developed. Even plants tolerant to mist after rooting should not be left under the mist (12). With carnations and chrysanthemums, reducing the frequency or shutting off the mist for the last several days prevents excessive wilting after transplanting (82).

The appearance of drought or wilting will be delayed the larger the root absorbing surface and the smaller the leaf area of the plant. The factors influencing the uptake of water by roots are not the same as those influencing the losses from leaves. The increase in uptake may lag behind the rate of water loss resulting in negative water balance and wilting (140). The plant depends on its root absorptive surface for maintaining a balance between water loss and uptake (131). Kramer (72) observed that the efficiency of a root's absorptive capacity is a function of the number of roots and size of its root hair region. Kelley (67) claimed that the wilting which accompanies transplanting is a result of the absorbing root hairs being torn off during the moving of plants from starting beds.

Loomis (76) made a study of transpiration rates and recovery after transplanting with hardened and tender vegetable seedlings. Expressed as grams of water lost per grams of fresh weight, the tender seedlings transpired over twice as much before transplanting. After transplanting, the hardened plants transpired more even though they recovered quicker. These hardened vegetable plants renewed growth sooner and their growth curve, plotted on a percent basis, rose more rapidly. This recovery rate was accompanied by faster root development. Loomis cautioned that extended hardening periods result in smaller transplants. A sharp line between hardening and stunting exists. Excessive hardening might be disastrous with some plants. He suggested that the beneficial effects of hardening could be accomplished rapidly in a few days.

Section 2. Root Inducing Substances

Influence on Root Development. The discovery of the stimulating effects of auxins or growth regulators on root initiation has been of great value in plant propagation. In 1925, Van der Lek published the first extensive report on the mechanism of root development in cuttings. He reported that the presence of both active buds and leaves was essential. In 1934, Thimann and Went found that an auxin isolated from urine had a stimulating effect on rooting. The discovery of other useful synthetic auxins soon followed (5). Thimann and Koepfli (123) showed that the auxin prepared from urine was an organic acid, readily destroyed by oxidizing agents.

The most beneficial response from growth regulators is a quicker rate of root meristem initiation. This results in heavier root systems (5, 6, 127). From his work with dark grown pea seedlings, Went (136) stated, "without auxin, no root formation is possible." He claimed that when roots are formed without the addition of some auxin material, the plant contained some of its own. Audus (5) summarized with these points; 1. auxins appear to be the stimulus for starting an ordinary cell toward becoming a root meristem,

2. the application of correct auxin concentrations develops root meristems in otherwise mature non-meristematic tissue, 3. the rooting response of a cutting can be initiated by arrival at the base of naturally occurring auxins from buds and leaves, 4. supplementary applications of synthetic auxins greatly increase this production of roots. Recently, Odom and Carpenter (93) obtained evidence indicating that species having a low supply of endogenous acidic auxins root more slowly. These species also benefit most by added "root promoting" substances.

Commercial plant propagators make regular use of root inducing substances. Tukey (127) stated that often 1/3 of the bench time is saved. As rooting is more rapid, there is less chance of cuttings deteriorating as a result of basal rotting or other problems caused by prolonged time in the medium (5, 127). The use of these chemicals results in a better quality root system. Usually, a higher percentage of cuttings produce roots and, therefore, become saleable plants (5). The response of plants to these growth regulators is confined to the rooting phase. No noticeable improvement or change in the growth of crop plants is produced through treatment (5, 21). Avery et al. (6) emphasized that these chemicals are not a substitute for good care. The proper physiological condition of the plant is of primary importance during root development.

The synthetic organic acids, NAA and IBA, are the most commonly used chemicals for stimulating root development in cuttings (5, 6, 127). They are considered superior to IAA, the original auxin discovered, as they do not retard shoot development. NAA and IBA are more chemically stable, resulting in longer periods of action. Also, they are relatively immobile when applied to the base of a cutting. The herbicide chemicals 2-4D and 2-4-5TP may be effective but can also have undesirable side effects (5).

There is abundant evidence that a primary effect of auxin, when applied to plant tissue like leaves and stems, is the rapid conversion of starch reserves to transportable sugars. Auxin, in optimal concentrations for rooting, promote movement of sugars in the phloem. These sugars accumulate at the base of the cutting (5). Strydom and Hartmann (120) reported that 48 hours after treating the bases with a quick dip of 4,000 ppm IBA in 50% alcohol a distinctly higher level of free amino acids was found in the treated bases than in the bases of untreated cuttings. They believed nitrogenous substances that accumulated in the bases of treated cuttings were translocated from leafy tops as asparagine, the readily translocated organic N compound. They further reported that, 36 hours after treatment, differences began to occur in respiration rates in the bases of treated vs. control cuttings. The respiration rate was four times faster in the treated group by the time roots had formed.

The indole compounds, like IBA, usually promote a more fibrous root system than do the naphthalene compounds such as NAA or NAD (5, 127). The avena coleoptile curvature test indicates that NAA has much greater biological activity than does NAD (47). Tukey (127) reported IBA is less likely to inhibit the growth of terminal buds than is NAA.

Audus (5) stated that IBA is more flexible in its concentration ranges. NAA concentrations that promote optimum root development are close to toxic levels. Loreti and Hartmann (77) found "Ascolano" olive cuttings would root well with concentrations of IBA at 4,000 ppm, but that toxicity occurred from concentrations of 7,000 and 10,000 ppm. The symptoms of this toxicity were; 1. leaves became yellow and abscissed, and 2. excessive proliferation of the cells of the cortex occurred along the basal portion of the cutting. Avery et al. (6) described general symptoms of toxic concentrations as; 1. bending and twisting of petioles and stems, 2. formation of a dense mass of aborted roots, and 3. death of basal stem tissue. They claimed that most herbaceous plants readily recover from less severe types of injury.

Went (136) reported that an excess of auxin prevented root elongation. He assumed that restricted growth was due to the increased number of roots initiated, producing competition from the limited carbohydrate materials available. More recently, Burstrom (15) revealed that the auxin effect on root cell elongation is a two phase process. Auxin promotes and stimulates the first phase but it retards the second and dominant phase. Therefore, an overall decrease in root cell elongation occurs in the presence of excess auxin.

Often mixtures of two chemicals, such as IBA and NAA, have proven superior to either used alone (5, 6). Root systems appear to be characteristic of the growth regulator used (6). It may be possible to regulate the form and appearance of root systems by manipulating the ratios of mixtures (5).

Application Methods. Growth regulators were first applied to cuttings in dilute solutions requiring an extended soaking period, often of 24 hours. This long soaking method was difficult for unskilled personnel, required many different concentrations depending on species, and became a burden when large quantities of cuttings were being handled (117). Chadwick and Kiplinger (21) tried application of IBA as a foliage spray to chrysanthemum cuttings after insertion in the rooting medium. The results were inferior to the soak method and more actual growth substance was required. Concentrated solutions of growth regulators, in alcohol as a quick dip, have been used successfully (5, 51, 77, 127).

Stoutemyer (117) found that incorporating growth regulators into finely ground talc resulted in a useful means of application. He pointed out that this method was simple. It required no extra apparatus while treating and offered a saving in time and material over the 24 hour soak method. He reported that Dianthus and chrysanthemum cuttings were not injured by 10,000 ppm in talc, though they were sensitive to an equal concentration in aqueous solution. Stoutemyer recommended that a wide trench, rather than a knife slit, be used for inserting cuttings treated with talc preparations. Consistently superior root development resulted because less material was scraped from the base during insertion of the cuttings. Avery et al. (6) stated that proper concentrations of IBA and NAA applied with a talc carrier resulted in little danger of shoot or bud inhibition.

Preparations of IBA are unstable and lose their effectiveness when stored as dry powder of concentrated solutions. Dilute solutions should never be stored and must be used as soon as prepared. Solutions of NAA are stable unless organic matter contaminants are present. Strong stock solutions in alcohol of all growth regulators may be kept safely for indefinite periods (5).

The application of growth regulators as a spray to the foliage of cuttings or stock plants has been effective in some instances (5, 81, 87). Mitchell and Marth (87) suggested the method might be particularly useful in large scale commercial propagation. Mahlstede and Lana (81) sprayed privet stock plants with a solution of NAA two hours before taking the cuttings. Rooting was significantly improved over a control group but was no better than were cuttings treated at the base with talc preparations. Audus (5) cautioned: "Much more work is required with this spray technique before it can be adopted as a regular practice."

Use with Carnation Cuttings. Carnation plants contain lower levels of "free" or endogenous auxins than do the more rapid rooting species like coleus and chrysanthemums. They are also slower in converting neutral auxin precursors into the acidic auxins. Slower rooting responses of carnations and geraniums appear to be associated with both a lack of acidic auxins and accumulation of these auxins. With the carnation variety 'Alaska,' increased amounts of endogenous acidic auxins accumulated at the basal end of cuttings between 8 and 16 days after sticking. Root emergence occurred at about 15 days (93). Research by Stangler on the anatomy and morphology of root initials in carnation cuttings is reported in Hartmann and Kester (51). Root initials or meristems arise in parenchymatous tissue inside of an exterior band of fiber cells. As the new roots begin to grow outward they are forced downward by these fiber cells and emerge from the base of the cutting. The initials were observed microscopically within five days, though visible roots took 21 days to emerge.

Avery et al. (6) reported both IBA and NAA were effective in promoting root development in carnation cuttings. Kirkpatrick (70) found that IBA was effective with carnations at a lower concentration than was NAA or IAA. He also found carnations rather tolerant to IBA, showing basal injury only when extremely high concentrations were used. Excessive concentrations caused retarded root and top growth. Hitchcock and Zimmerman (56) recommended concentrations of 1,000-5,000 ppm IBA in talc. They placed carnations in an intermediate category as to concentration requirements when compared with most plant species. Kirkpatrick (70) established 2,000 ppm IBA in talc as the optimum concentration for carnations. Mitchell and Marth (87) reported good rooting results with carnations from a foliar spray application to cuttings after inserting in the medium. This spray consisted of one teaspoon of IBA, dissolved in two tablespoons of alcohol, added to one gallon of water.

The use of root inducing substances shortens the rooting period required for carnation cuttings by about one week. When treated within a reasonable concentration range, a higher percentage of cuttings will root and a larger root system results. Plants from treated cuttings grew and flowered normally (70). Woycicki (146) found that the presence of flower buds in the apex of carnation cuttings inhibited rooting. More recently, while working with mist propagation, Wilkins and Kamp (142) obtained evidence that stronger concentrations of IBA were required under the mist. They suggested leaching of natural hormones might take place. Holley and Baker (58) recommended that carnation cuttings never be placed in concentration dips for reasons of sanitation. They suggested dusting the bases of cuttings with talc preparations or spraying with aerosol solutions.

Foliar Penetration and Translocation. An excellent summary on the foliar absorption of growth regulators has been compiled by Sargent (110). He emphasized that two conditions are essential for penetration of growth regulators into leaves, when applied as a solution to foliage; 1. "the solution must adhere to the surface with a minimum of run-off," and 2. the active ingredient must remain in solution for a considerable period. Carrier solvents that attract moisture or dry out slowly are advisable. Growth regulators seem to diffuse across the leaf surface layers at a rate proportional to the concentration gradients across these layers. Favorable concentration gradients tend to be maintained by polar transport of the auxin material from the leaf with the assimilate stream.

There is an abundance of literature on foliar absorption of NAA by fruit trees. This growth regulator is useful for thinning and regulating fruit set, especially in apple. Harley et al. (48) stated that stomata were the avenue of leaf entry when Tween-20, a surfactant, was added to the NAA solution. The use of surfactants was beneficial only if environmental conditions were poor. A large portion of the NAA was absorbed after the spray appeared dry, indicating that cuticular penetration occurs (139). Van Overbeek (98) claimed penetration of NAA must take place through the cuticle and epidermal cells, when in aqueous solution without wetting agents. Through the use of humidity chambers to extend the drying time, Westwood and Batjer (138) found there was much greater absorption when the solution remained on the foliage for 15 hours than for only

5 hours. This study showed that surfactants were beneficial only if a five hour drying time was used. If the solution remained on the foliage for longer periods, there was no need for added surfactants. Luckwill and Lloyd-Jones (78) reported that a 50 ppm solution of NAA, held in darkness at 77^{o} with a non-ionic setting agent, was absorbed at the rate of 1% per minute until the surface deposit became dry. After drying, the rate was much slower and dependent on both temperature and humidity of the air.

Research on temperature effects of foliar absorption of NAA appears controversial. Donoho et al. (33) stated foliage preconditioning in a cool environment of 60^{o}, along with high humidity, resulted in most rapid absorption. However, Westwood and Batjer (138) claimed better absorption at 70 than at 50^{o}. Temperature may exert an effect on penetration by influencing the: 1. viscosity of the cycoplasm, 2. accumulation of binding sites, 3. metabolic conversion, and 4. translocation of the penetrant (110).

Leaves preconditioned under high light intensity absorbed less NAA than those under low light (37). Luckwill and Lloyd-Jones (78) reported, from a tracer study, that after four days a 20 ppm aqueous solution applied to apple leaves resulted in 10% within the leaf, 10% still on the surface, and 80% lost. They stated that ultraviolet light caused NAA to lose a carboxyl group, resulting in its inactivity as an auxin. Radioactive NAA applied to leaves was detected in fruits and seeds within four to six days (33). Under favorable conditions, NAA is absorbed in significant amounts within 30 minutes (37).

NAA solutions applied to apple foliage caused "flagging" on some varieties. It was caused by an increased rate of transpiration, ranging from 22-28%. This "flagging" is due to increased water loss. Young foliage is the most susceptible (68).

Both naturally occurring and foliar absorbed plant auxins exhibit a definite apex-to-base polar transport (27, 42, 98, 137). Growth regulators enter through the leaf cuticle and move out in the phloem with carbohydrate food materials. In bean plants, foliar absorbed 2, 4-D is transported from lower mature leaves to the roots within three hours. There was no evidence of 2, 4-D being transported out of leaves that had not matured to the point of becoming sources, or exporters, of carbohydrate assimilates (30). Crafts (29) emphasized that translocation seldom fails, given the appropriate physiological conditions. Mitchell and Brown (85) showed how the translocation of growth regulator stimuli seemed to occur as a continual flow when favorable conditions for carbohydrate movement were present. They reported the following factors resulted in a lack of translocation of applied growth regulators: 1. leaves low in sugar content, 2. leaves exposed to extended periods of darkness, and 3. leaves exposed to air free of CO_2.

