To the Graduate Council:

I am submitting herewith a thesis written by Scott J. McCrary entitled "Seasonal Rooting, as Measured by Four Parameters, of Ten Woody Ornamentals Treated with Acid (H_2SO_4), Base (NaOH) and IBA." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ornamental Horticulture and Landscape Design.

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SEASONAL ROOTING, AS MEASURED BY FOUR PARAMETERS, OF TEN WOODY ORNAMENTALS TREATED WITH ACID (H_2SO_4), BASE (NaOH) and IBA

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Scott J. McCrary

March 1980

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. G. Shannon Smith, Associate Professor, Department of Ornamental Horticulture and Landscape Design, for his role as his major professor and committee chairman.

The author also expresses appreciation to Dr. John Day, Assistant Professor, and Dr. Effin T. Graham, Associate Professor, Department of Ornamental Horticulture and Landscape Design, for their wise and patient advice, encouragement, and support.

To Dr. Donald B. Williams, Professor and Head of Ornamental Horticulture and Landscape Design, for his constructive suggestions, and encouragement during the period of graduate study, the author expresses appreciation.

Thanks are due to the author's parents and fiancêe for their unlimited encouragement and inspiration.

ABSTRACT

Cuttings of ten woody ornamentals were treated with acid (10 sec. dip in 2N H_2SO_4) and base (10 min. soak in NaOH pH 10.5) alone and in combination with two rates of IBA (1,000 and 3,000 or 8,000 ppm talc formulation) to determine pretreatment effects on percent rooting, root quality grade, root ball diameter, and root dry weight at three seasons. Five acid tolerant species (*Cornus florida*, *Tsuga canadensis*, *Rhododendron obtusum* 'Coral Bells', *Ilex cornuta* 'Burfordii', *Juniperus horizontalis* 'Bar Harbor') and five base tolerant plants (*Juniperus conferta*, *Juniperus virginiana*, *Cercis canadensis*, *Philadelphus coronarius*, *Euonymus japonicus*) were tested as softwood (Spring), semi-hardwood (Fall) and hardwood (Winter) cuttings to determine treatment effects but also to detect any correlation between pH tolerance and chemical treatment could be observed. Rooting parameters were correlated to see if a measure less laborious than dry weight could be adopted.

The majority of species had highest correlation coefficients between root quality grade and root ball diameter. These two parameters also correlated well with dry weight but coefficients varied from season to season and even among treatments. Thus, several parameters were used to evaluate rooting of most species.

Dry weight and root quality grade showed obvious differences in seasonal rooting. Euonymus was easily rooted at any season; shore juniper, mockorange and dogwood rooted best in spring; Burford holly and

'Bar Harbor' juniper in winter; and azalea in the fall. Red Cedar rooted very poorly and redbud and hemlock not at all. Averaged over all species rooting was generally better in spring followed by fall and winter.

The treatment giving best rooting for the fall experiment was high IBA. For winter hardwood cuttings, best treatments were IBA at either rate and combinations of IBA + base. Spring softwood cuttings rooted best when treated with high IBA, base + high IBA, base + low IBA and, usually, low IBA.

Best treatments for acid tolerant plants were base + high IBA, high IBA and base + low IBA. However, there was no obvious trend where base alone significantly increased rooting of acid-tolerant species. Base-tolerant species reacted much the same as acid-tolerant plants. Best response occurred with high IBA, base + high IBA, low IBA and base + low IBA. Acid treatment did not increase rooting of the base-tolerant plants tested.

Treatments which gave consistently best results for <u>Euonymus japonicus</u> were low or high IBA, acid + high IBA and base + high IBA. Best treatments for <u>Juniperus horizontalis</u> 'Bar Harbor' were base, high IBA, acid + high IBA, base + low or high IBA and even control plants were acceptable. Consistently good rooting occurred for <u>Juniperus conferta</u> treated with high or low IBA. <u>Juniperus virginiana</u> rooted only slightly in the winter with best results occurring with high IBA, or base + high IBA. Best treatments for <u>Ilex cornuta</u> were base, base + high IBA, low IBA and high IBA. For <u>Philadelphus coronarius</u> high IBA and base + high IBA gave best results. No significant differences due to treatments were recorded for Rhododendron obtusum 'Coral Bells'. For Cornus florida high IBA and base + high IBA were found to be superior treatments.

The single best treatment for Juniperus virginiana, Philadelphus coronarius, Rhododendron obtusum 'Coral Bells', Ilex cornuta 'Burfordii', and Cornus florida was base + high IBA. Euonymus japonicus and Juniperus conferta rooted best under high IBA. For Juniperus horizontalis 'Bar Harbor' base alone was the single best treatment. Both Tsuga canadensis and Cercis canadensis failed to root in any season regardless of chemical treatment.

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CHAPTER I

INTRODUCTION

Since the discovery of rooting hormones in 1934 (11), much research in plant propagation has been concerned with use of auxins like indolebutyric acid (IBA) and naphthalene acetic acid (NAA) to enhance rooting of cuttings. Over the years, less attention has been given to effects of other chemicals such as bases, nonhormonal acids, sugars, and compounds of manganese, iron, and phosphorus on rooting (5, 15, 19, 16).

In the early 1900s studies by Hitchcock (12) and Small (24) showed that rooting percentages could be increased in certain media due probably to pH (acidity). During the past few years (17) the dramatic effects of simple acid and base treatments on rooting of cuttings of ornamental plants have again been demonstrated. Pretreatment of cuttings with sulfuric acid (H_2SO_4) or sodium hydroxide (NaOH) has significantly increased rooting of certain species, the response apparently being correlated with the species' tolerance to acidic or basic soil conditions in its' natural habitat. In addition, acid treatments have been shown to increase root elongation (6, 7). It has been postulated that short exposure of cuttings to acid may break acid-labile linkages in the cell walls of base tolerant plants. Conversely, base pretreatment of cuttings may break base-labile linkages in the cell walls of acid tolerant plants. Reactions such as these may loosen cell walls, increase water permeability, facilitate absorption of applied auxin and hasten emergence of root initials (3, 4, 21, 17).

The purpose of this investigation was to determine effects of sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH), with and without IBA, on rooting of ten woody ornamentals. Specific objectives included: (1) determining chemical effects on rooting of softwood, semi-hardwood and hardwood cuttings; (2) comparing rooting at different times of year—spring, summer and winter; (3) attempting to correlate plant response to acid or base with the species tolerance to acid or alkaline soils; and (4) evaluation and correlation of four different measures of root development.

CHAPTER II

LITERATURE REVIEW

I. HISTORICAL DEVELOPMENT

Studies relating to rooting of cuttings have been conducted by numerous investigators over a period of many years. Before the use of synthetic root-promoting growth regulators (auxins), many other chemicals were tried with varying degrees of success (5, 15, 16, 19). Treatment of *Ligustrum* cuttings with sugars as well as with compounds of manganese, iron, and phosphorus often resulted in improved rooting; however, the effect of such compounds was often slight and variable (5). In the early 1920s researchers became concerned with the effect of pH of the propagation medium on the rooting of cuttings (18). Small (24) and Smith (25) were the first to discover that plants could be induced to increase rooting following exposure to a low pH medium. Small (24) added dilute acetic acid to coconut fiber and to soil and found that rooting percentages increased and time required for rooting was decreased when the pH of the media was lowered. Smith (25), studying root production in coleus, reported on the relationship of acidity of the soil medium to rooting percentages. After a series of acid-alkali tests, he showed that with solutions ranging from pH 4.0 to 9.0 rooting occurred best at pH 7.0 or lower. In these solutions there appeared to be a direct relationship between pH and rooting response, if the dry weight of roots per gram of dry matter was taken as the criterion of growth. However, Smith did infer that the favorable rooting in acid coconut fiber could be partially due to the efficient aeration provided by the medium. Hitchcock (12) tried to determine the effect of peat moss and sand on rooting response of cuttings in 1928 and found that pH was an important factor in the rooting of many plants. Good rooting of cuttings occurred for most varieties over an acid range of pH 4.5-7.0. However, some species rooted better at a higher pH level.

By 1930 researchers understood the gross effects of media pH on the rooting of numerous species but they did not know the physiological mechanisms involved or chemical reactions that affected the cells of the cuttings. In 1934 Bonner (1) conducted a study on the effects of hydrogen ions on the growth rate of the *Avena* coleoptile. His studies indicated that acid applied to the coleoptile induced cell elongation and growth. Though Bonner did not fully understand the physiology involved, his work with acid-induced growth became a reference point for researchers almost forty years later.

II. SURVEY OF RECENT DEVELOPMENT

In the early 1960s scientists again became concerned with how pH affected plant cells. Physiologists were interested in finding the factors involved in growth of cells at different pH levels. Taylor (26) in 1962 conducted a study on the responses of cells to pH changes in the micro-environment of the cell's surface. He suggested that the local pH changes that occurred around the cell surface were significant in controlling the cells' behavior in culture and *in vivo*. Hancock (10) in 1962 and Foster (8) in 1965 conducted studies which showed evidence that activity of cell enzymes are affected by H^+ion concentration and that external changes in pH can affect cell surfaces and cytoplasmic pH. They also found that pH can accelerate or retard cell activity and can change protoplasm permeability.

By 1970 horticulturists and plant propagators were beginning to consider the pH level of the rooting medium and misting water more seriously. Welch (27) repeated an experiment that was conducted 47 years earlier by Small (24). He took plants that were not rooting well in a medium at pH 8.0 and drenched them with dilute sulfuric acid. Cuttings so treated showed visible root growth in less than 48 hours. Welch concluded that good rooting occurred when the base of the plant cutting was kept in a pH range of 5.5 to 6.5.

Rayle and Cleland (21) and Cleland (2) in the early 1970s, while working on an explanation of the biochemical mechanism of auxin action, came across Bonner's 1934 experiment on acid-induced growth. Their reason for reinvestigating this work was to possibly provide a simple model system for studying cell wall loosening which could eventually be applied to auxin-induced wall loosening. After much research they concluded that acid-induced growth was directly related to auxin-induced growth.

When Rayle and Cleland (21) formulated their ideas on the biochemical mechanism of auxin action they already had the following model: First, when a plant cell enlarges, most of the increase in volume is due to the uptake of water into an expanding, centrally located vacuole. Second, they knew from earlier studies by Cleland that auxin enhances cell enlargement by increasing cell wall extensibility (cell wall loosening) rather than by making the osmotic potential of the cell more negative. Loosening leads to a transient decrease in cell water potential; water then enters the cell, causing the wall to stretch. The synthesis of new cell wall meanwhile repairs the expanded wall so that further wall loosening can occur later. Lastly, they knew that auxin did not act directly on the wall but rather in the cytoplasm or at the plasma membrane, so they reasoned that there must be some form of reaction between the cytoplasm and wall. Consequently, auxins must initiate the release of a wall loosening factor (WLF). Several critical questions remained. How does auxin initiate the release of WLF? What is the nature of the WLF? And, how does WLF initiate wall loosening?

In attempting to answer these questions Rayle and Cleland (21) reviewed Bonner's experiments and found that the optimum pH for elongation in Avena coleoptiles was 3.0 and that the extension response was indeed mediated by wall loosening. Further, the H^+ ion response, unlike the auxin response, was unaffected by virtually all metabolic poisons and could even be demonstrated using isolated wall matrices if tension was applied to replace turgor. In spite of these rather obvious differences between H^+ ion- and IAA-induced growth they began to discover some striking similarities. Both agents at optimal levels induced the same growth rate; both yielded responses that were similarly affected by changes in temperatures; and both seemed to loosen the cell wall in a similar manner. These similarities led Rayle and Cleland (21) to suspect that acid and auxin might be altering the same bonds in the cell wall. However, because the optimum pH for extension was physiologically unrealistic (pH=3.0) and eventually caused cells to die, they were still unconvinced that the H^+ion was the natural WLF. They felt it was more probable that simply by coincidence H^+ions and the natural WLF happen to loosen similar bonds within the cell wall. Later, Rayle and Cleland (21) discovered that they had misinterpreted the optimum pH for acid-induced growth by nearly two orders of magnitude. It was pH 4.8 rather than 3.0. The key to this discovery was the simple realization that the cuticle is a potent barrier to H^+ion flux and that all of their earlier work was performed with segments that had an intact cuticle. The simple step of rendering coleoptile segments permeable to H^+ions completely changed their thinking about acid growth and made it physiologically reasonable to propose H^+ion as the elusive WLF.

Rayle and Cleland (21) then suggested two possibilities on how hydrogen ions cause cell wall loosening. One is that hydrogen ions activate wall bound enzymes which break polysaccharide cross links in the cell wall, and the other is that hydrogen ions nonenzymatically break acid labile linkages in the cell wall. Acid labile linkages are bonds or bridges between molecules which are easily weakened or replaced with H^+ions.

Other investigators, chiefly Hagar et al. (9) and Marré, Lado and Caldogno (20), were independently arriving at similar conclusions. However, one important piece of critical evidence was still missing. Studies needed to show that auxin caused the release of protons into the cell wall region in sufficient quantities to lower the wall pH to 4.8, and thus induce cell wall loosening. In 1973, Cleland (2), Marré, Lado and Caldogno (20) and Rayle (22) all independently reported that auxin does indeed initiate H^+ ion extrusion and that the magnitude is sufficient to account for the subsequent growth response. Since 1973, these initial observations on proton pumping or H^+ ion extrusion have been refined and extended to other tissues exhibiting auxin-induced growth, thus allowing researchers to say with certainty that the wall-loosening factor is simply the hydrogen ion. In addition, Rubery and Sheldrake (23), in 1973, found that pH and surface charge affected the amount of auxin uptake in plants. They found that as pH was lowered in crown gall cells of Parthenocissus tricuspidata the amount of auxin taken up by the cells increased. The optimum pH for auxin uptake was found to be 4.8.

In 1974 Yamagata, Yamamoto, and Mascuda (28) did an extensive study on the effect of H^+ ions on the pea epicotyl and the effect of H^+ ions on the extension of the isolated epidermis. They examined Hager et al. hypothesis that auxin acts as an activator of a membrane-bound ATPase or proton pump and induces proton accumulation in the cell wall compartment, and Rayle and Cleland's suggestions on auxin-acid induced elongation. They discovered that in low pH-induced extension, epidermis which had been deproteinized with methanol or pronase extended very little in response to H^+ ions. Low temperatures also inhibited hydrogen ion-induced extension. These results suggested that hydrogen ions activated some enzymes which are tightly bound to the cell wall. However, Yamagata, Mascuda, and Yamamoto tested induced extension at pH 4.5

instead of pH 3.0. When epidermis boiled in methanol was tested at pH 3.0, extension was evident, however its extension was smaller than that at pH 4.5 on fresh epidermis. This suggested that a nonenzymatic process, cleavage of acid labile bonds, was involved in the mechanism of hydrogen ions at pH 3.0, while an enzymatic process was activated by hydrogen ions at a higher pH (4.5). They also reported that auxin enhanced the activity of B-1,3 glucanase, a hydrolytic enzyme which induces growth (exogenous application of B-1,3 glucanase to Avena or barley coleoptile segments induces elongation). They suggested that enzymatic cleavage of the cell wall components by glucosidases was involved in hydrogen ion action which induced extension of the epidermis. It seems that wall bound enzymes are activated by H^+ ions, thus causing cell wall loosening.

According to the evidence presented in Yamagata, Mascuda and Yamamoto's research, the hydrogen ion secretion hypothesis by Rayle and Cleland appears to be valid.

Also in 1974, Edwards and Scott (6) conducted a study on the effect of pH on the elongation of cells in roots. They reported that the response of root segments to H^+ ions is similar to that reported in the literature for shoot tissue. But the mode of action of H^+ ions may not be the same for root tissue and shoot tissue. Root segments, lacking a cuticle, do not respond to low pH in the same manner as shoot tissue. Acid response on root segments is at least 15-20 times greater than that of shoot tissue and root segments have an oxygen-dependent phase not evident for coleoptile tissue.

Evans (7) in 1976 reported on the interaction of auxin and acid pH in the regulation of intact root elongation. In this experiment Evans used a root auxanometer to help with the measurement of the intact root elongation. Experiments with the new auxanometer showed that auxin begins to inhibit intact pea root elongation within 10 minutes and continues to inhibit elongation for at least one hour following a 1-hour treatment by hormone. Exposure of pea roots to pH 4.0 results in a two to three fold increase in elongation rate beginning about 1 minute after treatment. Acid induced elongation in intact pea roots is much more long lived than in coleoptile or corn root segments in which growth rate begins to decline 15 to 30 minutes after initiation. The acid growth response in pea roots could be obtained repeatedly by alternating between pH 6.5 and 4.0 in the root medium. Such repeatability is reported not to happen in coleoptile segments between pH 3.0 and 7.0 (21).

Since auxin is observed to strongly inhibit root growth while acid is observed to promote growth, Evans (7) raised the question as to which effect would dominate if auxin were offered at pH 4.0. According to Evans, IAA is capable of strongly inhibiting acid-promoted elongation whether the hormone is added before or after acidification. The addition of auxin to the growth medium at pH 6.5 leads to maximal inhibition of root elongation in about 40 minutes. If auxin-containing medium is then acidified to pH 4.0 the resulting acid growth response is small. If IAA is applied to a root already growing at pH 4.0 inhibition begins about 7 to 8 minutes later and is maximal about 50 minutes later. Subsequent removal of IAA and replacement with root medium at pH 4.0 is totally ineffective in restoring acid-induced growth. It appears that auxin inhibition of acid-induced elongation is irreversible at least within 70 minutes following removal of the hormone.

More recently experiments have been conducted on the nature of acid-induced elongation of intact roots (13, 14). Of particular interest is the question of the role H^+ ions might play in the normal regulation of root growth or even root initiation. Could acid treatments induce and perhaps catalyze root promotion in stem cuttings? With these questions in mind Lee, Paul, and Hackett (17) investigated the use of acid and base pretreatments on stem cuttings of several ornamental plants. They felt that if part of the effect of auxin in cell wall loosening was due to enhanced acidity, then pretreatment of cuttings with acid may further stimulate rooting. The purpose of their study was to determine the influence of acid or base pretreatment of stem cuttings on the rooting of several ornamental plants. They used sufuric acid and sodium hydroxide as the acid and base pretreatments. A preliminary study was conducted to determine what optimum concentration of acid or base was best to use for various species and they found that 2N H_2SO_4 as a 15 second dip was most effective in promoting rooting on *Salix* species. A NaOH solution of pH 10.5 for a 10 minute soak gave the best results for rooting on *Bougainvillea* species. Therefore, the concentration of acid or base mentioned above was used in their study, although optimum dosage was not determined for all other plant species.

After treating 30 cuttings each of 17 species with acid or base followed by dipping in 3000 ppm aqueous solution of indolebutyric acid

(K-IBA), they found that these pretreatments significantly influenced the rooting of the cuttings. Stem cuttings of the plants tested had a significantly greater number of roots as a result of acid and base pretreatment. Also, cuttings treated with H_2SO_4 produced longer roots in many of the plants. However, concentrations and time of pretreatment may result in toxic effects for some plants. Generally, acid pretreatment promoted rooting of plants native to near neutral or alkaline soil while base pretreatments increased rooting of species native to acid soils.

These results led Lee, Paul, and Hackett (17) to suggest that a short exposure to acid may break acid-labile linkages (Ca bridges) in the cell walls of calciphilous plants. The base pretreatment may break base labile linkages (ester bridges) in the cell walls of acid-loving or acid-tolerant plants. Such reactions, whether induced by acid or base, may loosen cell walls, increase water permeability, facilitate absorption of applied auxin and subsequent emergence of root initials. Root initiation due to acid and base pretreatments has not been studied in detail, however, studies in California clearly showed that acid and base can promote rooting in certain plant species. Lee, Paul, and Hackett (17) speculated that promotion of rooting could be a direct morphogenetic effect of acid or an interaction of the acid with endogenous morphogenetic factors such as auxin. At present the direct mode of action of acid or base treatment is unknown. However, the acid-induced cell wall loosening theory of Rayle and Cleland (21) may be the answer.

Acid and base pretreatments used for root initiation is a new concept. Lee, Paul, and Hackett (17) were the first to propose that acid and base pretreatments could in fact promote better rooting in certain plant species. This concept was supported by the work of researchers over a prior period of 60 years. Scientists like Bonner (1) in 1934 and Hitchcock (12) in the late 1920s discovered many of the interesting effects of media pH on the rooting of plants, but did not suggest the practical application of these results. Plant physiologists like Hager et al. (9), Cleland (2), and Rayle (22) individually and together discovered the physiology involved in cell-wall-loosening and growth induced via the activity of the H^+ ion. More recent studies by Edwards and Scott (6) and Evans (7) on growth responses of root segments to pH have contributed to the idea that certain species could be rooted faster and more effectively by the use of acid or base pretreatment. With the possibility of finding a new and more efficient method of rooting cuttings, further experimentation in this area of vegetative propagation should be explored. Specific objectives should include: (1) determining the optimum acid and base concentrations; (2) determining the effects of acid and base with and without IBA, on the rooting of ornamentals; (3) determining the chemical effects on rooting at different times of the year; and (4) determining the correlation of acid- or base-tolerant species with the best pretreatment.