Van Overbeek (98) stated that auxins at higher concentrations than occur naturally will move in which ever transport system they contact. Auxins will move up in xylem as well as down in phloem. He reported that both rate and quantity transported were temperature dependent. These factors had a Q10 on the order of 2, between 50 and 86°. The optimum temperature for auxin transport was near 80°.

Lyon (79) showed how natural downward movement of auxins occurs within plants as a gravity response. Plants placed on a revolving clinostat, relieved of the normal gravity effect, developed epinastic symptoms. Auxin concentrations above normal also upset this gravity response, resulting in varying degrees of epinasty.

Section 3. Propagation Media

Air and Water Relationships. Before mist propagation, a high moisture content in the medium favored rooting of most cuttings in peat, sand, or mixtures. Maintenance of high moisture levels within the medium was especially important under environmental stress conditions (54). Pokorny (103) summarized the problems associated with mist propagation and media. "The relationship between air and moisture in the medium was apparently most important in the successful rooting of cuttings under mist. The large quantities of water used with mist propagation techniques require a rapidly draining and well aerated medium. Poor aeration and water-logging of the medium will result in poor rooting percentages and ultimate failure."

Knight et al. (71) emphasized the importance of adequate drainage in the mist propagation bench. Proper aeration at the cutting base, insuring an adequate O_2 supply, is essential for root development (5). Tinga (125) reported that a decrease in O_2 content of the root zone depressed root growth of carnation cuttings. Low O_2 levels caused cuttings to wilt. Wiegand and Lemon (141) pointed out the importance of proper aeration for normal root respiration. They claimed, however, the apparent diffusion path length in the liquid phase adjacent to the plant root surface is more often a limiting factor than the gaseous composition found in the soil pores. The critical diffusion path length of O_2 in the soil is influenced by root diameter. Finer roots are better adapted to poor aeration conditions (73).

pH and Root Development. Tinga (125) showed that a higher percentage of CO_2 in the carnation rooting medium was associated with a lower pH. He claimed this buildup of CO_2 was the cause of poor root development, though he did not mention possible ill effects of lower pH. According to Taylor (122), the concentration of H^+ in the medium causes cell reactions; not the concentration of CO_2 or HCO_3^-. Lowering of pH retarded and eventually stopped cell activity. Arnon and Johnson (3), however, found variations in the external pH of nutrient solutions had no significant effect on the pH of expressed sap. They stated, "within a relatively wide range of pH, between 4 and 8, fluctuations in the H^+ ion concentration are tolerated by plants provided an adequate supply of all nutrient elements is maintained."

There can be adverse effects when medium pH is lower than that of the cell sap. An increase in the H^+ ion concentration in the medium generally causes a decrease in the root absorption of cations. This results from competition between similarly charged ions for binding and carrier sites (121). Therefore, the H^+ ion concentration can have a direct effect upon nutrition by altering ion concentrations within plant cells (45). Olsen (94) reported H^+ ions actually causing plant injury when the pH of the external solution fell below 4.0. This is either direct damage or injury to the absorption mechanism. In 1959, Rasmussen and Smith (106) claimed there was no conclusive evidence as to the reasons for H^+ ion injury, whether direct or indirect. They considered H^+ ion toxicity, respiratory factors, and altered activity of enzymes as direct effects and solubility of minerals, ion antagonism, and altered base element absorption as indirect.

Arnon and Johnson (3) stated that, within wide limits, an acid or alkaline reaction is not itself responsible for poor plant performance. They concluded, "the significance of an acid pH in a soil will be determined by the extent to which it reflects a deficiency of calcium, and not infrequently magnesium, or the presence in the soil solution of toxic amounts of aluminum or manganese." In a highly acid medium, manganese, aluminum, copper, and nickel may become toxic (24). A low root cation exchange capacity also develops under acid conditions (106, 133). At pH 3.0, lettuce and tomato roots absorbed no Ca or P; in fact, some losses were evident to the external solution. Neither was there absorption of K or Mg in the first 96 hours from the pH 3.0 solution. Lettuce and tomato continued sub-optimum Ca absorption at both pH 4.0 and 5.0. At pH 9.0, no phosphorus was absorbed (2). Sutcliffe (121) believed poor root growth in an alkali medium resulted from the plant's inability to absorb phosphate

Rasmussen and Smith (106) described the roots of orange seedlings, placed in a nutrient solution of pH 4.0, as brown, stubby, and swollen. By comparison, roots at pH 6.0 were smooth and white. They observed the same injury with a pH 4.0 solution of dilute H_2SO_4. This was considered evidence for direct toxic effects from H^+ ions.

Arnon et al. (2) found that injury to lettuce and tomato roots was apparent only at pH 3.0 in a test with pH solutions ranging from 3 to 9. In the pH 3.0 solution, roots became greyish with loss of turgor. These plants wilted rapidly during conditions of stress. Hitchcock (54) doubted that instrument readings of pH represented the true pH with which the roots must contend.

Melon cuttings, rooted in aerated solutions, raised the pH of acid solutions and lowered the pH of basic solutions during all 24-hour periods of an experiment (45). The expressed melon sap averaged pH 6.2. These cuttings caused changes in the solution pH most effectively before adventitious roots develop. The change was attributed to the stem tissue itself, where free passage of ions occurred through cut ends of stems or through epidermal cells. An exchange of ions, according to the initial pH, evidently took place between stems and the medium. Adventitious root initiation and early growth was significantly affected by solution pH. The optimum growth of melon cuttings required pH 6.5 - 7.0. There was a definite increase in the time necessary for root development in more acid solutions. The results of many experiments indicate that the pH which the crop plant requires for maximum growth is also the most favorable to maintain in a rooting medium (54).

Aluminum Toxicity and Calcium Deficiency in Acid Media. The exact causes of aluminum toxicity to plants are difficult to determine. Aluminum may be a "root poison" and has caused root injury. Some investigators suggest that plants growing in acid soils, high in readily soluble aluminum, suffer from P starvation. This could result from aluminum phosphate precipitation in the soil or within the

the plant roots (111). Hortenstine and Fiskell (59) reported that sunflower plants show nearly immediate response to aluminum added to nutrient solutions at levels as low as 6 to 16 ppm. Root growth stopped, followed by development of stubby root tips and brown discoloration. Reduced height and weight of the affected plants indicated a marked depression of growth. Addition of aluminum accumulated in sunflower roots but not appreciably in tops. Jones (64) correlated physiological resistance to aluminum and the ability of the plant to immobilize it through the chelating action of certain organic acids.

The presence of toxic concentrations of aluminum has no effect on the uptake of boron, but higher levels of aluminum (16 ppm) greatly decreased the amount of Ca within the root tissue (59). There is evidence for a Ca-Al antagonism. High concentrations of Ca reduce Al toxicity. The addition of $CaSO_4$ to unlimed soil increased the Al in soil solution from 1.91 to 9.97 ppm without influencing the yield of alfalfa. The quantity of readily soluble Mn and Al, and their soil concentration, is decreased by either liming or diluting with quartz sand. Therefore, the beneficial effect of liming or diluting can be attributed to a decrease of Al and Mn concentration in the soil (111).

As pH decreases, the total amount of Ca, exchangeable and in available compounds, decreases within the medium. The absorbability or availability of the remaining exchangeable Ca is further decreased (24). Wander and Sites (133) reported that unbalanced cation nutrition and low plant Ca content can result from the use of acid forming NH_4 nitrogen fertilizers. At pH 4.0 and 5.0, increasing the Ca concentration resulted in increased growth of lettuce and tomato plants (2). Arnon and Johnson (3) state, "It was found that at acid reactions lettuce and tomato required for best growth a higher concentration of Ca than at reactions approaching neutrality. This observation is of particular interest since a high acidity in soils generally coincides with a low Ca supply. The plant thus suffers from a double disadvantage. Its increased physiological demand for calcium is met by decreased supply."

Paul and Smith (101) demonstrated how the substitution of Ca ions for H ions in peat moss favors root development in chrysanthemum cuttings. In H^+ saturated peat moss, with a pH of 3.5, the basal 0.5 cm of the cutting became brown and rotten. When the peat moss was 25% Ca saturated, with a pH of 4.9, the basal browning did not occur though emerging root tips were affected. A Ca saturation level between 37.5 and 50% was optimal for root development. The pH of the peat moss was then 5.3 - 6.6. Over this narrow but critical range, from 25 - 37.5% Ca saturation, the change in exchangeable Ca is 100 times as great as the change in solution concentration. Therefore, Paul and Smith assumed that the solid phase played a part in supplying Ca to the emerging roots through some contact mechanism. According to Peterson (102), the death of root tips is a primary symptom of Ca deficiency in carnations.

Inorganic Mineral Particles. Clean sand has been the traditional medium for carnation propagation (18, 54, 90, 146). In 1931, Esper and Roof (41) found that for rooting carnation cuttings, "slag," with a pH about 8.0, was superior to sand, peat, mixtures of peat and sand, or peat and slag. Woycicki (146) demonstrated the importance of water holding capacity in evaluating sand as a medium. He showed a variation existed among plant species as to their requirements. Geraniums rooted best in sand having a 50% water holding capacity. Carnations, fuchsias, and chrysanthemums required 75%. All the plant material tested died in sand holding only 25% of the water added.

Butterfield (18) recognized the problems, such as lack of uniformity of texture, that made sand troublesome for many carnation propagators. He showed that poor aeration caused unsatisfactory root development when the sand contained more than 15% of very fine dust-like particles. The speed of rooting and quality of the carnation root system decreases as the particle size decreases (90). Pridham (105) showed that vermiculite, screened cinders, and quartz sand were equally satisfactory for rooting nursery stock, providing dust-like particles were screened out. O'Rourke and Maxon (96), experimenting with various grades of vermiculite, found that most species tested rooted best in a 2-3 mm diameter size. Several species preferred the coarser, others the finer sizes, presumably due to differences in O_2 or water requirements.

During the 1950's, along with the advent of mist propagation, growers began to favor perlite for rooting carnations. Perlite is a light weight, porous, thermo-expanded aluminum silicate (58, 95). If moisture is not a limiting factor, it is an excellent rooting medium for carnations. The finest grade is not recommended because of poor aeration at the cutting base (58). Mastalerz (83) showed that all grades of perlite, from 1/32" to 1/8" as well as a mixture of sizes, were satisfactory media for carnations. However, he pointed out that the finest size demanded excellent drainage and the coarsest required heavy misting. Another well drained material adapted to mist propagation is arcillite, a montmorrillonite clay calcined to stabilize it as a porous structure (95).

Peat Moss. There is a direct effect of media on the rooting response of cuttings. Acid peat moss, either straight or mixed with sand, favors or hinders root development in cuttings depending upon species being tested (55). According to Hitchcock (54), cuttings which root poorly in peat moss, such as carnation, usually exhibit definite signs of injury. This injury consists of browning of the basal cut surface and may extend to one-fourth the length of a cutting. No callus is formed with this injury. Partial or complete neutralization of peat moss prevents injury.

Besides direct injury to the cutting, the low pH associated with peat moss affects the rate of root growth. When coleus and mint cuttings were transferred after rooting in sand (54), the rate of root growth was retarded in natural peat but was accelerated in neutral peat moss. The results were similar whether the peat was neutralized with $CaCO_3$, a calcium carbide waste product, an asbestos product, or by leaching with tap water. Compared with natural peat or a sand and natural peat combination, coleus cuttings produced the best root system in neutral peat moss. A medium containing straight peat or some combination with peat consistently stimulated a more rapid rate of root growth than occurred in sand alone. The addition of one gram of $CaCO_3$ per liter of peat was sufficient to stimulate pronounced callus formation on privet cuttings. This callus formed in sand but not in an unlimed peat and sand (1:1) combination. However, there was no relationship between callus formation and root development (55).

Adding neutralizing agents, or leaching, changes the color of peat moss from light brown to dark brown or nearly black. Addition of excessive alkali produces an immediate color change. A chemical reaction is believed to take place. Bacterial decomposition most likely is activated along with the change in color (54).

The pH of natural sphagnum peat is generally near 4.0 (41, 54, 109). Hitchcock (54) reported 4-5 grams of $CaCO_3$ added per liter of peat raised the pH to approximately 6.5. For accurate measurement, the moist mixture should set for at least five days. He observed, through using NaOH, that the neutralizing capacity of peat itself is fifty times as great as that of an extract of an equal volume of peat. Working with sphagnum peat soils in Canada, Mackay and Chipman (80) found heavy applications of N were required for four successive crop years. Additions of P during the last two years gave no response, indicating sufficient quantities had been retained from the previous years to support optimum crop growth. Evidently, peat soils are capable of retaining P in an available form, not subject to leaching losses.

Boelter (9) observed that relatively undecomposed sphagnum peat has large pores and, following saturation, retains only 20% of its water at 0.1 bar suction. Decomposed peat, deeper within the same bog, retained 65-75% of its water by volume after saturation at 0.1 bar suction. Dyal (35) stated six important factors that should be considered when evaluating peat. These factors are: 1. water holding capacity under varying conditions, 2. pH, 3. ash content,

4. moisture content as sold, 5. botanical origin, and 6. state of decomposition. He observed that higher moisture retaining peats are not necessarily best for adding to fine textured soils. Increased evaporation may occur following the addition of moss peats. Desirable properties other than moisture retention may be important when evaluating peat as an additive for a given soil. Dyal's studies revealed that baled peat is a better buy than moisture proof packages. The organic matter content, as a percent of total weight, is consistently higher in baled peat.

Combinations. If peat is used as a component of a rooting medium, care is necessary to insure adequate drainage (51). Mastalerz (82) claimed excellent drainage is more critical than the use of any particular medium for carnations under mist. Esper and Roof (41) pointed out that the moisture retaining properties of peat make it ideal for combination with granular materials having low moisture retaining capacity. Hitchcock (54) stated that both peat moss and sand are considered well aerated as straight materials. He claimed peat and sand mixtures derived their efficiency from; 1. a high moisture retaining capacity, 2. the presence of growth promoting substances furnished by the peat moss, and 3. proper aeration. Another advantage is that the pH of the mixture is raised somewhat above that of peat alone (41, 55).

Beneficial effects from combining peat and sand are expressed in performance of the rooting cuttings. Compared to sand, Hitchcock and Zimmerman (55) obtained a more desirable type of root system due to an early tendency toward secondary root formation. They also observed less callus associated with rooting. Knight et al. (71) reported that with mist propagation techniques, a 1:1 sand and peat mixture was best for chrysanthemum cuttings. Coleus root development was more rapid in sand-peat mixture than in either medium alone (54).