CHAPTER III

METHODS AND MATERIALS

Vegetative propagation of ten species of ornamentals was studied at three different seasons to determine differences in rooting following treatment with combinations of acid or base and IBA.

Plants chosen for this study included five species that require or tolerate acid soils and five species that tolerate alkaline soils in their natural environment. Acid tolerant species were *Cornus florida* (Flowering Dogwood), *Tsuga canadensis* (Canadian Hemlock), *Rhododendron obtusum* 'Coral Bells' ('Coral Bells' Azalea), *Ilex cornuta* 'Burfordii' (Burford Holly), and *Juniperus horizontalis* 'Bar Harbor' ('Bar Harbor' Juniper). Base tolerant plants included *Juniperus conferta* (Shore Juniper), *Juniperus virginiana* (Eastern Red Cedar), *Cercis canadensis* (Eastern Redbud), *Philadelphus coronarius* (Mockorange), and *Euonymus japonicus* (Japanese Euonymus).

Three replications of 10 cuttings per treatment were randomized over three mist propagation beds measuring 1.2 x 3 m (4 ft. x 10 ft.). Mist beds were filled with 25 cm (10 in.) depth of coarse grade perlite having a pH of 7.0 to 7.5. The experiment was conducted in a glass greenhouse shaded with whitewash. The greenhouse was cooled in the summer months by an evaporative pad and fan cooling system which kept the temperature in a range of 24 to 35°C (75-95°F) during the day. During the winter, a heat fan jet system heated the greenhouse to a range of

21 to 24°C (70-75°F). The propagation medium was heated to a range of 22 to 24°C (71-75°F) by commercial heating cables. An intermittent mist system was used with 4 fog-mist nozzles per bed. Nozzles were calibrated at a 4 ft. spray diameter and used 6 gallons of water per hour at 20 lbs. pressure. The misting cycle was calibrated at 10 seconds on every 4 minutes starting at 8:00 a.m. and stopping at 5:00 p.m during the summer months. Fall and winter calibrations were adjusted weekly to insure that there was not an excess amount of mist during the cooler seasons. The natural photoperiod ranged from 15 hours in the summer months to 10 hours in the winter; no artificial lighting was used.

All cuttings were taken from local stock plants and placed directly into water. Cuttings were then stored in a refrigerated cooler until chemical treatments were applied. All species were treated and individually placed in mist beds within one or two days after cutting. Size and type of cuttings is described later.

I. CHEMICAL TREATMENTS

Chemical treatments included eight combinations of acid or base with or without Indolebutyric acid (IBA) and a control. Treatment combinations are shown in Table 3.1. Acid and base treatments were processed in pyrex beakers filled to approximately 2 to 2.5 cm with the respective chemical. Groups of 10 cuttings per beaker were treated for the allotted time and then dipped in tap water to remove excess acid or base. For treatment combinations of IBA with acid or base the same procedure was used except the basal 2 cm (3/4 in.) of the cuttings were

Table 3.1. Chemical treatments used on the ten species.

Treatment Code	Chemical Concentrations and Time
1. Control	No Treatment, cuttings in water
2. Acid[1]	15 sec. dip in 2N H_2SO_4
3. Base[1]	10 min. dip in NaOH pH 10.5
4. Low IBA	1,000 ppm IBA in talc
5. High IBA	3,000 ppm IBA talc (Hemlock and Dogwood treated with 8,000 ppm IBA)
6. Acid + Low IBA	15 sec. dip 2N H_2SO_4 + 1,000 ppm IBA talc
7. Acid + High IBA	15 sec. dip 2N H_2SO_4 + 3,000 ppm IBA or 8,000 IBA ppm
8. Base + Low IBA	10 min. dip NaOH pH 10.5 + 1,000 ppm IBA talc
9. Base + High IBA	10 min. dip NaOH pH 10.5 + 3,000 ppm IBA or 8,000 ppm IBA talc

[1]Concentrations used by Lee, Paul, and Hackett (17).

dipped in talc formulation of IBA, with excess tapped off before being placed into mist beds.

II. SEASONAL COMPARISONS

Experimental treatments were repeated three times per year at selected seasons to compare treatment effects on different types (maturity) of cuttings taken from the same plants and to generally find optimum seasons for rooting. The first run started August 25, 1978, when the cuttings were considered to be at the semi-hardwood stage; the second began on December 20, 1978, to compare rooting response of hardwood cuttings; and the third experiment began on June 7, 1979, to examine cuttings at the softwood stage. Cuttings were taken from the same stock plants each season and a description of each cutting is given in Table 3.2.

III. DATA AND ANALYSIS

Due to biochemical factors and anatomical structure of the stem, as expected, time required for each species to form a sufficient root system was different. Therefore, harvest dates ranged from 25 to 97 days (under mist) after sticking cuttings. Rooting times for species are given in Table 3.3. The statistical parameters used to determine rooting were: root-percentage; root quality grade; root ball diameter; and root dry weight.

Rooting percentage was determined by simply examining the cutting for roots. If the cutting showed any roots (no callus) then it was

Table 3.2. Location and size of cuttings used in the experiment.

Species	Cutting Description	Size
Acid tolerant		
Cornus florida	Terminals cut at the 4th node	10 to 16 cm
Ilex cornuta 'Burfordii'	Terminals cut at the 7th node	10 to 13 cm
Juniperus horizontalis 'Bar Harbor'	Terminals cut back 2.5 cm into brown wood	10 to 15 cm
Tsuga canadensis	Terminals cut back 2.5 cm into brown wood	15 to 25 cm
Rhododendron obtsusum 'Coral Bells'	Terminals cut at 10 to 12.5 cm	9 to 11 cm
Base tolerant		
Philadelphus coronarius	Terminals cut at the 4th node	10 to 16 cm
Euonymus japonicus	Terminals cut at the 4th node	10 to 13 cm
Cercis canadensis	Terminals cut at the 4th node	10 to 16 cm
Juniperus virginiana	Terminals cut back 2.5 cm into brown wood	15 to 20 cm
Juniperus conferta	Terminals cut back 2.5 cm into brown wood	15 to 20 cm

Table 3.3. Number of days that the plants were under mist.

Species	Days
Euonymus japonicus	25
Juniperus conferta	62
Juniperus horizontalis 'Bar Harbor'	70
Cornus florida	97
Rhododendron obtusum 'Coral Bells'	97
Tsuga canadensis	97
Juniperus virginiana	97
Cercis canadensis	97
Philadelphus coronarius	97
Ilex cornuta 'Burfordii'	97

considered a rooted cutting. By counting the number of rooted cuttings per treatment, dividing by the original number planted and then multiplying by 100, the rooting percentage was determined.

Root quality grade for each species was determined on a visual scale of 0 to 5 (Figure 1). Zero was equal to no rooting and no callusing; 1 was equal to callusing but no rooting; 2 was equal to slight rooting with or without callusing; 3 was equal to average rooting; 4 was equal to good rooting; and 5 was equal to excellent rooting. Quality standards for each species were selected, photographed and used throughout the study to maintain consistency. Quality grade is a rapid subjective measurement of the quantity of roots.

Root ball diameter was determined by laying the plants on a table and measuring the maximum width of the root ball. Root ball diameters also give a measure of quantity or length of root systems but are more time consuming to measure than root quality grade. Once the root ball diameters were determined, 10 cuttings were randomly selected by replication and photographed for further reference.

After photographing, roots were removed from the cuttings, dried at 100°C (212°F) for 48 hours and root dry weights determined. Root dry weights were considered to be the best indication of rooting and thus were used as the standard against which other methods would be compared.

All rooting data were statistically analyzed by the Statistical Analysis System (SAS) at The University of Tennessee Computing Center

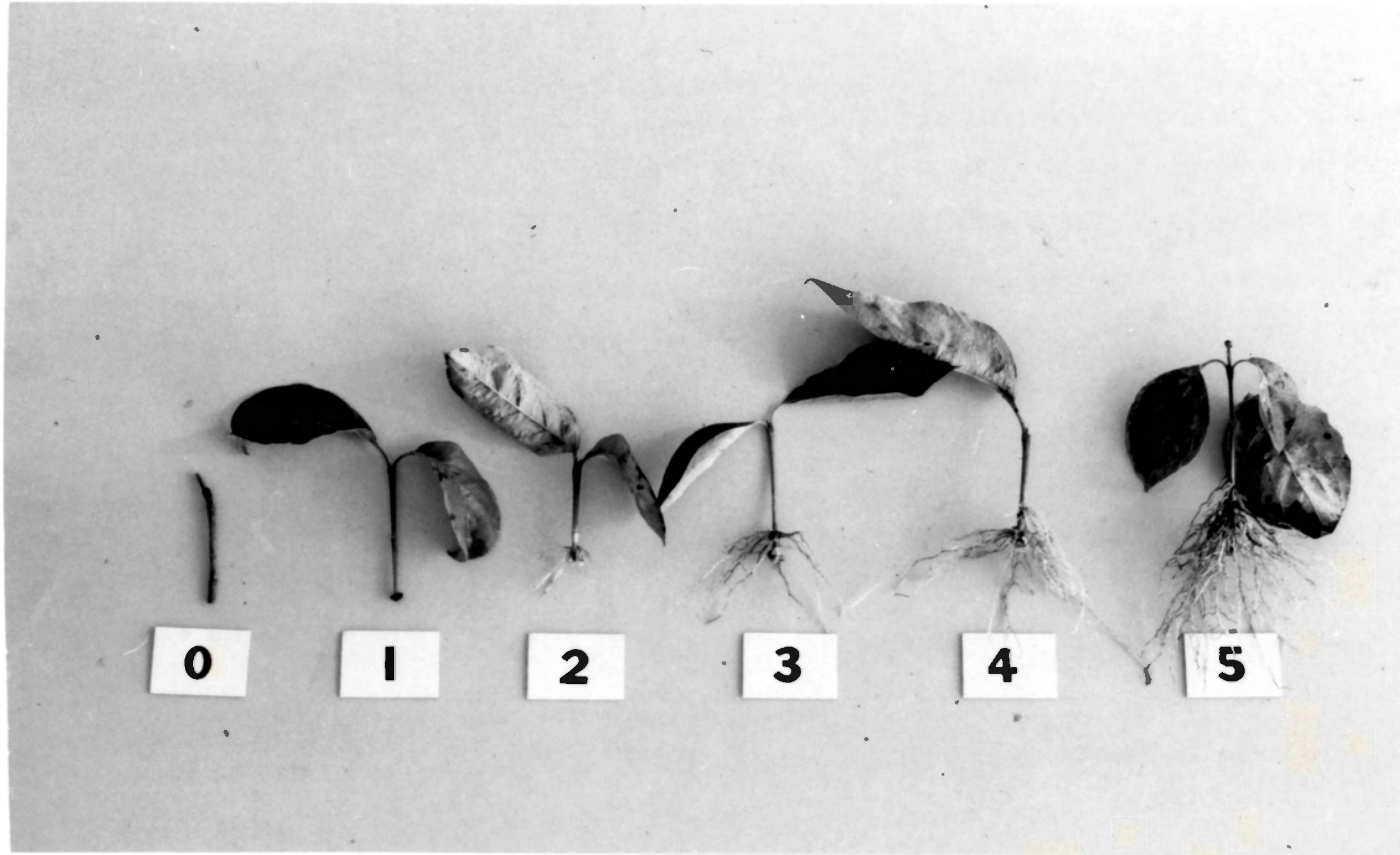

Figure 1. Root quality grade for each species determined on a visual scale of 0 to 5.