For carnation cuttings under mist, peat and sand mixes have usually proven inferior to good sand alone. The high water holding capacity of the mixture is assumed at fault (58). Before the use of mist for propagating carnations, workers reported excellent results with peat moss and sand combinations (54, 70). In 1955, Kemmerer and Kamp (69) rooted several carnation varieties under mist using a peat and sand mixture as well as sand alone. Both media were satisfactory with the mix superior for some varieties. Roots from the peat mix were more "brittle" than those from sand, in the variety 'Virginia Miller.' The variety 'Starlight' did not show this brittleness as much and rooted best in the mix. The 'Starlight' cuttings appeared stockier with closer internodes than when rooted in sand.

Many combinations of media have been used by propagators. Chadwick (20) observed that equal parts of vermiculite (5-8 mm) and silica sand proved better than either medium alone. For apple cuttings under intermittent mist, fine sand was improved by adding either peat or perlite. This was assumed due to better aeration (60). A 1:1 combination of pine sawdust and vermiculite proved satisfactory for rooting grape cuttings under continuous mist, though the leaves were light colored and in poor condition after 45 days (115). Mixtures of peat moss and perlite as well as peat alone proved superior to coarse perlite (32). Loreti and Hartmann (77) found certain olive varieties would not root properly in peat and perlite, though a perlite and vermiculite combination could be used. Other varieties rooted well in either of the mixtures. O'Rourke and Dedolph (95) showed 1:1 mixtures of arcillite and peat, perlite and peat, and pulverized styrofoam and peat were all suitable for most species tested. For almond cuttings, peat and perlite 1:1 was superior to equal parts of vermiculite and peat or vermiculite and perlite (84). Peat and perlite, in equal parts as a container medium, exhibited toxicity toward lemon and bean plants. No attempt was made to explain this observation (40).

Following a comprehensive study of propagating media, Hitchcock (54) stated that neither pH nor mechanical texture was an independent controlling single factor. He explained that this complicated situation resulted from a combination of factors operating to bring about a given rooting response.

Section 4. Nutrition and Root Development

Propagators generally agree that in cuttings from healthy plants the internal supply of mineral elements will be adequate for "early" growth of new roots (5). However, Joiner and Gruis (63) emphasized that previous research has not provided definite insight into the benefits of nutritional treatment of propagative material. They pointed out how recent work has been confined to mist techniques and root inducing substances. Altstadt (1) reported that the best quality carnation cuttings in Colorado are produced from stock plants grown at high nutrient levels and provided supplemental CO_2. Audus (5) stated that, although nutritional status of cuttings is important, supplementary balanced nutrient feeding shows little response unless some deficiency exists. He claimed age and vigor of the cutting and its position on the stock plant are of primary importance. Young stock plants generally provide better rooting cuttings (5), as well as superior growing plants (1).

Nutritional Status of the Cutting. Nitrogen is the element found most important in its effect on root development in cuttings. High N levels within the cutting, relative to the total nutrient supply, has a depressing effect on root development (5, 8, 52, 104, 112, 116). This effect may be due to the fact that high N favors growth of tops over that of roots (8, 63). Schrader (112) reported that N can stimulate both root and top growth if carbohydrate levels remain high enough within the cutting. As the N supply increases, aerial parts use more carbohydrate resulting in less being available for translocation to roots (8). Von Hentig (53) demonstrated with fuchsia stock plants that trebling the ratio of N in a balanced nutrient solution increased the production of cuttings without benefitting their rooting ability.

Starring (116) reported that withholding nitrate from stock plants for a short period prior to harvesting cuttings enabled these cuttings to produce total root lengths of 22.9 cm compared to 7.5 cm for well fed controls. He showed how a high nitrate content in the sand rooting medium depressed the root development of tomato cuttings. Starring concluded that a carbohydrate-to-nitrogen level favoring root growth may be different from the ratio best for top growth. Odom (91) reported that nutrients added to a vermiculite medium delayed rooting of carnation cuttings. Rooting of bean leaf cuttings was depressed by a complete nutrient solution (124). The presence of KNO_3 stimulated rooting whereas $(NH_4)_2SO_4$ was inhibitory even when very dilute. Once roots were formed their growth and maintenance were improved by complete nutrient solutions.

Bosemark (10) pointed out that N deficiency is associated with long slender roots. As N increases, roots grow shorter and sturdier. He showed that inhibition of root growth under high N conditions is due to a combined reduction in cell multiplication and elongation. Because production of endogenous auxins in the plant increases with N supply, root elongation is reduced (8). Avery et al. (6) found that plants with high proportions of N in the nutrient solution exhibited vigorous growth and had higher relative amounts of hormones in shoot tips. These same growth hormones were barely detectable in N deficient plants. Bosemark (10) further showed that a deficiency of N increased root length due to greater cell elongation. Plants deficient in N were found sensitive to added NAA but insensitive to the "anti-auxin" PCIB. The reverse was true with plants having high N content. Bosemark suggested that production of endogenous auxins in the plant increases as the N supply increases.

Research with poinsettia stock plants indicated that high N levels must be accompanied by moderately high P levels for proper rooting of cuttings (114). Von Hentig (53) reported that chrysanthemum cuttings rooted poorly if increases in P levels were not accompanied by increases in N. Black (8) stated that P has no "stimulating" effect on growth of absorbing plant roots. He explained that P deficient plants became high in carbohydrates and exhibited greater top growth than absorbing root growth when fed P.

Von Hentig (53) showed that potassium in the plant at high levels in proportion to N and P was detrimental to rooting of cuttings. Changing the ratio of N and K had a great effect. Joiner and Gruis (63) reported that K, absorbed as a foliar spray of potassium citrate, seemed to stimulate the rooting of Viburnum that had been depressed by N applications.

Burstrom (17) reported a continuous supply of calcium essential in a culture root medium. According to Chapman (24) calcium deficiency symptoms in plants appear first as a definite impairment of root growth accompanied by root rotting. He showed how chrysanthemum plants become severely stunted with roots short, thick, dirty brown, and finally decomposing. Root hairs also die as calcium becomes deficient. Cormack (28) found normal production of root hairs in an aqueous medium is dependent on sufficient calcium along with suitable pH. He stated that calcium is essential for hardening of cell walls, by combination with pectic acid, and that pH regulates the rate of this action.

pH and root growth curves normally reach an optimum near 6.0, with the acid side more depressive. Calcium deficiency in the medium aggravates this pH effect. Root growth is permitted in low pH solutions by an abundance of calcium. At pH 4.0 the low growth rate is caused by an inhibition of cell multiplication rather than by a low rate of elongation. As this inhibition of cell multiplication is alleviated by addition of calcium ions, the action of calcium seems to be an antagonism against toxic concentrations of hydrogen ions (17). In another study, Burstrom (16) reported an interdependence between calcium and auxin. This likely depends upon some mutual interaction in the formation or stabilization of the wall. The initial cell elongation is stimulated by auxins. The second step requires calcium during deposition of new cell wall materials. At pH 6.0 calcium is a definite elongation factor.

Sanderson et al. (109) demonstrated that carnation plants are able to develop a "physiological resistance" to bacterial wilt (P. caryophyllus) through liming acid or highly fertile soils with $CaCO_3$. It is not clear whether this effect is due to Ca or a result of lowering the H^+ ion concentration. Arnon and Johnson (3) stated that Ca is not readily absorbed at pH 4.0 or 5.0 due to the competition from H^+ ions. This condition can be corrected by maintaining high Ca levels in solution. Citrus trees growing in aerated water culture were severely affected by root rots when Ca levels were low or deficient. Adequate Ca nutrition enabled the trees to resist rotting and anaerobic conditions. This factor is relevant to all high Ca requiring crops (25). Bukovac and Wittwer (14) assumed the immobility of Ca within the plant results from a lack of phloem transport and polar movement. They showed how foliar applied Ca is readily absorbed by the leaf but its transport out is negligible with movement only toward the apex and periphery.

Boron is reported essential for healthy root development of cuttings, having its greatest effect on root growth rather than on initiation (89, 134). However, Weiser and Blaney (135) showed a synergistic effect between B and IBA in stimulating both root initiation and rate of development in holly cuttings. Working with

Clematis, Weiser (134) found B stimulatory on IBA action. Treatments with B in absence of IBA showed no response over controls. Murray et al. (89) assumed that B requirement of currant and geranium cuttings was evidence that B is essential for optimal sugar transport and therefore supply of carbohydrates to developing roots. Burstrom (17) reported B essential in a culture root medium. He suggested a mutual interaction might exist between Ca, B, and auxin in root growth. Measuring the curvature of bean stems, Mitchell et al. (86) found that B accelerated the translocation of NAA from bean leaves to stems.

Leaching of Minerals and Organic Metabolites. Mist for propagation has been reported to cause leaching of nutrients and organic metabolites from cuttings (63, 75, 128). Leaves of many varieties of cuttings develop severe chlorosis while under mist. It is suspected that certain organic materials needed for metabolism of the plant as well as essential elements are lost through leaching. Loss of metabolites may affect the ability to root and the subsequent growth of the cuttings. Under an intermittent mist system, on for five seconds each minute from 7 AM to 7 PM, the greatest actual loss occurred during the first several weeks. With Viburnum, 18% of the N and 26% of the P in the original cuttings were lost after four weeks under mist. After 6 weeks, 22% of the K and 26% of the Mg had been removed (63). Long et al. (75) showed how a continuous mist removed approximately 10% of the Ca, Mg, K, N, and P from plants within 48 hours. They also recovered the reducing material, galactan, as well as five amino acids from the leachate.

Old leaves, approaching senescence, are most subject to leaching loss (129, 144). The loss of nutrients is a direct function of time. If extended, this loss could equal several times the nutrients in the leaves. This means translocation from stems and roots is necessary, resulting in depletion of the entire plant. Surprisingly, deficient plants suffer the greater losses. Twice as much Ca^{45} was lost from Ca deficient plants as from normal plants. Phosphorus losses were 15 times as great from P deficient plants. Leaching from foliage cannot be regarded as an overflow mechanism for release of excess nutrients. Outdoor plants, subject to rain and dew, have a lower nutritional status than greenhouse or covered controls (129). Wittwer and Teubner (144) claimed that ion exchange and diffusion account for the losses reported during rainfall or heavy dew. Providing that no fixation or excessive soil leaching occurs, losses from rain could be recovered by roots (11, 129).

Tukey, Jr. et al. (130) found that the greatest amount of soluble carbohydrates are lost during periods of peak light intensity. They offered two explanations: 1. The solubility of newly formed carbohydrates makes them subject to leaching immediately after their manufacture. 2. Light may affect the removal pathway by increasing the amount of plasmodesmatal connections between the leaf surface and underlying mesophyl cells. This last possibility is supported by the research of Wittwer et al. (143). Tukey, Jr. et al. (130) further reported that carbohydrate loss may reduce the dry weight of misted plants by 4.8% in a 24-hour period. They found no correlation between temperature and carbohydrate loss.

Leaching losses are aggravated by mechanical injury (7), necrotic lesions (129), and spray material residues such as oils and salts (128). Sutcliffe (121) showed how acid rain water could remove metalic cations through cuticular H^+ ion exchange. Wetting agents in spray solutions, by reducing the hydrophobic properties of leaf surfaces, may increase leaching of nutrients (128). Bahn et al. (7) found great variation between species and individual plants in their susceptibility to leaching losses.

Roots readily lose nutrients by passive processes when placed in distilled water (121). According to Emmert (38), there is evidence that ion losses from roots may have an important effect on the overall nutrient status of the plant. These losses may cause considerable reduction in the nutrient content of the tops. He showed that foliar absorbed radioactive P definitely passed into the roots of plants and on into solution. Breazeale et al. (13) reported that tomato plants, growing in a saturated atmosphere with roots in stoppered flasks, exude nutrients into these empty flasks. Analysis of this exudate in ppm: Ca-50, Na-11, PO_4-28, NO_3-27.

The loss of nutrients through leaching may affect yield, quality, disease susceptibility, and nutritional disorders (129). Tukey and Tukey, Jr. (128) emphasized that the nutritional status within the host affects susceptibility to disease. They claimed it possible that moist conditions associated with severity of some diseases may actually affect the nutrient balance and therefore susceptibility.

Foliar Application of Fertilizers. Sutcliffe (121) claimed that aquatic vascular plants obtain most of their nutrient supply through leaf surfaces. He stated, "Terrestrial plants which do not normally absorb salt in this way will readily do so when salt solutions are applied to the leaf surface." Joiner and Gruis (63) investigated the possibility of supplying the nutrients to mist propagated ornamentals through foliar applications. They found the use of urea nitrogen raised N tissue levels in all their experiments but had no beneficial influence on rooting and actually reduced rooting of Viburnum. Propagating with nutrient mist, Wott and Tukey, Jr. (145) were able to raise the content of N, P, and K in the treated plant tissue over that found in the controls. They used a solution of 23-19-17 applied at the rate of 4 oz./100 gallons of water. There was a specific rooting and growth response to nutrient mist for each ornamental species tested.

Mechanism of Foliar Absorption. Important factors effecting foliar absorption are surface area, shape, and arrangement of leaves. Dicotyledons are more efficient than are monocots (121). Foliar absorption is a linear function of time (39, 65) and is clearly dependent on the length of time an aqueous solution remains in contact with the leaf surface (121). High relative humidity is a favorable condition (121, 132, 144). Jyung and Wittwer (65) reported that light stimulates foliar absorption. However, other workers showed that the greatest absorption of urea occurs at night (132, 144). Wittwer et al. (143) stated that ectodesmata, the interconnecting cellular strands, are most abundant during the evening and early morning hours. These ectodesmata are located most abundantly where the best absorption pathways exist: epidermal cells above veins, leaf hairs, and stomatal guard cells. Turgid leaves contain more ectodesmata than do wilted ones.

The entry point of nutrient ions into leaves is the subject of much discussion and contradiction in the literature. Boynton (11) showed that penetration occurs through both cuticle and stomatal apertures, depending upon the materials being considered and the plant species. He further reported that stomata have the greatest effect for short periods whereas the cuticular means is equally effective over time. Dybing and Currier (36) found the stomata a rapid source of entry when the proper surfactants and concentrations are used. However, Wittwer and Teubner (144) claimed that surfactants or wetting agents did not have a dominant role in mineral uptake by foliage. Rodney (108) reported equal penetration from upper or lower surfaces of apple leaves which have no stomates on their upper surfaces.

Boynton (11) showed that nutrients are absorbed through the leaves over a considerable period of time and that penetration occurs when leaves appear dry. Thin aqueous films, associated with transpiration, are frequently more important than the original aqueous carrying solution for absorption of mineral nutrients.

Younger leaves consistently show the greatest uptake (26, 121, 144). Sutcliffe (121) assumed that structural differences may be important. The proportion of surface covered with stomates is greater in young expanding leaves. Stomates are formed early and guard cells mature before the rest of the epidermal cells (11). Young leaves are also more lightly cutinized (121, 144).

Ease of wetting depends on fat content of cuticle, surface tension of applied solution, and number of appendages (121). Van Overbeek (98) stated that contact between a solution and the cuticle results in turgidity that stretches and separates the wax particles of cuticle. This stretching of wax particles or platelets during hydration favors penetration of ions into leaf tissue (143) and absorption by ectodesmata (61). Therefore, a "dry" cuticle or less turgid leaf is tighter (143). All absorption pathways into the leaf must overcome cuticular substances since even substomatal chambers are protected with an internal cuticle (144, 147). Cuticle is a barrier to penetration that can be overcome (36). Cations pass through cuticular membranes more readily than do anions (143).

Roberts (107) showed that bands of very water absorbent pectinaceous materials, within the cuticle of apple leaves, extend from outside of the leaf to the walls of interior veins. He reported that water soluble materials such as N compounds, minor elements, and hormones enter leaves through these pectinaceous channels.

Translocation within the plant of the absorbed nutrients is an essential feature for the efficiency of foliar applications. Wittwer et al. (143) found that rates of both absorption into and transport from leaves is most rapid with the major elements. Foliar absorbed nutrients are initially transported within the phloem (14, 144). Wittwer and Tuebner (144) showed this to occur as an active process, retarded by low temperatures. Bukovac and Wittwer (14) stated that mass flow of foliar absorbed nutrients is unlikely due to differences between ion species like K^+ and Ca^{++}. They claimed that lack of mobility within the plant may lead to symptoms of malnutrition as readily as will lack of nutrient absorption or availability. Calcium is immobile within the phloem transport system with a similar situation in regard to magnesium. Sutcliffe (121) reported that young leaves, functioning as both sources and sinks, retain much of the absorbed nutrient salts. Older leaves, functioning as sources only, transport them via the phloem system.

Section 5. Medium Temperature

Maintenance of temperature between 65-75° within the rooting medium is generally advised (51). Within the same species, somewhat higher temperatures are optimum for propagation than are optimum for growth. Both surrounding air and medium temperature are important when rooting cuttings. A bottom heat or medium temperature of 5-10° above air temperature is generally desirable. This differential promotes root growth without stimulating top growth which would use up carbohydrate reserve. Trial and error has indicated that root inducing substances are not effective unless the medium temperature ranges from 65-75°. Though not always true, this is a likely rule for herbaceous non-resting cuttings (127).

Mercado-Flores and Kester (84) maintained temperatures of 60, 70, and 80° for a three-week period when rooting hardwood almond cuttings. The 70° treatment provided the best rooting with 80° being poor and actually injurious. The cuttings rooted at 60°, though appearing somewhat inferior to the 70° group, had a better final survival rate in the nursery.

Heating of irrigation water, or otherwise manipulating soil temperature, has no effect on yield, grade, quality, or timing of carnations during flower production (57, 113). Knight et al. (71) reported that the speed of rooting carnation cuttings is governed by the amount of bottom heat used. Carnation cuttings required one month to root in February without bottom heat, though 100% rooting was obtained. Esper and Roof (41) rooted carnations 4-16 days faster in winter with 70^{o} bottom heat compared to 60. In bright spring weather the difference was only 3-4 days. Occasionally, the 60^{o} plot produced higher rooting percentages during sunny spring weather. Esper and Roof did this propagating in 1931, before the use of root inducing substances or mist.

In 1939, Kirkpatrick (70) showed that carnations rooted about 4 days faster at 80 than at 70^{o}. The same year, Hitchcock and Zimmermann (56) studied the effects of both medium temperature and root inducing substances on carnation cuttings. They obtained a better response from a medium temperature of 78-80 than from $70\text{-}73^{o}$. The beneficial effect of bottom heat was gained through quicker root initiation and increased rate of root growth. They found that cooler media temperatures required more concentration of root inducing substances.

Using intermittent mist, Wilkins and Kamp (142) observed that carnation cuttings, not treated with root inducing substances, rooted best at 65^{o}. Root systems were somewhat poorer at 70 and 75^{o}. Holley and Baker (58) recommend maintenance of a 50^{o} air temperature, whenever possible to reduce top growth, together with approximately 10^{o} higher medium temperature. In connection with bottom heat, they state that uneven rooting may be due to excessive depth of media or shallow sticking of the cuttings.

Section 6. Spacing of Cuttings

While no publications have been found on spacing of carnation cuttings in the propagation bench, many papers on other crops supply evidence that adequate space and light for the cuttings is essential to rooting and subsequent growth. Hartmann and Kester (51) reported that in the growing of nursery and forest planting stock the aim is to produce a maximum yield of high quality plants. Low stand density reduces yield per unit area. Excessive density results in decreased size and quality.

Before the discovery of stimulatory effects of auxins on root development, it was known that cuttings required adequate carbohydrate reserves for successful rooting. Starring (116), in 1923, stated that cuttings low or lacking in carbohydrates were not able to develop roots. He claimed that plants slightly yellow and appearing to lack vigor, being high in carbohydrates, produced better rooted cuttings than did lush, vigorous plants.

Because of the importance of the leaf in root development inadequate space in the propagation bench may be detrimental to cutting quality. A study with coleus cuttings by Calma and Richey (19), in 1930, revealed that the rate and amount of root growth was directly related to the amount of leaf area on the cuttings. They questioned the common practice of partially defoliating cuttings to prevent excessive wilting. Though cuttings that were not defoliated exhibited greater wilting during daylight, they rooted quickly and in a superior fashion. Calma and Richey believed that reserves and newly synthesized food materials in leaves were used by the cuttings to develop roots. They showed how defoliation of one side of a cutting resulted in heavier rooting on the leafy side. Once the coleus cuttings had formed roots, the tops began to resume growth. The following year, experiments by Esper and Roof (41) also indicated that root development and growth were proportional to the amount of leaf surface exposed. They found that carnation cuttings, having little leaf area exposed, are not benefited by defoliation. Chrysanthemum cuttings that were not defoliated grew one third taller while in the cutting bench.

More exact knowledge concerning the function of the leaf was revealed in studies by Van Overbeek and co-workers during the mid 1940's. They found that cuttings of a white Hibiscus variety, difficult to root, would not respond to auxin treatment unless leafy twigs of an easily rooting red variety were grafted to it (100). They were able to replace the leaves of the red Hibiscus by supplementing sucrose and nitrogenous substances like arginine or even NH_4SO_4. Chemical analysis showed that these types of material were actually contributed by leaves to the cuttings (97). The primary function of the leaf is to provide nutrition for root initiation. The number of roots increased with the number of leaves (99). For deciduous plants like grapes, the presence of active buds in the process of growth are essential for root development. Grape cuttings will not strike roots in early winter though they do so in late winter and spring.

The absorption spectrum for chlorophyll is similar to that promoting the best root development in cuttings. This is considered empirical evidence that photosynthetic products are the stimulants (5).

Tukey (127) reported that CO_2 applied to propagating frames by two French researchers (Mauri and Mauri) increased rooting ability of cuttings. This was especially true when the cuttings had been treated with root inducing substances. In fact, they found that in the presence of CO_2, the concentration of these substances could be increased well above normal without causing injury.

Section 7. Evaluation of Cuttings

Altstadt (1) showed fresh weight a most accurate measurement of carnation cutting quality, providing the percent dry matter remained fairly constant. The percent dry matter was a less reliable measurement than either fresh or dry weight. Odom (92) reported dry weight measurements an indication of reserve food supply in carnation cuttings.

The Index Rank System. The number of roots per cutting has proven a more reliable measure of response to root inducing substances than percent rooted (56). Mahlstede and Lana (81) found no large loss of information through grading by personal judgment when compared to exhaustive weighing and measuring of roots. They stated, "The method of ranks (assignment of arbitrary index numbers) is a simple one which can be used accurately to determine differences in rooting response of cuttings". According to Stoutemyer (119), the grading of cuttings by visual observation has consistently yielded conclusions similar to those obtained by careful statistical analysis of dry weight of roots. He claimed that effects would not show up through more detailed analysis if they were not observed by visual inspection.

Methylene Blue Dye Method. The fact that methylene blue dye is readily absorbed by roots can be used to evaluate the rooting quality of cuttings. Roots are washed under the tap and the cutting is placed for 10 minutes in a 0.05 mg/liter solution of methylene blue dye. The roots and solution should be swirled occasionally. Next, the roots are transferred to a beaker containing a measured amount of acidified isopropyl alcohol solution. This is a 25% alcohol solution with 5 ml of concentrated HCl/liter. After 10 minutes in this alcohol extracting solution, the cuttings are removed. The light transmittancy of this alcoholic dye solution is then read at a wavelength of 620 mu. The colorimeter is standardized at 100 using the alcohol extracting solution. The percent transmittance recorded is taken as a measure of the amount of roots. This method is closely correlated with the index ranking system as an evaluation of root development on cuttings. However, the dye method is more sensitive. It actually measures the absorptive capacity of roots and has distinguished a significant difference in favor of a well aerated media, when statistically analyzed. This difference was not distinguished by the index ranking technique (34).

CHAPTER III

METHODS AND RESULTS

General Methods and Materials

Physical Facilities. The north half of a greenhouse was used for this research. A polyethylene film baffle 10 feet in height down the center of the house and across the fan end served to contain the mist and prevent excessive air movement. Four raised wooden benches were constructed 14 feet long and 6 inches deep. One bench was 3 feet wide, two were 4 feet and the fourth was 5 feet in width. These widths were designed to give the facilities flexibility in studying layout of mist lines and determining efficiency for commercial application. The bottom boards, 3 inches wide, were spaced 3/8 of an inch apart for adequate drainage.

Lead encased electric heating cables were laid at 6-inch intervals over a 1-inch layer of scoria. A layer of 3/4" mesh galvanized hardware cloth was placed directly on these cables to spread the heat evenly. Media under test were placed on saran screen directly on the hardware cloth.

Mist was provided by "Florida" deflection nozzles tapped into 3/4" galvanized pipe suspended 2 feet above the media. On the 5-foot-wide bench a double mist line containing 10 nozzles was used. The other 3 benches had single center lines of 6 nozzles. Movable fiberglass panels prevented drift between benches. Each mist line was connected to a solenoid valve.

A mist timing device, gift of Fred C. Gloeckner & Co., was used to adjust intermittent mist cycles. This timer was restricted to daylight use by a 24-hour time clock. An electric cord connected to the solenoid valves could be plugged into one of six outlets on the timer for the desired mist interval and frequency.

Propagation Procedures. Carnation cuttings were broken from stock plants in such a way that the basal end always consisted of a section of internode (Figure 1). This assures morphological uniformity of the tissue from which the roots initiate and develop. This method provides good connection between the new roots and the vascular system of the young carnation plant. No peeling or handling of the cutting base is required. Cuttings taken in this way can be handled more easily and inserted in the medium with a minimum of effort.

As a result of tests with many commercial root inducing "hormone" preparations, as well as chemical compounds known to stimulate root development, the commercial product Jiffy Grow # 2 was selected for use. Jiffy Grow # 2 is a concentrated alcohol preparation consisting of the following:

Component		Concentration
NAA	a - naphthalene acetic acid	5,000 PPM
IBA	3 - indolebutyric acid	5,000 PPM
Boron	as boric acid	0.0175 %
PMA	phenyl mercuric acetate	0.01 %
Propylene glycol	(surfactant and solvent for PMA)	"small amount"
Alcohol	(90% ethanol and 10% isopropanol)	46 %

Fig. 1 Cutting removed by two-hand method (left) and lower row; upper row removed from stock plant by one hand.

Fig. 2 Grading system used for obtaining rooting score; top row rooted in peat perlite mix; bottom row rooted in perlite.


4 3 2 1 0

This mixture was diluted 1:15 with tap water and applied to the cuttings as a foliar spray on the first evening after they were stuck. The spray was applied after sunset so the aqueous solution could remain on the foliage for the maximum possible time. Mist on the cuttings at application time was removed by hand watering.

A peg-board was constructed by driving 2" cut nails through holes drilled in marine plywood at 1½" spacing. This board facilitated uniform spacing of cuttings at a constant depth, 64 per square foot. Benches were always steamed within 48 hours before a lot of cuttings were stuck. After sticking, the cuttings were watered in with a high volume, low pressure nozzle. A preliminary test showed that this procedure, a regular commercial practice, was important when rooting cuttings in horticultural perlite.

Intermittent mist was applied at intervals sufficient to maintain a constant water film on all leaf surfaces during daylight hours. The amount of mist actually delivered on cuttings was measured by placing test tubes adjacent to the cuttings and recording the accumulated water daily. This acted as a check on the system as well. If for any reason either too little or too much mist was applied, the fact could be recognized.

Experimental Design

A replicate consisted of 25 (5x5) uniform cuttings. The cuttings most heavily rooted were awarded 4 points each on a 4, 3, 2, 1, 0 grading system (Figure 2). By using 25 cuttings as a sample, 100 points would be a perfect score. Each block of 25 cuttings was surrounded

TABLE 1. Physical Properties of 12 Media and Rooting Score after 14 Days.