(Program #034021). Treatment effects were determined for each species at each season as well as a comparison across seasons. An analysis of variance was run for each rooting parameter and means compared by Duncan's Multiple Range Test.

In addition, rooting measurement methods were compared by determining correlation coefficients (R values) for all possible pairs of measurements. Correlation coefficients were produced for rooting percentage, quality grade, root ball diameter, and dry weights within treatments per species, within species and for seasons. Rooting measurement methods were compared to determine if some accurate method less time consuming than dry weights could be adopted.

CHAPTER IV

RESULTS AND DISCUSSION

Rooting responses for 10 woody ornamentals are presented in four divisions. Comparison of four root development measures will be presented first followed by a section on seasonal comparison of rooting. The third portion will discuss effects of nine treatments on rooting, while the last segment will compare seasonal effects, treatment effects, and statistical parameters for individual species.

I. ROOT DEVELOPMENT (ROOTING PARAMETERS)

Correlations were made between rooting measures to determine if rapid methods such as quality grade and root ball diameters were as good as standard root dry weight, an accurate but highly laborious measure. Rapid but accurate root measuring systems would offer a tremendous savings in time in rooting studies.

Four parameters used to measure rooting of species tested were: root ball diameter, percent rooting, root quality grade and root dry weight. Treatment effects, as measured by each parameter, were then determined by analysis of variance, pooled F-tests and Duncan's Multiple Range to compare means.

In order to determine the relationship between these methods, correlation among the four root development systems was tested. Correlation of the four parameters was first pooled across treatments and tested on individual species. Data were tabulated to determine which parameters were most closely related within each species and all three seasons. Next, seasonal averages were computed to better determine repeatability of the four parameters for the individual species. Third, all species were averaged to look at correlations over the three seasons and last, averages were made for all species and all seasons to have a composite table which could be used to generalize on correlation of four root development systems.

1. Correlation Coefficients for Individual Species and Seasons (Table 4.1)

Analysis of the four root parameters showed positive correlation among the systems. High correlation between certain parameters was evident within certain species, but variable across all species. Euonymus, mockorange, dogwood and red cedar had highest positive correlation between root ball diameter and root quality grade with values up to 0.84, 0.87, 0.89, and 0.93, respectively. For 'Bar Harbor' juniper, Burford holly and azalea, highest correlations were between root quality grade and percent rooting with values of 0.99, 0.99, and 0.85, respectively. Shore juniper had highest positive correlations between root ball diameter and root dry weight with a value of 0.76.

Shore juniper, mockorange and azalea had highest positive correlation coefficients between rooting parameters during the winter experiment; euonymus and dogwood had highest correlations during the fall experiment; while 'Bar Harbor' juniper and Burford holly had highest R values in spring.

Table 4.1. Correlation coefficients for individual species and seasons (reported as R values).

Root Analysis System	Root Quality Grade			Percent Rooting			Root Ball Diameter			Root Dry Weight		
	*1	2	3	1	2	3	1	2	3	1	2	3
Euonymus japonicus (Japanese euonymus)												
Root Quality Grade	1.000	1.000	1.000	0.545	0.490	0.439	0.842	0.819	0.757	0.615	0.673	0.640
Percent Rooting	0.545	0.490	0.439	1.000	1.000	1.000	0.488	0.398	0.359	0.190	0.200	0.105
Root Ball Diameter	0.842	0.819	0.757	0.488	0.398	0.359	1.000	1.000	1.000	0.793	0.618	0.570
Root Dry Weight	0.615	0.673	0.640	0.190	0.200	0.105	0.574	0.618	0.570	1.000	1.000	1.000
Juniperus horizontalis ('Bar Harbor' juniper)												
Root Quality Grade	1.000	1.000	1.000	0.815	0.717	0.989	0.844	0.714	0.782	0.723	0.719	0.654
Percent Rooting	0.815	0.717	0.989	1.000	1.000	1.000	0.621	0.569	0.642	0.447	0.507	0.441
Root Ball Diameter	0.844	0.714	0.782	0.621	0.569	0.642	1.000	1.000	1.000	0.793	0.790	0.753
Root Dry Weight	0.723	0.719	0.654	0.447	0.507	0.441	0.793	0.790	0.753	1.000	1.000	1.000

Table 4.1. (Continued)

Root Analysis System	Root Quality Grade			Percent Rooting			Root Ball Diameter			Root Dry Weight		
	*1	2	3	1	2	3	1	2	3	1	2	3
<u>Ilex cornuta (Burford holly)</u>												
Root Quality Grade	1.000	1.000	1.000	0.656	0.728	0.989	0.656	0.821	0.759	...	0.677	0.658
Percent Rooting	0.656	0.728	0.989	1.000	1.000	1.000	0.511	0.462	0.693	...	0.347	0.566
Root Ball Diameter	0.656	0.821	0.759	0.511	0.467	0.693	1.000	1.000	1.000	...	0.691	0.907
Root Dry Weight	...	0.677	0.658	...	0.347	0.566	...	0.735	0.907	...	1.000	1.000
<u>Juniper conferta (Shore juniper)</u>												
Root Quality Grade	1.000	1.000	1.000	0.488	0.719	0.540	0.637	0.734	0.579	0.521	0.597	0.745
Percent Rooting	0.488	0.719	0.540	1.000	1.000	1.000	0.280	0.387	0.308	0.135	0.251	0.187
Root Ball Diameter	0.637	0.734	0.579	0.280	0.387	0.308	1.000	1.000	1.000	0.691	0.762	0.596
Root Dry Weight	0.521	0.597	0.745	0.135	0.251	0.187	0.691	0.762	0.596	1.000	1.000	1.000

Table 4.1. (Continued)

Root Analysis System	Root Quality Grade *1	2	3	Percent Rooting 1	2	3	Root Ball Diameter 1	2	3	Root Dry Weight 1	2	3
Philadelphus coronarius (Mockorange)												
Root Quality Grade	1.000	1.000	1.000	0.813	0.794	0.649	0.821	0.874	0.817	0.651	0.798	0.654
Percent Rooting	0.813	0.794	0.649	1.000	1.000	1.000	0.636	0.646	0.436	0.367	0.497	0.272
Root Ball Diameter	0.821	0.874	0.817	0.636	0.646	0.436	1.000	1.000	1.000	0.745	0.811	0.663
Root Dry Weight	0.651	0.798	0.654	0.367	0.497	0.272	0.745	0.811	0.663	1.000	1.000	1.000
Rhododendron obtusum ('Coral Bells' azalea)												
Root Quality Grade	1.000	1.000	1.000	0.597	0.850	0.597	0.469	0.726	0.469	0.688	0.563	0.688
Percent Rooting	0.597	0.850	0.597	1.000	1.000	1.000	0.244	0.537	0.244	0.239	0.390	0.239
Root Ball Diameter	0.469	0.726	0.469	0.244	0.537	0.244	1.000	1.000	1.000	0.379	0.708	0.379
Root Dry Weight	0.688	0.563	0.688	0.239	0.390	0.239	0.379	0.708	0.379	1.000	1.000	1.000

Table 4.1. (Continued)

Root Analysis System	Root Quality Grade			Percent Rooting			Root Ball Diameter			Root Dry Weight		
	*1	2	3	1	2	3	1	2	3	1	2	3
				<u>Cornus florida</u> (Flowering dogwood)**								
Root Quality Grade	1.000	...	1.000	0.819	...	0.581	0.886	...	0.366	0.560	...	0.627
Percent Rooting	0.819	...	0.581	1.000	...	1.000	0.727	...	0.226	0.440	...	0.275
Root Ball Diameter	0.886	...	0.366	0.727	...	0.226	1.000	...	1.000	0.596	...	0.403
Root Dry Weight	0.560	...	0.627	0.440	...	0.275	0.596	...	0.403	1.000	...	1.000
				<u>Juniperus virginiana</u> (Eastern red cedar)**								
Root Quality Grade	...	1.000	...	...	0.683	...	...	0.928	...	...	0.865	...
Percent Rooting	...	0.683	...	...	1.000	...	...	0.562	...	...	0.502	...
Root Ball Diameter	...	0.928	...	...	0.562	...	...	1.000	...	...	0.926	...
Root Dry Weight	...	0.865	...	...	0.502	...	...	0.926	...	...	1.000	...

*Seasonal Code: 1 = Fall, 2 = Winter, 3 = Spring.

**<u>Cornus florida</u> only rooted two seasons and <u>Juniperus virginiana</u> rooted only one. <u>Tsuga canadensis</u> and <u>Cercis canadensis</u> did not root at any time.

... = No measure since no rooting.

The majority of the species had highest correlation with root quality grade and root ball diameter; root quality and percent rooting correlated almost as well. Also, no one season was clearly better than the others when comparing correlation coefficients. Individual correlation coefficients for each species and season are shown in Table 4.1.

2. Correlation Coefficients for Individual Species (Seasons Averaged) (Table 4.2)

Correlation coefficients for the four root development systems averaged over three seasons for individual species provided more definite trends (Table 4.2). Euonymus, shore juniper, mockorange and red cedar had high positive correlations between root ball diameter and root quality grade. Bar Harbor juniper, azalea, and dogwood had highest positive correlations between percent rooting and root quality grade. Buford holly varied from this with its highest positive correlation being between root ball diameter and root dry weight.