Medium	Mean score	% marketable	Medium Properties 1/ pH	% Water	% Air
A. Horticultural perlite	72.8	65	6.2	41.7	36.7
B. Coarse perlite	56.0	39	6.1	32.9	47.5
C. Medium perlite	57.8	40	6.0	36.7	42.3
D. Medium coarse perlite	54.8	38	6.1	36.3	48.2
E. Fine perlite	63.5	57	6.7	59.7	23.3
F. Standard perlite	70.0	64	6.1	38.8	42.2
G. 9:1 Standard perlite, peat	58.0	38	6.6	41.2	44.5
H. 7:3 Standard perlite, peat	56.8	37	5.1	44.2	39.4
I. 4:1 Coarse perlite, peat	35.5	7	5.3	36.8	46.5
J. 3:2 Coarse perlite, peat	36.0	8	5.0	43.2	41.4
K. 2:3 Coarse perlite, peat	40.0	12	4.9	46.1	40.4
L. 1:1:1 Horticultural perlite, peat, Terragreen	82.0	83	6.3	45.2	37.0

1/ Water and air expressed as % of total volume at bench capacity.

by sufficient buffer rows to eliminate border effects. Usually one row was considered sufficient (72). Whenever an extended time period of several hours was required for sticking or lifting cuttings, or for collecting data, operations were done by blocks to reduce within-block variation (49). Randomization of cuttings and plot locations was observed throughout.

Recovery Rate. Rooted cuttings from each treatment were randomized into 3 replicates of 12 cuttings each and planted in soil. After approximately one month of growth, plants were cut just beneath the bottom leaf pair and weighed to the nearest 0.1 g. Fresh weight was considered indicative of recovery rate in response to a given treatment during the rooting phase.

Media

Methods. Aeration, water holding capacity, and pH were measured and correlated with rooting score obtained in 12 media. The following materials were used as components of these 12 media (Table 1):

Peat moss - Canadian sphagnum, pH 4.65, screened through 5 mm.

Horticultural perlite - Approximately 2 mm in diameter, commonly used for rooting cuttings under mist.

Standard perlite - A mixture of particle sizes, ranging from dust to 6 mm.

Coarse perlite - Particles retained on a 3 mm screen.

Terragreen - A brand of arcillite, particle size 1-4 mm.

Measurements were made of water and air contained in each medium at bench capacity, expressed as % of total volume. The measurements were made as follows:

1. For each medium, 4 replications of 3" clay pots were soaked under water for 3 days, numbered and their capacity recorded in cc of water. Tare weight of the wet pots was obtained in grams.
2. Following weighing, each pot was filled level full with a sample of air dried medium and weighed.
3. The pots were then plunged to the rim in plots of the same medium and soaked under constant mist for 3 days. They were weighed at bench capacity and the water content calculated.
4. After weighing, each pot was plugged at the bottom and water added until visible at the top of the medium. The volume of water added was assumed to represent the open pore space.

The measurements were used for comparative purposes in order to reveal cause and effect relationships. The weights and measurements at bench capacity were made three times: before steaming, after steaming, and one day after lifting the cuttings. This would reveal changes taking place in a given medium as a result of steaming or of time under mist. pH measurements were made before sticking and after lifting cuttings.

Cuttings of Flamingo Sim were stuck 11 August 1966, 100 per medium plot and adjacent to the 4 pots. Intermittent mist was applied from 6 AM to 6 PM, using a 20-sec duration with an interval of 3.75 min. Average mist delivered per day was 3.7 cm. Bottom heat was not necessary during August. The cuttings were lifted after 14 days on 25 August and graded for rooting score.

Cuttings from two of the best scoring media were stored in plastic bags at 33^{o} for 2 weeks and planted for recovery rate evaluation. The young plants were harvested 22 days later and their fresh

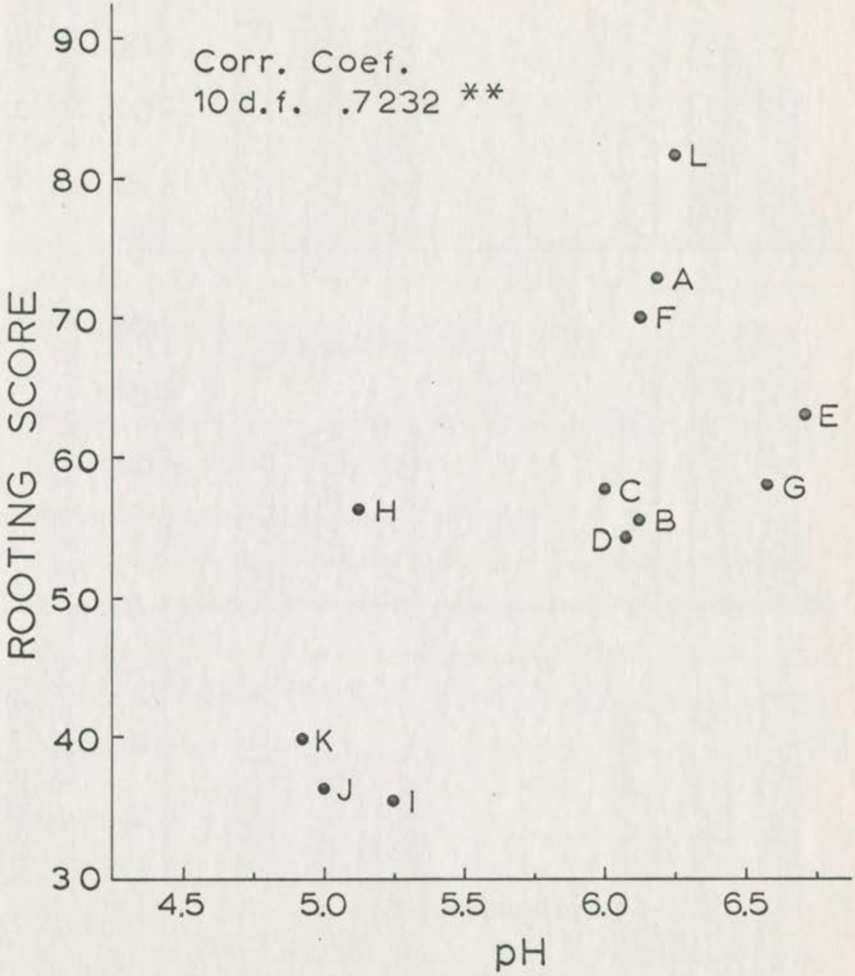


Fig. 3 Relationship of rooting score to pH in 12 media.

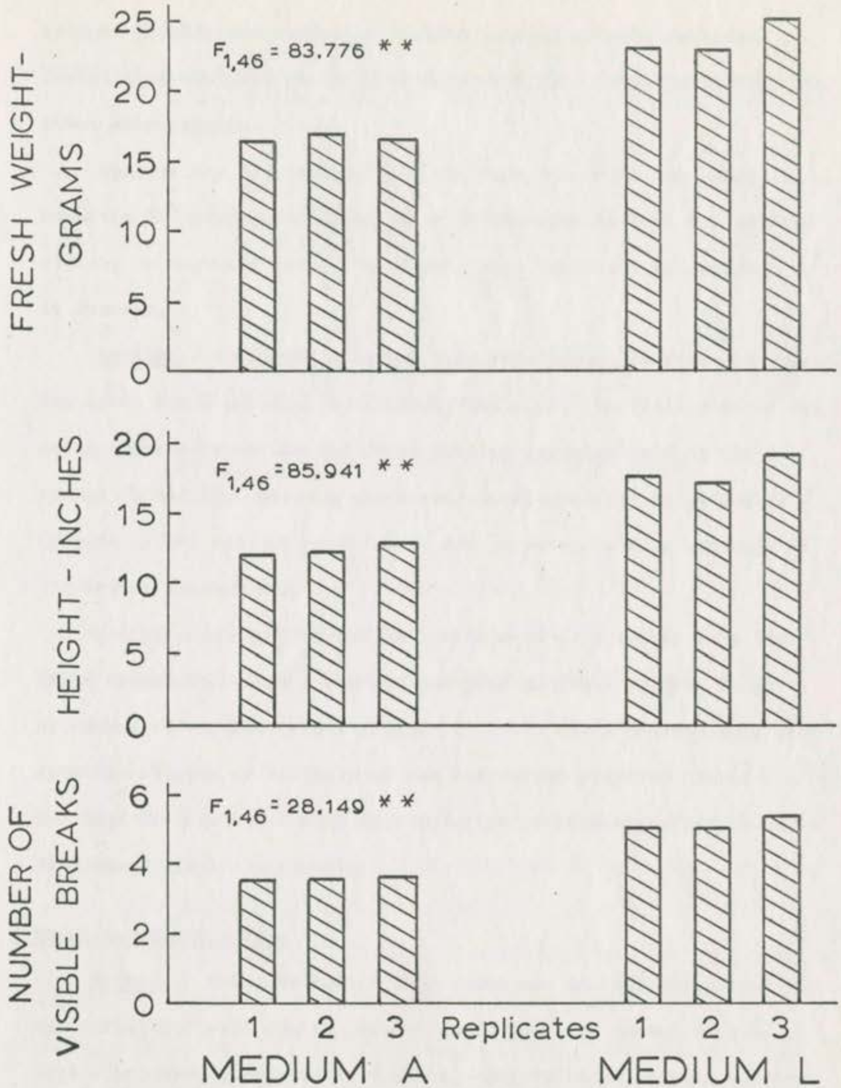


Fig. 4 Height, weight, and number of visible breaks one month after benching cuttings propagated in 2 media.

weight, height, and number of visible lateral growths recorded. Correlation analysis was used to determine relationships between the three measurements.

Another set of cuttings from the same two media were kept 15 weeks in 33^{o} storage and planted on 10 December to test for storage effects on recovery rate. The plants were harvested and weighed on 14 January.

Results. The media affected root development as shown by rooting score and % marketable cuttings (Table 1). Particle size of the media affected aeration and water holding capacity only at the extremes (B and E). Rooting score was closely related to medium pH (Figure 3) but was not effected by air or water holding capacity of the medium (Appendix A).

Rooted cuttings from medium L recovered at a faster rate than those rooted in medium A whether measured as fresh weight, height, or number of visible breaks (Figure 4). All three measurements were equally reliable as criteria of recovery after planting (Table 2). Cuttings from medium L were also superior in recovery after 15 weeks of storage (data not shown).

Media and Rooting Time

Methods. From the media study there was an indication that pH was correlated with rooting score. A pH near 7.0 seemed optimal. This experiment consisted of 6 media, ranging in pH between 6.0 and 7.25. Twelve plots were divided into 2 north-south blocks with the 6 media shown in Table 3 placed at random within blocks.

TABLE 2. Correlation of fresh weight, height and number of visible breaks as measurements of recovery rate on young carnations.

Source of variables	Variable x	Variable y	d.f.	Corr.coef.
All 72 plants in	weight	height	70	0.859**
recovery trial	weight	breaks	70	0.758**
	height	breaks	70	0.557**

Corr. coef. 70 d.f. (05) = 0.229 (01) = 0.298

Cuttings were stuck in 3 groups, each 3 days apart. The first group, stuck on 7 November 1966, occupied the west third of a bench. The second and third groups were stuck in the central and east thirds, respectively. Cuttings of varieties S. Arthur and Gayety were randomized by sticking one complete row at a time across all 12 plots. A temperature of 70° was maintained in the media. Intermittent mist was applied from 7 AM to 4 PM, using a 15-sec duration with an interval of 3.75 min, delivering 2.1 cm per day.

All the cuttings were lifted on 26 November and graded for rooting score. There were 6 media treatments, replicated twice, and 3 day treatments for a total of 36 sample blocks. Cuttings from the three best media were planted out 10 December for recovery rate evaluation. There were 3 media and 3 days replicated 3 times for a total of 27 sample groups. Plants were harvested on 14 January and individual fresh weights recorded.

TABLE 3. Rooting score and percent marketable cuttings in 6 media at 3 time intervals.

Media	pH	Mean Score			Percent marketable		
		13 days	16 days	19 days	13 days	16 days	19 days
A. Horticultural perlite	6.8	67.0	72.5	89.5	70	78	100
B. 1-1-1 Hort. perlite, peat, Terragreen	6.3	63.5	79.0	81.0	56	88	80
C. 1-1-1 Hort. perlite, peat, Turface	6.2	57.5	71.5	88.5	42	80	94
D. 2-2-1 Hort. perlite, peat, Terragreen	6.3	52.0	63.5	78.0	20	54	78
E. 7-3 Hort. perlite, peat plus 50 g $CaCO_3/ft^3$	6.5	60.5	69.5	84.0	52	68	84
F. 7-3 Hort. perlite, peat plus 100 g $CaCO_3/ft^3$	7.2	76.0	78.5	88.5	82	88	88

Results. Both media and length of time in the propagating bench affected rooting score (Table 3) though there was no interaction between the two factors (Appendix B).

Rooted cuttings from media A, B, and F were planted out for recovery trial. Although the three had similar and generally superior rooting scores, it was important to determine whether cuttings from B or F performed best after planting. The better of the two could then be used in subsequent experiments. A, the medium currently employed by most propagators, served as a standard. Gain in fresh weight from unrooted cuttings (average weight 7 g) was affected by media and time in the propagating bench (Figure 5). The interaction

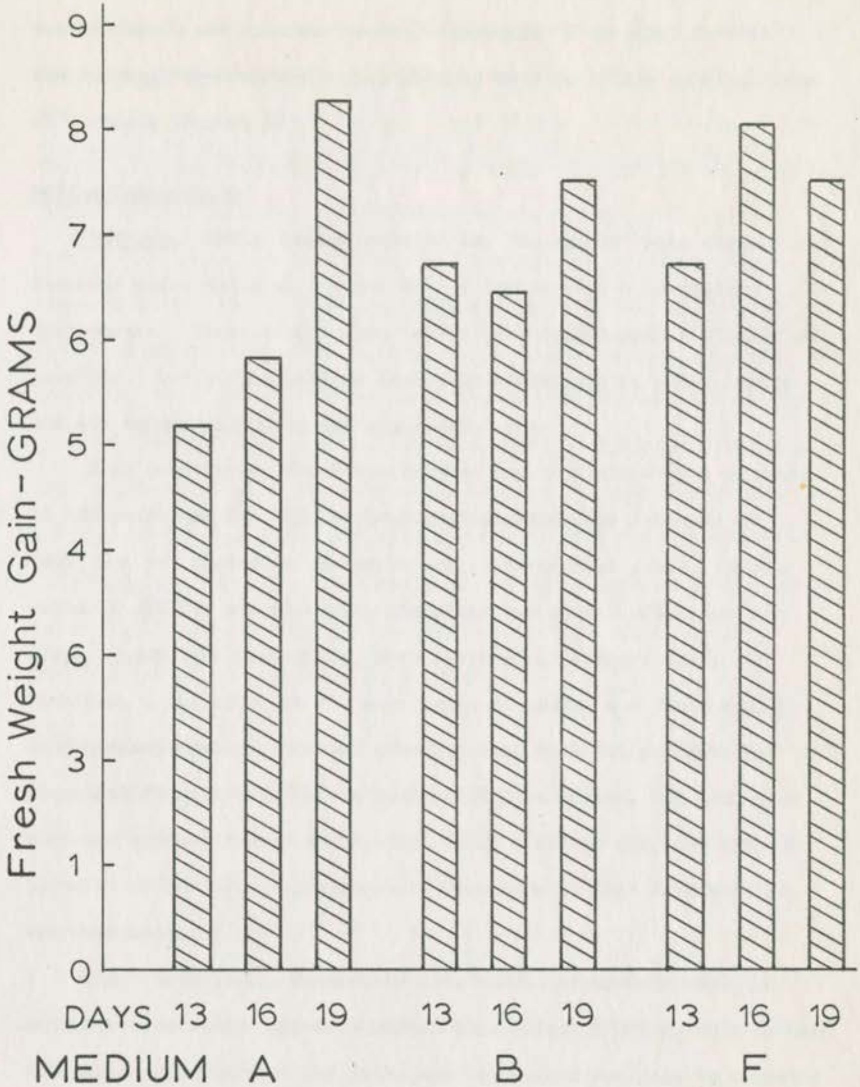


Fig. 5 Relative fresh weight gain 1 month after benching cuttings rooted in 3 media and removed from the propagation bed at 13, 16, and 19 days.