Dry weight is often considered the standard rooting parameter by researchers, therefore it was important to compare the other three systems to it. A high positive correlation between root dry weight and another rooting parameter may indicate that the parameter could be substituted for the much more laborious root dry weight method. Those rooting parameters having low positive correlation with root dry weight could not be used alone but must be combined with two or more other rooting parameters to adequately evaluate rooting.

Red cedar, Burford holly, 'Bar Harbor' juniper, euonymus and mockorange had highest positive correlation between root dry weight and

Table 4.2. Correlation coefficients for individual species averaged over three seasons (reported as R values).

Root Analysis System	Root Quality Grade	Percent Rooting	Root Ball Diameter	Root Dry Weight
	Euonymus japonicus (Japanese euonymus)			
Root Quality Grade	1.000	0.491	0.806	0.642
Percent Rooting	0.491	1.000	0.415	0.165
Root Ball Diameter	0.806	0.415	1.000	0.778
Root Dry Weight	0.642	0.165	0.778	1.000
	Juniperus horizontalis ('Bar Harbor' juniper)			
Root Quality Grade	1.000	0.813	0.780	0.698
Percent Rooting	0.813	1.000	0.610	0.465
Root Ball Diameter	0.780	0.610	1.000	0.778
Root Dry Weight	0.698	0.465	0.778	1.000

Table 4.2. (Continued)

Root Analysis System	Root Quality Grade	Percent Rooting	Root Ball Diameter	Root Dry Weight
Juniperus conferta (Shore juniper)				
Root Quality Grade	1.000	0.752	0.837	0.701
Percent Rooting	0.752	1.000	0.325	0.191
Root Ball Diameter	0.837	0.325	1.000	0.683
Root Dry Weight	0.701	0.191	0.683	1.000
Ilex cornuta (Burford holly)				
Root Quality Grade	1.000	0.791	0.745	0.667
Percent Rooting	0.791	1.000	0.551	0.456
Root Ball Diameter	0.745	0.551	1.000	0.821
Root Dry Weight	0.667	0.456	0.821	1.000

Table 4.2. (Continued)

Root Analysis System	Root Quality Grade	Percent Rooting	Root Ball Diameter	Root Dry Weight
	Philadelphus coronarius (Mockorange)			
Root Quality Grade	1.000	0.752	0.837	0.621
Percent Rooting	0.752	1.000	0.572	0.378
Root Ball Diameter	0.837	0.572	1.000	0.739
Root Dry Weight	0.621	0.378	0.739	1.000
	Rhododendron obtusum ('Coral Bells' azalea)			
Root Quality Grade	1.000	0.681	0.554	0.646
Percent Rooting	0.681	1.000	0.341	0.289
Root Ball Diameter	0.554	0.341	1.000	0.488
Root Dry Weight	0.646	0.289	0.488	1.000

Table 4.2. (Continued)

Root Analysis System	Root Quality Grade	Percent Rooting	Root Ball Diameter	Root Dry Weight
	Cornus florida (Flowering dogwood)			
Root Quality Grade	1.000	0.700	0.626	0.593
Percent Rooting	0.700	1.000	0.476	0.357
Root Ball Diameter	0.626	0.476	1.000	0.499
Root Dry Weight	0.593	0.357	0.499	1.000
	Juniperus virginiana (Eastern red cedar)			
Root Quality Grade	1.000	0.683	0.928	0.865
Percent Rooting	0.683	1.000	0.562	0.502
Root Ball Diameter	0.928	0.562	1.000	0.926
Root Dry Weight	0.865	0.502	0.926	1.000

root ball diameter with values of 0.92, 0.82, 0.77, 0.77, and 0.73, respectively. For shore juniper, azalea and dogwood, correlation was second highest between root dry weight and root ball diameter being 0.68, 0.48, and 0.49, respectively, however for these species higher correlation was found between root dry weight and root quality grade. Values were 0.70, 0.64, and 0.59 for shore juniper, azalea, and dogwood, respectively. Data showed that for most species, root dry weight was best correlated to root ball diameter and secondly to root quality grade but for some species these two measurements were reversed.

If R values are squared, a percent value is given which estimates the variation in one parameter answered by the other (R^2 simply measures closeness of fit). Assuming that the minimum acceptable R value for substituting one rooting parameter for another is 0.70, then root ball diameter could be used rather than dry weight for 'Bar Harbor' juniper, Burford holly, shore juniper, mockorange, and red cedar but not for other species.

3. Correlation Coefficients Over all Species but Seasons Not Averaged (Table 4.3)

Correlation coefficients averaged over all species showed highest positive correlation between root ball diameter and root quality grade for fall and winter experiments (Table 4.3). The spring experiment showed highest correlation between percent rooting and quality grade but was followed closely by correlations with root dry weight and root ball diameter. When comparing root dry weight (the standard parameter) to the other rooting parameters, root quality grade correlated best with

Table 4.3. Correlation coefficients averaged over all species for three seasons (reported as R values).

Root Analysis System	Root Quality Grade			Percent Rooting			Root Ball Diameter			Root Dry Weight		
	1*	2	3	1	2	3	1	2	3	1	2	3
Root Quality Grade	1.000	1.000	1.000	0.676	0.711	0.684	0.729	0.802	0.647	0.642	0.698	0.666
Percent Rooting	0.676	0.711	0.684	1.000	1.000	1.000	0.501	0.509	0.415	0.281	0.384	0.306
Root Ball Diameter	0.729	0.802	0.647	0.501	0.509	0.415	1.000	1.000	1.000	0.629	0.764	0.610
Root Dry Weight	0.642	0.698	0.666	0.281	0.384	0.306	0.629	0.764	0.610	1.000	1.000	1.000

*Seasonal Code: 1 = Fall, 2 = Winter, 3 = Spring.

dry weight for the fall and spring seasons giving values of 0.64 and 0.66, respectively. Root dry weight and root ball diameter had the highest positive correlation (0.76) for the winter season.

4. Correlation Coefficients Averaged Over All Species and Seasons (Table 4.4)

Correlation coefficients averaged over all species and seasons showed highest positive correlation between root ball diameter and root quality grade (0.72) (Table 4.4). When comparing the standard root dry weight to the other rooting parameters, root quality grade and root ball diameter correlated well with root dry weight, values being 0.66 and 0.66, respectively.

Data on correlation coefficients among four root development systems points out the difficulty and yet importance of choosing an accurate and reliable method of measuring rooting response. In general, coefficients showed that root quality grade and root ball diameter, both quickly measurable, are reasonably good measures of rooting since they show high positive correlation with the laborious but standard root dry weight method. Correlations, however, vary with overall seasonal response of rooting, for seasonal rooting of a given species, and for different species. Such variation makes it difficult to select any one root measurement technique which is as accurate as dry weights but which requires much less time and one which does not vary from plant to plant, season to season, or even treatment to treatment. Rooting percent correlates poorly with other parameters and its use exclusively could lead to serious errors in judging rooting, at least as regards extent and/or quality of rooting.

Table 4.4. Correlation coefficients averaged over all species and seasons (reported as R values).

Root Analysis System	Root Quality Grade	Percent Rooting	Root Ball Diameter	Root Dry Weight
Root Quality Grade	1.000	0.690	0.726	0.668
Percent Rooting	0.690	1.000	0.475	0.323
Root Ball Diameter	0.726	0.475	1.000	0.667
Root Dry Weight	0.668	0.323	0.667	1.000

Trends suggest that quality grade and root ball diameter may be acceptable substitutes for root dry weight, however, positive R values which have to be accepted as the minimum value for substitution are subjective. Furthermore, no standard values are found in the literature.

Due to the variation found in these data and the fact that R values were generally lower than 0.90, all four rooting measures are presented in this research with selected parameters used where appropriate.

II. SEASONAL COMPARISON OF ROOTING AVERAGED OVER ALL CHEMICAL TREATMENTS

Analysis of variance and pooled F-tests were performed on rooting data so that seasonal means could be compared by Duncan's Multiple Range Test. Seasonal rooting responses for the 10 species are shown in Table 4.5.

There was significant variation among the three seasons for all four rooting parameters measured, however, there was not enough difference to justify discussion of more than two major parameters. Root dry weight and root quality grade were chosen because root dry weight was considered the standard measure and quality was positively correlated with weight.

Based on root dry weight, euonymus, shore juniper, mockorange and dogwood rooted best during the spring from softwood cuttings, though euonymus rooted equally well in all seasons. Burford holly, and 'Bar Harbor' juniper rooted significantly better in the winter season. Azalea produced best root dry weight in the fall. Red cedar essentially did not root while redbud and hemlock did not root at all.

Table 4.5. Seasonal comparison of rooting averaged over all chemical treatments.

Species	Root Dry Weight (mg)			Root Quality Grade			Percent Rooting			Root Ball Diameter (mm)		
	1*	2	3	1	2	3	1	2	3	1	2	3
Euonymus japonicus	72.8b	62.9b	85.9a	2.9a	2.5b	2.9a	82.5a	85.5a	85.1a	43.0a	45.8a	47.0a
Juniperus horizontalis	21.2a	19.6a	11.0b	1.6b	2.6a	1.1c	63.9b	75.9a	42.2c	34.8b	53.4a	25.0b
Ilex cornuta	...	14.7a	1.2b	0.6b	1.8a	0.5b	15.6b	60.7a	23.3b	5.4b	22.2a	5.9b
Juniperus conferta	12.2b	11.5b	74.2a	1.8b	1.7b	3.1a	79.6b	69.6c	89.2a	23.2b	28.0b	86.8a
Philadelphus coronarius	17.6b	6.2b	54.2a	1.2b	0.9b	2.9a	46.3b	35.9b	81.8a	24.3b	14.5c	56.0a
Rhododendron obtusum	19.6a	1.6c	8.2b	2.4a	0.8b	2.4a	88.5a	41.1b	83.3a	31.1a	8.6c	23.5b
Cornus florida	39.3b	...	179.7a	1.6b	...	3.2a	36.1b	...	87.0a	32.3b	...	99.4a
Juniperus virginiana	...	2.6a	...	...	0.1a	...	...	6.2a	...	...	4.8a	...
Cercis canadensis	...	...	...	...	...	...	...	...	...	...	...	...
Tsuga canadensis	...	...	...	...	...	...	...	...	...	...	...	...

*Seasonal Code: 1 = Fall, 2 = Winter, 3 = Spring.

... = No measure since no rooting. Means in rows separated by different lower case letters are significantly different at the 0.05 level according to Duncan's Multiple Range Test.

Root quality grade was very similar to root dry weight except for euonymus and azalea which showed significant difference between fall and winter for quality measurements. Root ball diameter values followed the trends shown by quality grade almost exactly.