The top 4 bars not significantly different according to Duncan's New Multiple Range Test.

between media and time on recovery (Appendix C) revealed that 16 day cuttings from medium F recovered as well as 19 day cuttings from all 3 media (Figure 5).

Medium Temperature

Methods. Media temperatures of 60, 70, and 80^{o} were checked and recorded twice daily at a depth of 1.5 inches with a laboratory thermometer. These temperature levels were maintained as closely as possible. Daily fluctuations caused by variations in solar energy and air temperature were not compensated for.

Each temperature bench was divided into 4 plots with a mixture of 30% peat moss and 70% horticultural perlite plus 5 pounds of $CaCO_3$ per yd^3 placed in the north and south-central plots. Horticultural perlite was placed in the other two plots. Pink Sim cuttings, graded for uniformity, were stuck on 29 January 1967. 40 cuttings, 1 out of every 25, were taken at random for fresh and dry weight measurements so actual growth during both the propagating phase and the recovery rate trials could be measured. Intermittent mist was applied from 8 AM to 4 PM, using a 10-sec duration with an interval of 3.75 min. Measurements were made of mist delivered to each medium plot.

The 3 temperature treatments were lifted separately when the majority of cuttings appeared marketable. After grading, 10 from each subsample were prepared for fresh and dry weight analysis by removing the roots and washing. The remainder was placed in 33^{o} storage and planted for recovery rate on 4 March. When harvested 1 April, the 12 plants in each replicate were weighed as a group.

Results. Media temperature affected length of time needed by carnation cuttings to develop satisfactory root systems. The 80 and 70° treatments were lifted after 14 and 15 days respectively, whereas the 60° lot was not ready until the 23rd day. Though lifted on different dates, there was no difference in rooting score (Table 4). Fresh weight gain during rooting was greatest in the 70° treatment whereas the 60° plot showed the greatest dry weight accumulation. The fresh weight gain during rooting was associated with a medium and block interaction as a result of different mist delivery to the 4 plots. Analysis of covariance showed that fresh weight increased with increasing mist. Dry weight gain was not affected by medium during rooting though fresh weight gain was greatest in perlite.

Cuttings rooted in the limed peat-perlite mixture showed greater gains during the recovery period (Table 4, Appendix D). Recovery rate was not affected by medium temperature.

Foliar Feeding of Cuttings

Methods. Growth measurements were made both at lifting and after recovery trials. Cuttings from the same lot used in temperature experiments were stuck with 70° temperature treatment. The 70° treatment was used as the untreated control group with misting procedure, media, and weight measurements the same as described under Medium Temperature. Recovery trials of the 2 experiments were also integrated.

Two complete nutrient solutions, donated by the NaChurs Plant Food Company, Marion, Ohio, were tested. The ratio of major elements

TABLE 4. Effects of 3 temperatures and 2 media on rooting and top growth of carnation cuttings. 1/

Treatment		Rooting Score 2/	Rooting Gain in fresh weight g 3/	Rooting Gain in dry weight g 3/	Recovery Gain in fresh weight g 4/
80°	mix	86.3	12.6	2.21	144
	perlite	91.3	19.0	2.92	117
	mean	88.8	15.8	2.56	130
70°	mix	80.8	17.0	2.78	122
	perlite	91.0	24.4	3.14	127
	mean	85.9	20.7*	2.96	124
60°	mix	84.3	17.1	3.79	149
	perlite	80.0	17.4	3.78	117
	mean	82.2	17.2	3.79**	133
Media means					
	mix	83.8	15.6	2.93	138*
	perlite	87.4	20.3**	3.28	120

1/ Cuttings were lifted and stored when the majority were marketable.

2/ Mean of 100 cuttings, 2 replicates of 2 subsamples.

3/ Mean of 4 subsamples of 10 cuttings.

4/ Mean of 3 replicates of 12 plants. Weight gained from rooted cuttings.

and their concentrations were:

	N P K	Dilution for application:	Concentration applied: %
Treatment A	2- 20- 18	1:3 (tap water)	.5 - 5 - 4.5
Treatment B	10- 20- 10	1:3 (tap water)	2.5 - 5 - 2.5

The dilute liquid fertilizer was applied at dusk with a 2-gallon garden sprayer, using relatively high pressure with the finest adjustment. Mist was washed from the cuttings before application. Three applications were made at 2 day intervals, beginning when visible roots began to emerge from the cutting base. The first was made on 7 February, 9 days after striking. Eight sample groups of cuttings were subjected to each treatment. During the spraying operation individual groups were enclosed with a plastic covered box, having an opening in the top. This protected adjacent groups not being treated. For experimental uniformity, tap water was sprayed on the control plots.

Results. Nutrient solutions applied to the foliage depressed both fresh and dry weight accumulation while rooting but had no effect on rooting score (Table 5). No difference in recovery rate was measured. Media had no effects (Appendix E).

Mist Delivery, Media, and Spacing

Methods. Uniformly graded Pink Sim cuttings were stuck 8 March 1967 under 3 mist levels. Within each mist level were 3 randomized blocks containing 2 media. Cuttings were stuck at 4 spacings to

TABLE 5. Effects of liquid foliar feeding at the end of the rooting period on rooting and top growth.

Treatment	Rooting Score 1/	Rooting Gain in fresh weight g 2/	Rooting Gain in dry weight g 2/	Recovery Gain in fresh weight g 3/
A. 2-20-18				
mix	76.3	11.4	2.11	127
perlite	83.5	11.8	1.59	130
mean	79.9	11.6	1.85	129
B. 10-20-10				
mix	86.8	14.2	1.98	142
perlite	84.3	19.0	2.56	115
mean	85.5	16.6	2.27	129
C. Control				
mix	80.8	17.0	2.78	122
perlite	91.0	24.4	3.14	127
mean	85.9	20.8	2.96	124
Media means				
mix	81.3	14.2	2.29	130
perlite	86.3	18.4	2.43	124

1/ Mean of 100 cuttings, 2 replicates of 2 subsamples.

2/ Mean of 4 subsamples of 10 cuttings.

3/ Mean of 3 replicates of 12 plants. Weight gained from rooted cuttings.

complete the design. The number of treatments totaled 24. The main plot levels were as follows:

Treatment	Days	Interval min.	Duration sec.	Hours/day	Mist delivered/ day cm
A	1-15	3.75	30	9	8.32
B	1-15	3.75	10	9	2.32
C	1-11	3.75	10	9	2.45
	12	7.50	10	6	.90
	13	7.50	10	4	.60
	14	7.50	10	2	.30
	15		No mist		

Media used were perlite and the peat-perlite mixture described previously. Cuttings were spaced 3, 4, 5, and 6 cm. Because of the different spacings, Jiffy Grow #2, diluted 1:20, was sprayed on the cutting bases with a hand atomizer rather than on the foliage. A 70° temperature was maintained in the media. Fresh and dry starting weights were obtained.

On the evening of 23 March, the cuttings were lifted and graded. Measurements of growth during the rooting phase (fresh and dry weight) were made on 10 cuttings per sample. Twelve of the remaining cuttings were stored and planted in flats on 29 March to measure recovery rate. The 72 flats were randomized on a greenhouse bench and rotated twice a week to minimize variation due to position.

Groups of growers evaluated appearance of the 24 treatments on 1, 8, and 15 days after planting by rating each treatment as good, fair, or poor. The recovery rate trials were harvested 30 April.

TABLE 6. Effects of 2 media, 4 spacings and 3 misting programs on rooting and recovery rate of carnation cuttings.

Density and misting program	Rooting: Score		Rooting: Gain in fresh wt. g 1/		Rooting: Gain in dry wt. g 1/		Recovery: Gain in fresh wt. g 2/	
	Mix	Perlite	Mix	Perlite	Mix	Perlite	Mix	Perlite
3 cm A	70.3	67.3	13.5	13.4	2.62	2.20	50	26
B	86.0	77.0	16.7	15.3	2.80	2.42	109	31
C	84.7	73.7	11.4	15.2	1.94	2.34	70	14
mean	80.3	72.7	13.9	14.6	2.45	2.32	76	23
4 cm A	84.3	74.3	20.0	15.1	3.85	3.82	83	50
B	86.3	83.3	16.6	14.5	3.08	3.44	100	69
C	90.7	81.3	19.4	10.9	4.02	2.49	92	48
mean	87.1	80.7	18.7	13.5	3.65	3.25	92	56
5 cm A	96.0	78.7	22.0	24.3	4.92	6.82	128	45
B	89.0	92.3	17.7	24.7	4.10	5.74	135	68
C	95.3	81.7	28.2	19.7	5.50	5.05	94	49
mean	93.4	84.2	22.6	22.9	4.84	5.87	119	54
6 cm A	85.0	80.3	19.9	26.6	6.62	6.68	127	64
B	91.3	83.3	14.6	20.2	4.80	6.29	120	79
C	93.0	82.0	22.9	22.2	5.49	6.52	127	67
mean	89.8	81.9	19.1	23.0	5.64	6.50	125	70
Mist level means A	83.9	75.2	18.8	19.8	4.50	4.88	97	46
B	88.2	84.8	16.4	18.6	3.68	4.47	116	62
C	90.9	79.7	20.5	17.0	4.24	4.10	96	44
mean for medium	87.7	79.9	19.4	18.5	4.15	4.48	103	51

1/ Mean of 3 samples of 10 cuttings.

2/ Mean of 3 samples of 12 cuttings.

Results. Media and spacing affected rooting score and growth during both propagation and recovery (Table 6). Rooting score was superior in the mix and depressed in both media by heavy misting at close spacings. Fresh weight gain during propagation was not affected by media, however, the optimal fresh weight gain in mix was at 5 cm spacing, while the optimal gain in perlite was at 6 cm. Dry weight gain for the same period increased with space.

Growers showed no preference between media the first day but favored the mixture by the second week. Mist preference also shifted from C to B during the first 2 weeks with A remaining last throughout. Spacing decreased in importance to the growers with time for recovery (Table 7).

Correlation analysis (Appendix G) shows that grower evaluation is not reliable when cuttings are first planted but increases in accuracy with recovery time. Rooting score was closely related to recovery.

Cuttings rooted in peat and perlite mix were superior in recovery rate. 5 cm was an optimal spacing in the mix while 6 cm was superior for perlite rooted cuttings. Mist level B made the greatest fresh weight gains during recovery in both media. Mist program A depressed recovery in the mix whereas C was depressive in perlite (Figure 6).

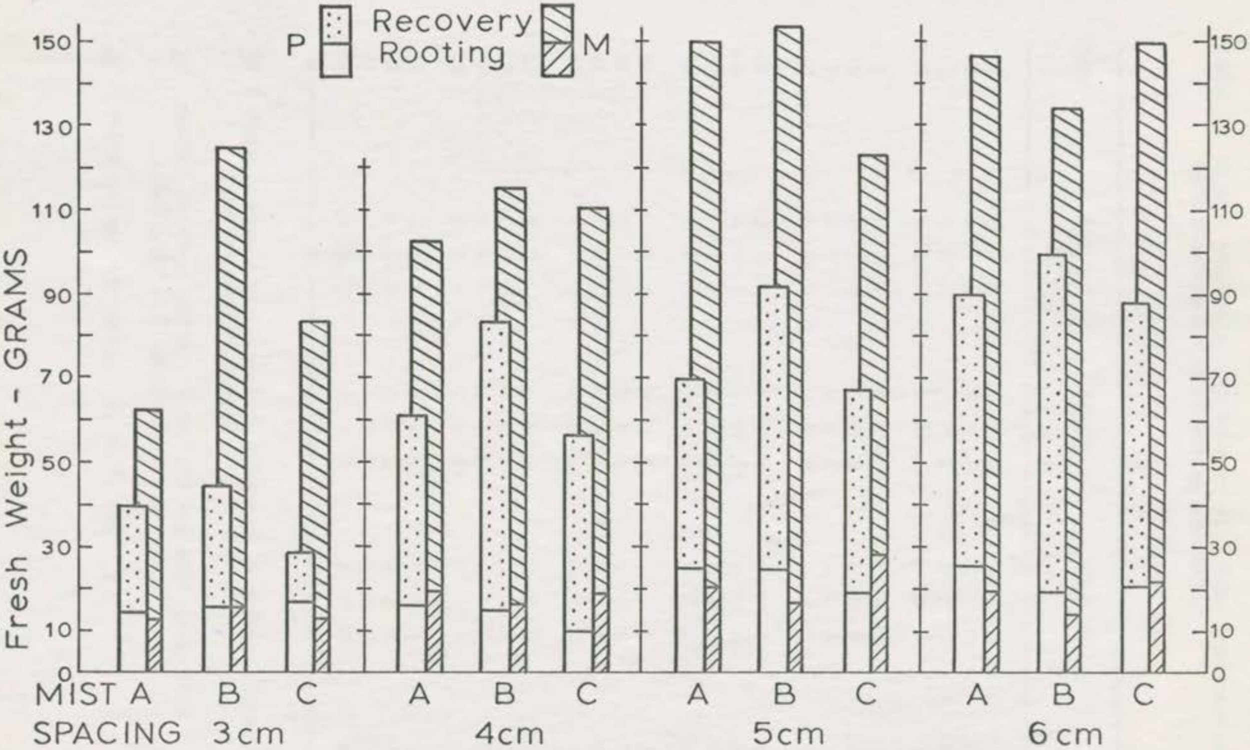


Fig. 6 Relative fresh weight gain during propagation and during the first month after planting for cuttings rooted under 3 misting programs in 2 media at 4 spacings.