Averaged over all species, rooting was generally better in spring followed by fall and then winter with little difference between fall and winter. Redbud and hemlock did not root in any of the seasons, while red cedar rooted only slightly in the winter. Rooting percent varied widely as shown in Table 4.5.

III. TREATMENT COMPARISON OF ROOTING

To get an overall impression of chemical treatment effects, an analysis of variance was performed on data averaged over all species. These data showing treatment effects and seasonal averages are shown in Table 9.1. Then, to compare acid and base-tolerant plants, two additional tables were formed where data were averaged for these two groups of plants (see Methods and Materials for definition of these two groups). And finally, Duncan's Multiple Range Test was performed on treatment means for each root parameter at each season within each species.

1. Chemical Treatments Averaged Over All Species (Table 4.6)

In the fall experiment, best rooting occurred for high IBA followed closely by low IBA then acid or base + high IBA. Poorest rooting occurred for acid alone which was worse than the untreated control plants.

Table 4.6. Rooting responses to chemical treatments averaged over all species.

Treatments	Root Dry Weight (mg)			Root Quality Grade			Percent Rooting			Root Ball Diameter (mm)		
	1*	2	3	1	2	3	1	2	3	1	2	3
Control	17.7	8.2	35.0	1.7	1.1	2.2	59.1	42.3	71.9	26.7	20.4	45.4
Acid	13.7	12.3	36.9	0.6	1.2	1.7	52.2	45.7	56.1	21.6	19.5	37.0
Base	19.3	13.7	36.6	1.7	1.5	2.2	56.1	55.7	69.5	26.9	25.0	47.2
IBA (low)	33.7	18.4	64.7	2.1	1.5	2.3	60.0	52.3	72.3	31.7	28.4	55.5
IBA (high)	42.2	42.2	100.3	2.3	1.7	2.7	68.2	65.2	75.2	39.2	27.0	57.2
Acid + IBA (low)	19.3	15.2	47.5	1.4	1.5	2.2	57.2	50.9	69.9	22.7	24.0	47.3
Acid + IBA (high)	33.5	16.2	56.9	1.9	1.3	2.3	60.1	50.0	71.3	27.9	22.8	45.0
Base + IBA (low)	19.8	21.1	64.9	1.5	1.8	2.4	53.5	59.5	72.8	22.0	30.8	51.3
Base + IBA (high)	28.7	26.6	88.1	1.9	1.7	2.6	64.5	60.9	73.3	30.8	25.7	56.7
Averages	25.3	19.3	58.9	1.7	1.3	2.3	58.9	53.6	70.3	27.7	24.8	49.2

*Seasonal Code: 1 = Fall, 2 = Winter, 3 = Spring.

The beneficial effect of IBA was obvious even when combined with H_2SO_4 or NaOH. Generally, all rooting parameters showed these trends.

In the winter experiment the best treatments were again IBA at either rate and combinations of IBA + base. Acid treatment was again poor but control plants were poorest.

For the spring experiment poorest rooting was seen for control plants while the best rooting treatments were high IBA, base + high IBA, base + low IBA and usually low IBA.

The consistently positive effects on rooting of IBA either alone or when combined with base was obvious. Acid + high IBA was nearly as good in fall, however. All rooting parameters showed this same trend. Average rooting, as measured by all parameters, was best by far in the spring, followed by fall then winter.

2. Treatments Averaged for Acid and Base Plants

Averages for all acid and base tolerant plants, excluding those that did not root, are shown in Tables 4.7 and 4.8, respectively. Much variation occurred in treatment effect on acid-tolerant plants but the better treatments included base + high IBA, high IBA and base + low IBA. Acid and control were consistently poor treatments. There was no obvious trend where base significantly increased rooting of acid-tolerant species as suggested by Lee, Paul, and Hackett (17).

Base-tolerant species reacted much the same as acid-tolerant plants. Best response occurred with high IBA, base + high IBA, low IBA and base + low IBA. Acid treatment did not produce increased rooting of

Table 4.7. Rooting responses to chemical treatments averaged for acid-tolerant plants.

Treatments	Root Dry Weight (mg)			Root Quality Grade			Percent Rooting			Root Ball Diameter (mm)		
	1*	2	3	1	2	3	1	2	3	1	2	3
Control	14.0	8.6	27.7	1.7	1.2	2.1	48.8	43.8	67.6	27.1	21.9	38.8
Acid	15.9	6.6	40.1	1.6	1.1	1.4	57.6	40.0	47.6	27.5	17.4	31.8
Base	18.1	11.4	41.9	1.6	1.6	2.1	49.5	58.1	67.6	28.2	26.3	45.4
IBA (low)	15.0	7.2	68.2	1.7	1.3	2.0	52.5	42.8	66.6	26.5	22.5	48.5
IBA (high)	35.5	11.3	86.2	2.0	1.7	2.1	61.9	63.8	69.5	35.5	24.7	50.0
Acid + IBA (low)	24.7	7.8	53.6	1.6	1.4	2.2	64.3	45.7	75.2	27.1	21.6	43.1
Acid + IBA (high)	29.0	7.2	53.6	2.1	1.2	2.1	72.6	46.7	72.3	34.4	20.4	41.8
Base + IBA (low)	16.1	13.1	57.5	1.5	1.9	2.1	51.7	60.0	67.6	22.8	31.4	42.7
Base + IBA (high)	29.8	19.0	85.8	2.0	1.8	2.4	67.1	56.1	72.4	37.4	30.4	55.5
Averages	22.0	10.2	57.2	1.8	1.5	2.1	58.4	50.8	67.4	29.6	24.1	44.2

*Seasonal Code: 1 = Fall, 2 = Winter, 3 = Spring.

Table 4.8. Rooting responses to chemical treatments averaged for base tolerant plants.

Treatments	Root Dry Weight (mg)			Root Quality Grade			Percent Rooting			Root Ball Diameter (mm)		
	1*	2	3	1	2	3	1	2	3	1	2	3
Control	21.3	8.2	42.4	1.8	1.1	2.4	69.5	40.9	76.2	26.4	18.9	52.1
Acid	11.4	18.1	33.8	1.2	1.3	2.1	46.9	51.4	64.7	15.7	21.6	42.3
Base	20.6	16.1	31.2	1.7	1.5	2.1	62.8	53.3	71.4	25.7	23.7	49.1
IBA (low)	52.7	29.9	50.0	2.6	1.7	2.5	67.6	61.9	78.1	36.9	34.3	62.5
IBA (high)	55.7	30.9	118.3	2.7	1.7	3.3	74.5	66.6	80.9	43.0	29.3	64.4
Acid + IBA (low)	13.9	22.6	41.4	1.2	1.5	2.2	50.1	56.1	64.7	18.3	26.5	51.5
Acid + IBA (high)	38.0	25.3	60.0	1.6	1.4	2.5	47.6	53.3	70.4	21.5	25.2	48.3
Base + IBA (low)	23.4	29.2	72.3	1.6	1.7	2.7	55.2	59.0	78.1	21.2	30.3	60.0
Base + IBA (high)	27.5	34.1	90.5	1.8	1.7	2.7	62.0	65.7	74.3	24.2	21.0	57.9
Averages	29.3	23.8	60.0	1.8	1.5	2.5	59.6	56.5	73.2	25.9	25.6	54.2

*Seasonal Code: 1 = Fall, 2 = Winter, 3 = Spring.

base-tolerant plants tested. Data again disagreed with the theory put forth by Lee, Paul, and Hackett (17).

IV. ANALYSIS OF ROOTING FOR INDIVIDUAL SPECIES

Seasonal rooting response of all 10 species to all chemical treatments are shown in Tables 4.9 through 4.24. Duncan's Multiple Range Test was used to compare treatment means and seasonal averages. Discussion of results will be by individual species.

1. Euonymus japonicus (Japanese Euonymus)

Euonymus was easily rooted in most all seasons and for all treatments except winter-rooted control plants (Tables 4.9 and 4.10). Seasonal averages showed at least 82 percent rooting. Based on root dry weight, euonymus rooted best in spring but when comparing cuttings by quality grade, percent rooting and root ball diameter, fall rooting was equally as good. Winter rooting was poorest as measured by two of the four parameters.

Treatments which gave consistently best results for all seasons were low or high IBA, acid + high IBA and base + high IBA. The single best treatment over all seasons was 3000 ppm IBA, especially in the spring (Figure 2). Poorest results were obtained for untreated cuttings taken in winter (Figure 3). Euonymus showed no increased rooting under acid treatment as compared to other chemicals, however, 100 percent rooting occurred for acid-treated cuttings taken during the winter.

Table 4.9. Rooting response of _Euonymus japonicus_ (Japanese euonymus) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

	Rooting Parameters							
	Root Dry Weight (mg)				Root Quality Grade			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	56.6Abc	15.3Bd	56.0Adef	42.6	2.5Acde	1.4Bd	2.6Acd	2.2
Acid	16.0Ad	52.2Abc	31.7Afg	33.3	1.7Bf	2.7Aab	2.2ABd	2.2
Base	34.4Acd	38.7Acd	42.2Aef	38.5	2.4Ade	2.2Ac	2.6Acd	2.4
IBA (low)	129.4Aa	77.1Bab	66.6Bde	91.0	4.1Aa	2.6Bb	3.2Bbc	3.3
IBA (high)	122.9Ba	79.4Cab	234.7Aa	145.7	3.6Bab	2.7Cab	4.6Aa	3.6
Acid + IBA (low)	30.5ABcd	62.6Aabc	10.3Bg	34.5	2.1Aef	2.6Ab	1.3Be	2.0
Acid + IBA (high)	124.0Aa	71.5Babc	78.1Bcd	91.2	3.8Aa	2.6Bb	2.7Bcd	3.0
Base + IBA (low)	75.4Ab	78.6Aab	107.4Ac	87.1	3.1Abc	3.1Aa	3.3Abc	3.2
Base + IBA (high	66.2Bb	90.8Ba	146.4Ab	101.1	2.9Acd	2.8Aab	3.6Ab	3.1
Averages	72.8B	62.9B	85.9A	73.9	2.9A	2.5B	2.9A	2.8

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.10. Rooting response of *Euonymus japonicus* (Japanese euonymus) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

Treatment	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	80.0Aabc	36.6Bc	93.3Aab	70.0	41.6Ade	21.3Bc	53.6Abc	38.8
Acid	60.0Bc	100.0Aa	73.3Bb	77.8	14.7Bf	44.7Aab	29.9ABd	29.8
Base	66.6Abc	80.0Ab	86.6Aab	77.7	33.8Ade	34.3Ab	42.4Ac	36.8
IBA (low)	93.3Aab	93.3Aa	93.3Aab	93.3	61.5Aa	55.3Aa	53.5Abc	56.8
IBA (high)	100.0Aa	90.0Ab	100.0Aa	96.7	59.1Aab	51.7Aa	70.8Aa	60.5
Acid + IBA (low)	70.Aabc	93.3Aa	43.3Bc	68.9	29.7Be	49.7Aa	17.9Bd	32.4
Acid + IBA (high)	93.3Aab	90.0Aab	76.6Aab	86.6	56.2Aabc	49.6Aa	43.1Ac	49.6
Base + IBA (low)	90.0Aabc	90.0Aab	100.0Aa	93.3	46.3Abcd	55.7Aa	56.6Ab	52.9
Base + IBA (high)	90.0Aabc	96.6Aa	100.0Aa	95.5	44.3Acd	49.8Aa	55.6Abc	49.9
Averages	82.5A	85.5A	85.1A	84.4	43.0A	45.8A	47.0A	45.3

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.11. Rooting response of _Juniperus horizontalis_ 'Bar Harbor' ('Bar Harbor' juniper) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

Treatment	Rooting Parameters							
	Root Dry Weight (mg)				Root Quality Grade			
	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	20.8Ab	20.5Aab	23.0Aab	21.4	1.8Aab	2.5Aab	1.7Aab	2.0
Acid	17.5Ab	15.1Ab	2.6Ab	11.7	1.6ABabc	2.0Ab	0.6Bc	1.4
Base	42.2Aa	19.1Bab	27.0ABa	29.4	2.3Aa	2.4Aab	1.8Aa	2.2
IBA (low)	22.0Ab	15.4Ab	5.6Aab	14.3	1.8ABab	2.8Aab	0.9Bbc	1.8
IBA (high)	24.9Ab	21.4Aab	7.9Aab	18.1	1.5ABabc	2.7Aab	1.0Babc	1.7
Acid + IBA (low)	20.2Ab	18.3Aab	2.9Ab	13.8	1.4Bbc	2.7Aab	0.9Bbc	1.7
Acid + IBA (high)	19.7Ab	21.1Aab	6.2Aab	15.7	1.9ABab	2.6Aab	1.2Babc	1.9
Base + IBA (low	10.4ABb	28.3Aa	4.5Bab	14.4	0.9Bc	3.2Aa	0.7Bc	1.6
Base + IBA (high)	13.4Ab	17.1Aab	19.2Aab	16.6	1.1Abc	2.3Aab	1.4Aabc	1.6
Averages	21.2A	19.6A	11.0B	17.3	1.6B	2.6A	1.1C	1.8

Quality = 0 to 5 rating scale
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.12. Rooting response of *Juniperus horizontalis* 'Bar Harbor' ('Bar Harbor' juniper) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	66.6Aabc	86.6Aa	60.0Aab	71.1	34.6Ab	52.9Aab	40.5Aab	42.7
Acid	73.3Aab	60.0Ab	30.0Ac	54.4	35.4Ab	38.5Ab	12.2Ab	28.7
Base	73.3Aab	83.3Aa	63.3Aa	73.3	60.7Aa	52.0Aab	49.8Aa	54.2
IBA (low)	73.3Aab	80.0Aab	36.6Bbc	63.3	37.2ABb	55.7Aab	16.9Bb	36.6
IBA (high)	66.6ABabc	76.6Aab	33.6Bbc	59.9	33.9Ab	53.5Aab	22.2Aab	36.5
Acid + IBA (low)	60.0ABabc	66.6Aab	33.3Bc	53.3	33.4ABb	52.2Aab	15.2Aab	33.6
Acid + IBA (high)	76.6ABa	80.0Aab	46.6Babc	67.7	35.2Ab	54.1Aab	23.8Aab	37.7
Base + IBA (low)	40.0Bc	86.6Aa	30.0Bc	52.2	17.8Bb	74.9Aa	17.0Bb	36.6
Base + IBA (high)	44.8Abc	63.3Aab	53.3Aabc	50.5	24.4Ab	46.7Ab	27.2Aab	32.8
Averages	63.9B	75.9A	42.2C	60.7	34.8B	53.4A	24.0B	37.7

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.13. Rooting response of Juniperus conferta (Shore juniper) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

Treatment	Root Dry Weight (mg) Fall	Winter	Spring	X	Root Quality Grade Fall	Winter	Spring	X
Control	5.9Bb	9.1Ba	78.44Aabc	31.1	1.7Bc	1.8Bab	3.6Aab	2.4
Acid	9.8Ab	5.2Aa	51.8Abc	22.3	1.6ABc	1.1Bb	2.5Ad	1.7
Base	7.5Ab	8.3Aa	48.1Ac	21.3	1.5Bc	1.7Bab	2.6Acd	1.9
IBA (low)	25.1Ba	18.2Ba	89.7Aab	44.3	2.8ABb	2.2Ba	3.4Aabc	2.8
IBA (high)	34.2Ba	7.3Ba	97.6Aa	46.4	3.5Aa	1.6Bab	3.7Aa	2.9
Acid + IBA (low)	9.8Bb	9.0Ba	72.9Aabc	30.6	1.4Bc	1.7Bab	3.3Aabc	2.1
Acid + IBA (high)	3.3Bb	14.1Ba	78.2Aabc	31.9	1.1Bc	1.7Bab	3.0Aabcd	1.9
Base + IBA (low)	5.5Bb	19.2Ba	68.2Aabc	31.0	1.6Bc	2.1ABab	2.7Acd	2.1
Base + IBA (high)	9.9Bb	13.2Ba	83.3Aabc	35.5	1.4Bc	1.9Bab	2.9Abcd	2.1
Averages	12.2B	11.5B	74.2A	32.6	1.8B	1.7B	3.1A	2.2

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's multiple range across treatments (in columns) at 5% level.

Table 4.14. Rooting response of *Juniperus conferta* (Shore juniper) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	86.6ABab	66.6Ba	100.0Aa	84.4	23.1Bc	27.4Bab	94.6Aab	48.4
Acid	73.3ABabc	46.6Ba	76.6Ab	65.5	21.4Bc	15.5Bb	64.5Ac	33.8
Base	80.0Aabc	66.6Aa	86.6Aab	77.7	19.6Bc	24.4Bab	86.7Aabc	43.6
IBA (low)	100.0Aa	83.3Aa	90.0Aab	91.1	36.7Bb	43.4Ba	108.2Aa	62.8
IBA (high)	100.0Aa	73.3Aa	100.0Aa	91.1	49.3Ba	20.1Bab	93.2Aab	54.2
Acid + IBA (low)	73.3Aabc	66.6Aa	90.0Aab	76.6	19.0Bc	22.5Bab	89.3Aabc	43.6
Acid + IBA (high)	56.6Bc	66.6ABa	86.6Aab	69.9	6.0Bd	26.0Bab	72.1Abc	34.7
Base + IBA (low)	76.6Aabc	83.3Aa	90.0Aab	83.3	17.7Bcd	39.6Bab	87.5Aabc	48.3
Base + IBA (high)	70.0Abc	76.6Aa	83.3Aab	76.6	15.7Bcd	32.9Bab	84.9Aabc	44.5
Averages	79.6B	69.6	89.2A	79.5	23.2	28.0B	86.8A	46.0

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.15. Rooting response of _Juniperus virginiana_ (Eastern Red Cedar) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

	Rooting Parameters							
	Root Dry Weight (mg)				Root Quality Grade			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control		1.0ab			0.7Aab	0.1Aa		
Acid		0.0b			0.03Ab	0.0Ab		
Base		0.0b			0.2Aab	0.0Ab		
IBA (low)		0.0b			0.3Aab	0.0Ab		
IBA (high)		11.0ab			0.4Aab	0.5Aa		
Acid + IBA (low)		0.0b			0.03Ab	0.0Ab		
Acid + IBA (high)		0.0b			0.3Aab	0.0Bb		
Base + IBA (low)		0.0b			0.5Aa	0.0Bb		
Base + IBA (high)		11.0a			0.4Aab	0.5Aa		
Averages		2.6A			0.3A	0.1A		

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.16. Rooting response of _Juniperus virginiana_ (Eastern Red Cedar) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control		6.6b				4.0b		
Acid		0.0b				3.0b		
Base		0.0b				3.0b		
IBA (low)		0.0b				3.0b		
IBA (high)		23.3a				11.2a		
Acid + IBA (low)		0.0b				3.0b		
Acid + IBA (high)		0.0b				3.0b		
Base + IBA (low)		0.0b				3.0b		
Base + IBA (high)		26.6a				10.1a		
Averages		6.2a				4.8A		

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's multiple range across treatments (in columns) at 5%.

Table 4.17. Rooting response of _Ilex cornuta_ 'Burfordii' (Burford holly) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

Treatment	Root Dry Weight (mg) Fall	Winter	Spring	X	Root Quality Grade Fall	Winter	Spring	X
Control		8.3Ab	0.8Aab	4.6	0.7ABa	1.3Abc	0.5Ba	0.8
Acid		7.3Ab	0.6Aab	3.9	0.6Ba	1.6Abc	0.2Ba	0.8
Base		18.0Ab	0.2Bb	9.1	0.4Ba	2.1Aab	0.4Ba	1.0
IBA (low)		9.3Ab	1.4Aab	3.6	0.6ABa	1.3Abc	0.3Ba	0.7
IBA (high)		16.7Ab	1.1Bab	8.9	0.6Ba	2.1Aab	0.4Ba	1.0
Acid + IBA (low)		7.9Ab	1.5Aab	4.7	0.6Ba	1.6Abc	0.7Ba	1.0
Acid + IBA (high)		3.6Ab	3.1Aa	2.2	0.7Aa	1.0Ac	0.6Aa	0.8
Base + IBA (low)		16.0Ab	2.0Bab	9.0	0.5Ba	2.3Aab	0.7Ba	1.2
Base + IBA (high)		45.1Aa	0.4Bab	22.8	0.7Ba	2.9Aa	0.2Ba	1.3
Averages		14.7A	1.2Bab	8.0	0.6B	1.8A	0.5B	1.0