TABLE 7. Grower evaluation of recovery at 3 time intervals compared with fresh weight gain during recovery.

Rank	Day 1 1/ 2/ 3/	Day 8	Day 15	Gain during recovery
1	C M 6	C M 6	A M 6	B M 5
2	C P 5	B M 5	A M 5	A M 5
3	A M 6	A M 5	B M 5	A M 6
4	B M 6	C M 5	C M 6	C M 6
5	B P 6	A P 6	C M 5	B M 6
6	C P 6	A M 6	B M 3	B M 3
7	A P 6	B M 6	B M 6	B M 4
8	C M 5	C P 6	C M 4	C M 5
9	A M 5	C M 4	C P 6	C M 4
10	A P 5	C P 5	A P 6	A M 4
11	C P 4	B P 6	B M 4	B P 6
12	B M 5	B M 4	B P 6	C M 3
13	C M 4	B P 5	A M 4	B P 4
14	B P 5	B P 4	C P 5	B P 5
15	C M 3	B M 3	B P 4	C P 6
16	C P 3	A M 4	A P 4	A P 6
17	B M 4	A P 5	C M 3	A P 4
18	B P 3	C P 4	B P 5	A M 3
19	B P 4	A P 4	A P 5	C P 5
20	A P 4	C M 3	C P 4	C P 4
21	A P 3	A M 3	C P 3	A P 5
22	A M 4	B P 3	A P 3	B P 3
23	B M 3	C P 3	A M 3	A P 3
24	A M 3	A P 3	B P 3	C P 3

1/ First column - mist levels; A heavy, B medium, C medium with gradual conditioning.

2/ Second column - media; M perlite and peat (7-3) plus 5 lbs $CaCO_3/yd^3$, P horticultural perlite.

3/ Third column - spacing; 3, 4, 5, and 6 cm.

Fig. 7 Relative growth 1 month after benching cuttings rooted under heavy mist (1 cm/hour - 9 hrs/day) in 2 media at 4 spacings.

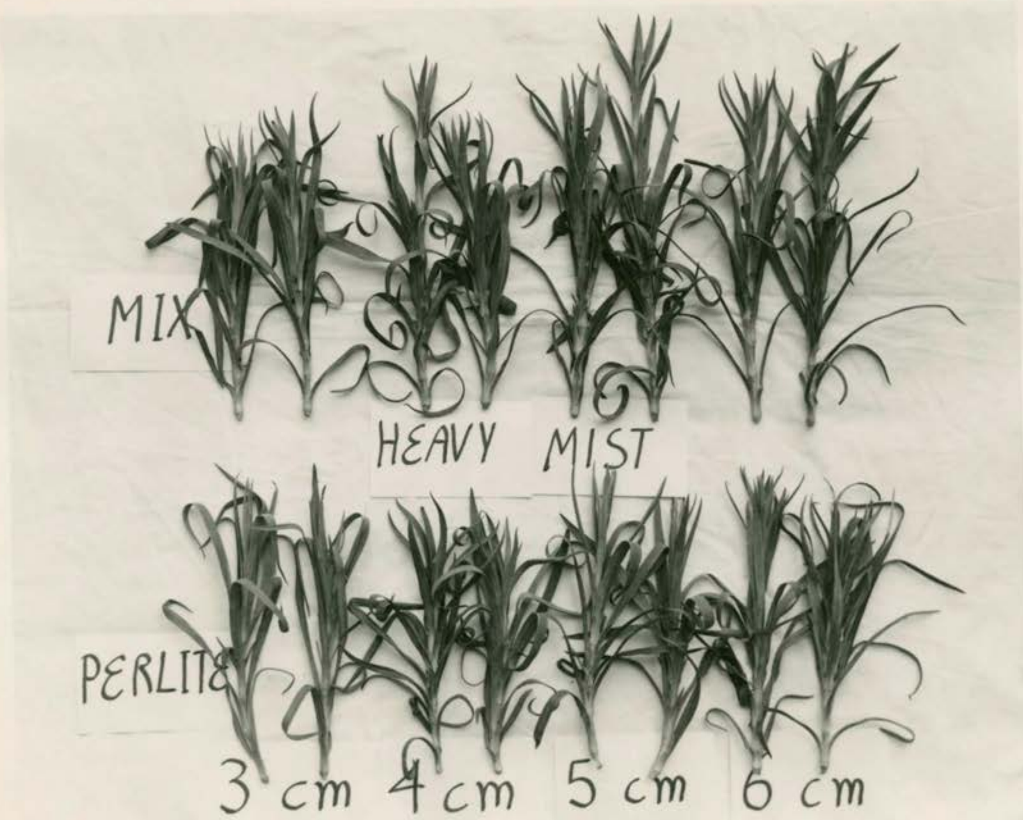

MIX
HEAVY MIST
PERLITE
3 cm 4 cm 5 cm 6 cm

Fig. 8 Relative growth 1 month after benching cuttings rooted under medium mist (2.32 cm/day) in 2 media at 4 spacings.

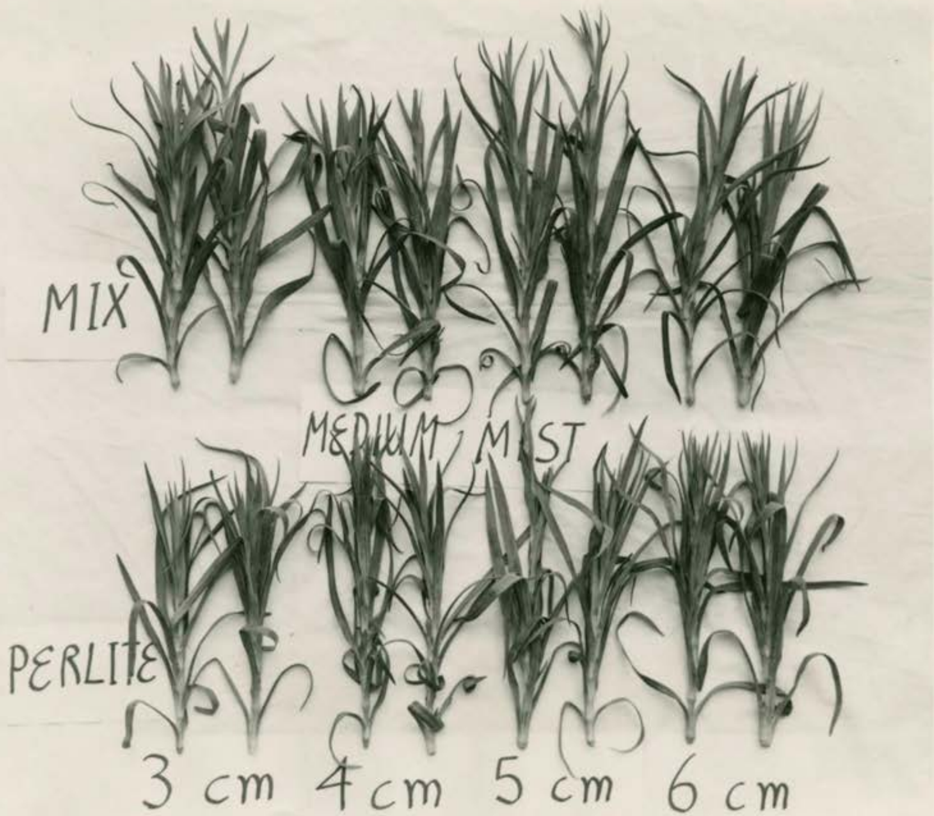
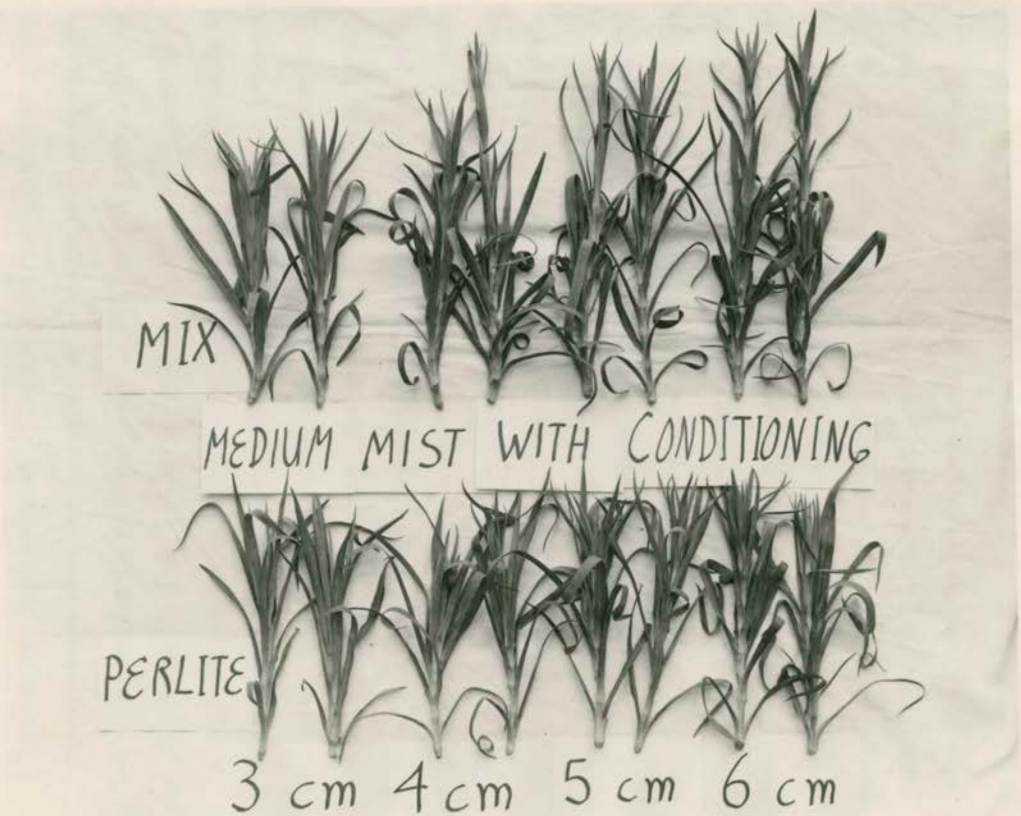

MIX
MEDIUM MIST
PERLITE
3 cm 4 cm 5 cm 6 cm

Fig. 9 Relative growth 1 month after benching cuttings rooted under medium mist with gradual conditioning from day 12 to 14 and no mist on the 15th and final day.


MIX
MEDIUM MIST WITH CONDITIONING
PERLITE
3 cm 4 cm 5 cm 6 cm

CHAPTER IV

DISCUSSION AND SUMMARY

Procedures and materials for carnation propagation are discussed in this chapter by subjects. Points relating to these specific factors brought out in the 5 experiments are considered and evaluated together. Because of the interrelationship between many of the factors some duplication and repetition is unavoidable. Future readers of this manuscript may be interested only in certain subjects and should be provided a complete presentation.

Foliar Application of Root Inducing Substances

This method has obvious advantages over any alternative. Contact of any kind with bases of cuttings is avoided, providing a step forward in sanitation. A step in handling is eliminated as a large area of cuttings may be treated quickly at one time. In large operations the chemicals might be injected into the mist in dilute quantities. Penetration of leaf surfaces in response to concentration gradients (110) suggests that toxic quantities would not likely be absorbed from concentrations used for the desired rooting response. With the present methods, such as quick dips in alcohol or talc preparations, basal injury is not uncommon. Adequate spacing of cuttings should insure greater success with foliar sprays of growth regulators because of better contact with the lower mature leaves which serve as sources of assimilates for developing root areas.

The commercial preparation Jiffy Grow # 2 was applied to stock plants to test its effectiveness as a foliar penetrant. Sprayed plants exhibited stunting, shortened internodes, brittleness, and a reddish color of nodal stem tissue. Production of cuttings was reduced to half the number from check plants during the first month. These findings indicated leaf penetration actually occurred and that application of the compound to intact stock plants was detrimental.

Evening application, necessary because of the interference from mist during daylight, has several theoretical advantages. The applied solution should remain on the foliage for periods as long as 15 hours (138) with high humidity (common to the greenhouse environment at night) being beneficial (33). Inactivation of the NAA should be minimal at night (78).

<u>Propagation Media</u>

Almost any medium may be used for rooting carnation cuttings. However, the present cultural practices involving storage of rooted cuttings, distance shipping, tight scheduling, and direct benching in minimum-care large scale production place restrictions and specifications upon suitable media. The experiments in this series showed that a combination of peat and perlite (1:2) plus sufficient limestone to neutralize the mixture is an excellent medium. It is light in weight enabling a reasonably large root ball to be handled and shipped with a minimum of root loss. Cuttings rooted in this mixture repeatedly made greater fresh weight gains after planting than those in perlite.

Although these experiments proved limestone, sufficient to neutralize the peat-perlite mix, made the difference between success and failure, the reasons for this are unclear. Peat and perlite in equal parts proved toxic to lemon and bean plants (4). Perhaps acid peat extracts small but harmful amounts of aluminum from the perlite, a thermo-expanded aluminum silicate. Aluminum has been reported a "root poison" (111) with concentrations as low as 6-16 ppm shown to cause root injury (59). There is also evidence for a Ca - Al antagonism, where high Ca concentrations reduce Al toxicity (111).

Paul and Smith (101) showed how the substitution of Ca^{++} for H^{+} in peat favors root development in chrysanthemum cuttings. Other studies support the evidence that Ca plays a vital role in root development (16, 17, 24, 28). Since Ca is immobile in the plant (14), newly formed roots must obtain this essential element from the medium. It is likely that the beneficial addition of limestone to the medium was due to Ca rather than to an effect of higher pH per se. Perhaps liming of perlite would improve its efficiency as a medium for carnation propagation should organic matter like peat be undesirable for future growing practices.

Cuttings lifted from the peat-perlite mix appear to have their roots coated with fine particles of peat. This should act as an insulation against excessive root hair damage during handling and provide a reservoir of water during extended storage. Providing adequate drainage is available, peat contributes the benefits of high moisture retaining properties to combinations with inorganic mineral media (54).

Several interesting factors of secondary importance were observed during the course of the media studies. Small quantities of peat (5-15%) when added to perlite resulted in higher pH readings than observed in the straight perlite. Greater percentages resulted in a rapid drop in pH. Water holding capacity increased and air pore space decreased about 5% in most media during two weeks under intermittent mist. It is not known how this trend continues with time and which media are most affected. There was evidence that steaming increased pore space about 5% in perlite and peat-perlite combinations containing less than 40% peat. Perhaps steaming returns the air pore volume to original levels between each lot of cuttings. Mixtures containing peat are soft, facilitating the sticking of cuttings, and have no glare in bright sunshine, an offensive feature of perlite.

Data indicated that cuttings could be spaced somewhat closer in the peat mix than in perlite without detrimental effects. This trend was particularly true if an adequate, but not heavy, mist quantity was delivered. Extending the time in the propagation bench or overrooting resulted in some mechanical root loss in the mixture, especially at spacings closer than optimal.

Medium Temperature

A study was designed to test for possible detrimental effects from high temperature "forcing" employed by propagators faced with limited space and tight schedules. Medium temperature has been well documented in the literature as an important factor in increasing both root initiation and the efficiency of root inducing compounds (41, 56, 70, 71, 127, 142). No growth response differences were reported as a result of temperature.

There was no difference in recovery rate between carnation cuttings rooted at 60, 70, or 80^{o} medium temperature. The 60^{o} treatment required 8 days longer to root satisfactorily than did the 70° treatment. More dry weight accumulated during rooting at the lower temperature, probably a result of the extra time. Besides being a function of time, the extra dry weight could have accumulated at the lower temperature because of reduced respiration. Some heat emission must occur from the medium to the lower leaves of the cuttings. Although air temperature was assumed uniform for all treatments, this "leakage" from the medium would favor increased respiration levels with higher medium temperatures, especially at night with little air movement or mist. Adequate spacing should avoid the insulating effect of a dense leaf layer.

The most important function of bottom heat is in maintenance of a temperature differential favoring the cutting base over the tops (127). The differential should be from 10-15° and is favored by lower air temperature at night and the cooling effect of a constant water film on leaves during the day. In the present medium temperature experiment cuttings were rooted only one day faster at 80° than at 70°. Air temperature at night was near 52°. Mist coverage maintained leaf temperature somewhat lower than the 65-70° air temperature. It is probable that the differential obtained in the 70° treatment was sufficient to achieve the optimal result.

Foliar Feeding of Cuttings

The present study confirms the general view of propagators that cuttings from healthy plants contain sufficient nutrients for adequate growth of new roots (6). Foliar application of nutrients is beneficial if deficient conditions exist in the plant (4, 11, 144).

The present depression of top growth of cuttings during the rooting phase is difficult to explain. Although applied to the foliage, there is little doubt that some residue was carried to the root zone with the mist. There are several reports of delays in root development on cuttings caused by nutrients either in the medium (91, 124) or applied to the foliage (63). However, Wott and Tukey, Jr. (145) reported raising the levels of N, P, and K in cuttings through the use of a complete nutrient solution in the mist. If desirable, feeding of cuttings might better be accomplished by watering the medium with a nutrient solution after roots begin to develop. No effective response was obtained by supplemental feeding in this research.

Intermittent Mist and Spacing of Cuttings

The proper use of mist is an important tool for the propagator. It enables cuttings to continue growth during propagation, possibly resulting in a nutritional status more favorable for rooting than that present when first removed from the stock plant. Insufficient mist depresses both fresh and dry weight gain and delays rooting. Large cuttings given ample space can be rooted in minimum time. Crowding of cuttings is an outdated practice acquired before the use of mist as a means of avoiding excessive dehydration. By maintaining the cutting in a turgid condition, regardless of spacing, mist allows the propagator to choose the optimum spacing consistent with quality. Adequate spacing reduced the tendency of heavy mist (1 cm/hr) to adversely affect root development.

When sufficient space was provided no reduction of mist or other conditioning was necessary at the end of the rooting period. Conditioning of cuttings by providing no mist on the final day in the propagation bench reduced wilting for several days after planting but depressed fresh weight gains during the first month. Since resistance to transplant wilting is accomplished by adequate spacing without the reduced performance associated with gradual conditioning, spacing must be considered an important factor in production of superior carnation cuttings. Conditioning was more detrimental to recovery growth with cuttings rooted in perlite than with those rooted in the peat mix. The recovery rate of heavily misted cuttings was not as rapid as for cuttings receiving mist in moderate amounts.

Mist stimulates fresh weight gain during rooting up to a certain maximum growth level. It appears advisable for propagators to use sufficient mist to insure optimum growth during the rooting phase. Rooting score is related to fresh weight gain but not to dry weight gain or % dry matter. As spacing increases % dry matter increases which may explain why 6 cm is little better than 5 cm for a 7-8 g cutting. Although adequate spacing is an important quality factor it may be overdone.

<u>Evaluation of Cuttings</u>

Rooting score was found closely related to recovery rate after planting. Any treatment or procedure during the rooting phase that results in superior root development within a given time period should produce the best performing cutting.

Performance of cuttings cannot be judged by their appearance during the first week after planting. This was demonstrated when growers were asked to evaluate 24 groups of recently planted cuttings. Each group had received a different set of treatments during 15 days in the propagation bench. The first day following planting, growers preferred cuttings with high dry matter content that had been given the widest spacing (6 cm) and gradually reduced mist. At this time no preference was shown for either perlite or the peat-perlite medium. A week later the peat-perlite mix was preferred 15 to 1 and after two weeks 20 to 1.

With this grower evaluation, spacing gradually decreased in importance as a quality factor. This was probably the result of delayed recovery by widely spaced cuttings with higher than optimal dry matter content. More difficult to explain is the greater recovery rate occuring with cuttings rooted under an intermediate mist level maintained until lifting. Cuttings subjected to a conditioning period were delayed in recovery although they had greater resistance to wilting after planting. Perhaps transplanting is such a shock that cuttings cannot be prepared for it or protected from it. By conditioning cuttings the propagator may actually be subjecting them to an extended period of excessive stress. Two days of stress may be more than twice as detrimental as one day. Loomis (76) emphasized that a sharp line exists between conditioning and stunting and that excessive conditioning might be disastrous with some plants.

Suggestions for Further Study

1. More detailed research, basic and applied, is needed in the area of growth regulators and their application. Incorporation of root inducing substances into mist lines might be used to advantage.
2. Propagation during late spring and summer in outdoor raised benches protected with saran cloth might be economically sound. This procedure may not be as pathologically unsafe as it appears at first glance.
3. The results from this research should be incorporated into other current or proposed projects:
    a. Cuttings rooted in calcium-rich media may have built-in resistance to root drop.
    b. Cuttings from old stock plants may be rooted in such a way that % dry matter is reduced to that in young stock plants (1).
    c. Certain propagation practices may be required for planting stock for inert media.

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APPENDIX

TABLE A. CORRELATION OF ROOTING SCORE AND PHYSICAL PROPERTIES IN 12 MEDIA.

Correlation coefficient 10 d.f. (05) = 0.576 (01) = 0.708

	Water as % of volume	Air as % of volume	pH
Score	0.1687	- 0.3800	0.7232**
Water as % of volume		- 0.9308**	0.1476
Air as % of volume			- 0.2949

TABLE B. ANALYSIS OF VARIANCE OF ROOTING SCORE IN 6 MEDIA AT 3 TIME INTERVALS.

$F_{5,5}$ (05) = 5.0503 $F_{2,12}$ (05) = 3.8853 $F_{10,12}$ (05) = 2.7534
$F_{5,5}$ (01) = 10.9670 $F_{2,12}$ (01) = 6.9266 $F_{10,12}$ (01) = 4.2961

Sources of Variation	d.f.	m.s.	f.
Media	5	182.2278	11.0470**
Error	5	16.4944	
Days	2	1482.1111	38.4133**
Media x Days	10	33.3444	<1.0000
Error	12	38.5833	

TABLE C. ANALYSIS OF VARIANCE OF 3 MEDIA AND 3 TIME INTERVALS ON GAIN IN FRESH WEIGHT AFTER ROOTING.

$F_{2,22}$ (05) = 3.4434 $F_{2,66}$ (05) = 3.1426
$F_{2,22}$ (01) = 5.7190 $F_{2,66}$ (01) = 4.9583

$F_{2,198}$ (05) = 3.0000 $F_{4,198}$ (05) = 2.4000
$F_{2,198}$ (01) = 4.7000 $F_{4,198}$ (01) = 3.4000

Sources of Variation	d.f.	m.s.	f.
Blocks	2	18.5249	1.73
Error	22	10.6867	
Media	2	30.8616	3.221*
Error	66	9.5804	
Days	2	69.3310	9.305**
Media x Days	4	27.7919	3.729**
Error	198	7.4509	

TABLE D. ANALYSIS OF VARIANCE OF EFFECTS OF 3 TEMPERATURES AND 2 MEDIA ON ROOTING AND TOP GROWTH OF CARNATION CUTTINGS.

$F_{1,1}$ (05) = 161.45 $F_{1,2}$ (05) = 18.513 $F_{2,8}$ (05) = 4.4590
$F_{1,1}$ (01) = 4,052.2 $F_{1,2}$ (01) = 98.503 $F_{2,8}$ (01) = 8.6491

$F_{1,6}$ (05) = 5.9874 $F_{2,4}$ (05) = 6.9443 $F_{2,6}$ (05) = 5.1433
$F_{1,6}$ (01) = 13.7450 $F_{2,4}$ (01) = 18.0000 $F_{2,6}$ (01) = 10.9250

Sources of Variation	d.f.	m.s.	f.
Rooting Score			
Blocks	1	112.6667	2.3390
Error	1	48.1667	
Media	1	80.6667	2.5952
Error	2	31.0833	
Temperature	2	88.2917	1.8637
Error	8	47.3750	
Fresh Weight Gain during Rooting			
Blocks	1	22.9126	$<$1.0000
Error	1	48.8776	
Media	1	133.2459	443.4100**
Media x Blocks	1	86.4501	287.6870**
Error	2	.3005	
Temperature	2	51.1447	5.1690*
Error	8	9.8944	
Dry Weight Gain during Rooting			
Blocks	1	.0817	$<$1.000
Error	1	.4538	
Media	1	.7350	10.1100
Media x Blocks	1	.4538	6.2421
Error	2	.0727	
Temperature	2	3.1489	19.2947**
Error	8	.1632	
Fresh Weight Gain during Recovery			
Temperature	2	125.3430	1.4035
Error	4	89.3056	
Media	1	1424.3564	9.4362
Media x Temperature	2	619.0489	4.1012
Error	6	150.9444	

TABLE E. ANALYSIS OF VARIANCE OF EFFECTS OF LIQUID FOLIAR FEEDING AT THE END OF THE ROOTING PERIOD ON ROOTING AND TOP GROWTH.

$F_{1,1}$ (05) = 161.45 (01) = 4,052.2	$F_{1,2}$ (05) = 18.513 (01) = 98.503	$F_{2,8}$ (05) = 4.4590 (01) = 8.6491
$F_{1,6}$ (05) = 5.9874 (01) = 13.7450	$F_{2,4}$ (05) = 6.9443 (01) = 18.0000	

Sources of Variation	d.f.	m.s.	f.
Rooting Score			
Blocks	1	2.6667	15.9970
Error	1	.1667	
Media	1	150.0000	12.4138
Error	2	12.0833	
Nutrients	2	90.3750	1.1315
Error	8	79.8750	
Gain in Fresh Weight			
Blocks	1	.3267	< 1.0000
Error	1	121.0504	
Media	1	105.8400	4.1982
Error	2	25.2104	
Nutrients	2	166.8507	6.6797*
Error	8	24.9785	
Gain in Dry Weight			
Blocks	1	.0817	< 1.0000
Error	1	1.1267	
Media	1	.1204	< 1.0000
Error	2	.1652	
Nutrients	2	2.5257	11.2153**
Error	8	.2252	
Gain in Fresh Weight During Recovery Trial			
Nutrients	2	36.3813	< 1.0000
Error	4	121.8333	
Media	1	175.5938	1.3533
Error	6	129.7500	

TABLE F. ANALYSIS OF VARIANCE OF EFFECTS OF 2 MEDIA, 3 MIST LEVELS, AND 4 SPACINGS ON ROOTING SCORE AND TOP GROWTH OF CARNATION CUTTINGS.

$F_{2,4}$ (05) = 6.9443	$F_{1,42}$ (05) = 4.0764	$F_{3,42}$ (05) = 2.8306
$F_{2,4}$ (01) = 18.0000	$F_{1,42}$ (01) = 7.2904	$F_{3,42}$ (01) = 4.2939

Sources of Variation	d.f.	m.s.	f.
Rooting Score			
Mist	2	329.0556	3.3066
Error	4	99.5139	
Media	1	1096.6806	26.1110**
Spacing	3	496.5694	10.2155**
Error	42	48.6090	
Fresh Weight Gain during Rooting			
Mist	2	20.2317	$<$1.0000
Error	4	29.1822	
Media	1	.0703	$<$1.0000
Spacing	3	291.1746	9.1691**
Error	42	31.7560	
Dry Weight Gain during Rooting			
Mist	2	2.4985	3.2583
Error	4	.7668	
Media	1	2.1528	2.1498
Spacing	3	51.8937	51.8211**
Error	42	1.0014	
Fresh Weight Gain during Recovery			
Mist	2	2590.2170	1.8176
Error	4	1425.0912	
Media	1	48802.0868	79.5520**
Spacing	3	7557.6339	12.3196**
Error	42	613.4600	

TABLE G. CORRELATION OF GROWER EVALUATION WITH RECOVERY, ROOTING SCORE, AND TOP GROWTH DURING PROPAGATION.

Corr. coef. 22 d.f. * (05) = .404
** (01) = .515

	Grower evaluation			Rooting			
	Day 1	Day 8	Day 15	Score	Fresh weight gain	Dry weight gain	% dry matter
Recovery	.383	.817**	.911**	.795**	.283	.341	.366
Rooting % Dry matter	.793**	.626**	.483*	.328	.631**	.945**	
Dry weight gain	.734**	.649**	.499*	.381	.829**		
Fresh weight gain	.499*	.617**	.458*	.466*			
Score	.461*	.789**	.749**				
Grower evaluation Day 15	.529**	.900**					
Day 8	.710**						