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.18. Rooting response of _Ilex cornuta_ 'Burfordii' (Burford holly) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	10.0Aa	36.6Ab	26.6Aa	24.4	5.7ABa	18.0Ab	4.7Ba	9.5
Acid	56.6Ba	56.6Aab	13.3Ba	25.5	4.1Aa	16.0Ab	4.6Aa	8.2
Base	6.6Ba	73.3Aab	20.0Ba	33.3	3.9Ba	27.0Ab	4.3Ba	11.7
IBA (low)	20.0Aa	36.6Ab	16.6Aa	24.4	4.1Aa	16.4Ab	5.7Aa	8.7
IBA (high)	10.0Ba	83.3Aa	23.3Ba	38.9	5.4Ba	22.9Ab	5.4Ba	11.2
Acid + IBA (low)	16.6Ba	60.0Aab	36.6ABa	37.7	5.2Aa	16.1Ab	8.1Aa	9.8
Acid + IBA (high)	27.5Aa	40.0Ab	30.0Aa	32.5	8.4Aa	11.5Ab	8.6Aa	9.5
Base + IBA (low)	16.6Ba	73.3Aab	33.3Ba	41.1	4.8Ba	27.3Ab	8.4Ba	13.5
Base + IBA (high)	26.6Ba	86.6Aa	10.0Ba	41.1	7.0Ba	44.5Aa	3.8Ba	18.4
Averages	15.6B	60.7A	23.3B	33.2	5.4	22.2A	5.9B	11.2

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.19. Rooting response of Philadelphus coronarius (Mockorange) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

	Rooting Parameters							
	Root Dry Weight (mg)				Root Quality Grade			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	12.2Aab	3.2Aa	13.9Ad	9.8	2.0ABa	0.7Ba	2.2Ac	1.6
Acid	14.2Aab	5.9Aa	34.9Abcd	18.3	0.8Bbcd	0.8Ba	2.5Aabc	1.3
Base	30.1Aab	9.5Aa	18.8Acd	19.4	1.9Aa	1.2Aa	2.3Abc	1.8
IBA (low)	28.9ABab	8.5Ba	58.0Aabc	31.8	1.4Babc	1.0Ba	2.9Aabc	1.8
IBA (high)	37.8Ba	10.3Ba	81.9Aa	43.3	1.8ABa	1.2Ba	3.1Aab	2.0
Acid + IBA (low)	8.5Bab	7.4Ba	62.0Aab	26.0	0.8Bbcd	1.0Ba	3.2Aa	1.7
Acid + IBA (high)	5.7Bb	3.1Ba	53.7Aabcd	20.8	0.5Bcd	0.5Ba	3.0Aab	1.3
Base + IBA (low)	1.1Bb	4.5Ba	77.4Aa	27.7	0.3Bd	0.6Ba	3.3Aa	1.4
Base + IBA (high)	20.3Bab	3.6Ba	87.0Aa	37.0	1.6Bab	0.7Ba	3.1Aab	1.8
Averages	17.6B	6.2B	54.2A	26.0	1.24B	0.9B	2.87A	1.7

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.20. Rooting response of *Philadelphus coronarius* (Mockorange) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	76.6Aa	33.3Aa	73.3Aa	61.1	27.7Aabcd	13.3Aa	34.1Ad	25.0
Acid	31.0Acde	33.3Ba	76.6Ba	47.0	18.9Bbcd	12.3Aa	53.6Abc	28.3
Base	73.3Aab	40.0Aa	76.6Aa	63.3	36.7Aab	21.2Aa	42.7Acd	33.5
IBA (low)	43.3Bbcde	40.0Ab	90.0Aa	57.8	31.1Aabc	18.5Ba	56.9Aabc	35.5
IBA (high)	60.7Aabc	46.6Aa	83.3Aa	63.5	42.0ABa	19.6Ba	56.9Aabc	35.5
Acid + IBA (low)	32.1Bcde	36.6Ba	93.3Aa	54.0	15.5Bcd	17.4Ba	61.4Aabc	41.0
Acid + IBA (high)	16.6Be	30.0Ba	83.3Aa	43.3	13.2Bcd	9.7Ba	73.1Aa	35.3
Base + IBA (low)	26.6Bde	33.3Ba	83.3Aa	47.7	10.1Bd	7.8Ba	54.0Abc	25.6
Base + IBA (high)	57.1ABabcd	30.0Ba	76.6Aa	54.6	24.7Babcd	10.6Ba	62.0Aab	32.4
Averages	46.3B	35.9B	81.8A	54.7	24.3B	14.5C	56.0A	31.6

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.21. Rooting response of Rhododendron obtusum 'Coral Bells' ('Coral Bells' Azalea) to acid, base and IBA treatments in fall, winter, and spring as compared by root dry weight and root quality grade.

	Rooting Parameters							
	Root Dry Weight (mg)				Root Quality Grade			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	15.6Aa	1.3Ba	8.3ABab	8.4	2.2Abc	0.5Ba	2.7Ba	1.8
Acid	13.9Aa	0.6Ba	2.1Bb	5.5	2.3Aabc	0.4Ca	1.1Bb	1.3
Base	17.0Aa	2.8Ba	6.1Bab	8.6	1.9Ac	0.9Ba	2.2Aa	1.7
IBA (low)	24.4Aa	0.6Ba	4.7Bab	9.9	2.6Aabc	0.6Ba	2.1Aa	1.8
IBA (high)	23.0Aa	1.5Ba	10.9Bab	11.8	2.6Aabc	1.2Ba	2.8Aa	2.2
Acid + IBA (low)	12.3Aa	1.1Ba	11.5Aa	8.3	2.1Bbc	0.6Ca	2.8Aa	1.8
Acid + IBA (high)	25.5Aa	0.6Aa	8.0Bab	11.4	3.0Aa	0.7Ba	2.4Aa	2.0
Base + IBA (low)	19.6Aa	1.4Ba	9.4Bab	10.1	2.4Aabc	1.0Ba	2.4Aa	1.9
Base + IBA (high)	25.2Aa	4.4Ba	12.8Ba	14.1	2.8Aab	1.0Ba	2.9Aa	2.2
Averages	19.6A	1.6C	8.2B	9.8	2.4A	0.8B	2.4A	1.9

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.22. Rooting response of _Rhododendron obtusum_ 'Coral Bells' ('Coral Bells' Azalea) to acid, base and IBA treatments in fall, winter, and spring as compared by percent rooting and root ball diameter.

Treatment	Percent Rooting				Root Ball Diameter (mm)			
	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	80.0Ab	30.0Bab	86.6Aa	65.5	30.0Aab	5.9Ba	25.7Ab	20.5
Acid	93.3Aab	23.3Cb	46.6Bb	54.4	31.4Aab	6.4Ba	8.5Bc	15.4
Base	83.3Aab	46.6Bab	80.0Aa	70.0	22.3Ab	13.1Aa	18.8Abc	18.1
IBA (low)	80.0Ab	33.3Bab	80.0Aa	64.4	39.1Aa	6.6Ca	22.9Bb	22.9
IBA (high)	86.6Aab	63.3Ba	93.3Aa	81.1	33.7Aab	9.9Ba	40.0Aa	27.9
Acid + IBA (low)	96.6Aab	33.3Bab	93.3Aa	74.4	23.6Ab	7.2Ba	29.6Aab	20.1
Acid + IBA (high)	100.0Aa	43.3Bab	83.3Aa	75.5	34.6Aab	5.8Ca	17.8Bbc	19.4
Base + IBA (low)	93.3Aab	50.0Bab	86.6Aa	76.6	29.3Aab	7.7Ba	25.3Ab	20.8
Base + IBA (high)	93.3Aab	46.6Bab	100.0Aa	80.0	35.8Aab	15.2Ba	25.8ABb	25.6
Averages	88.5A	41.1B	83.3A	71.0	31.1A	8.6C	23.5B	21.1

(Column groups above under the spanning heading "Rooting Parameters".)

IBA (low) = 1,000 ppm.
IBA (high) = 3,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.23. Rooting response of _Cornus florida_ (Flowering Dogwood) to acid, base and IBA treatments in fall, _winter_, and _spring_ as compared to root dry weight and root quality grade.

Treatment	Root Dry Weight (mg) Fall	Winter	Spring	X	Root Quality Grade Fall	Winter	Spring	X
Control	12.9Abc		64.7Ae	38.8	1.1Bcd		2.3Ac	1.7
Acid	24.2Babc		134.9Acde	79.6	1.2Bbcd		2.9Abc	2.1
Base	4.0Bc		113.4Ade	58.7	0.9Bd		2.8Abc	1.9
IBA (low)	6.0		227.0Aabc	77.7	1.1Bcd		3.6Aab	2.4
IBA (high)	76.2Ba		281.7Aa	179.0	2.4Ba		3.3Aab	2.9
Acid + IBA (low)	53.8Babc		171.6Acde	112.7	1.6Bbc		3.3Aab	2.5
Acid + IBA (high)	56.4Babc		170.9Abcde	113.7	1.9Bab		3.3Aab	2.6
Base + IBA (low)	26.4Babc		185.4Aabcd	105.9	1.5Bbcd		3.4Aab	2.5
Base + IBA (high)	65.8Bab		267.8Aab	166.8	2.3Ba		3.8Aa	3.1
Averages	39.3B		179.7A	109.5	1.6B		3.2A	2.4

Quality = 0 to 5 rating scale.
IBA (low) = 1,000 ppm.
IBA (high) = 8,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

Table 4.24. Rooting response of _Cornus florida_ (Flowering Dogwood) to acid, base and IBA treatments in fall, winter, and spring as compared to percent rooting and root ball diameter.

	Rooting Parameters							
	Percent Rooting				Root Ball Diameter (mm)			
Treatment	Fall	Winter	Spring	X	Fall	Winter	Spring	X
Control	14.2Bd		63.3Ac	38.8	24.5Bcd		65.0Ac	44.8
Acid	28.5Bcd		76.6Acb	52.6	25.2Bcd		81.9Ac	53.6
Base	10.0Bd		73.3Acb	41.7	11.8Bd		86.0Aabc	48.9
IBA (low)	10.3Bd		100.0Aa	55.2	12.2Bd		124.1Aab	68.2
IBA (high)	53.5Bab		90.0Aab	71.8	51.1Bab		107.4Aabc	79.3
Acid + IBA (low)	51.8Babc		100.0Aa	75.9	32.5Bbcd		98.0Aabc	65.3
Acid + IBA (high)	50.0Babc		93.3Aab	71.7	42.1Babc		96.2Aabc	69.2
Base + IBA (low)	31.0Bbcd		86.6Aab	58.8	27.9Bbcd		98.6Aabc	63.3
Base + IBA (high)	70.0Ba		100.0Aa	85.5	63.6Ba		137.4Aa	100.5
Averages	36.1B		87.0A	61.6	32.3B		99.4A	65.9

IBA (low) = 1,000 ppm.
IBA (high) = 8,000 ppm.
Upper case letters = Duncan's Multiple Range for treatments across seasons (in rows) at 5% level.
Lower case letters = Duncan's Multiple Range across treatments (in columns) at 5% level.

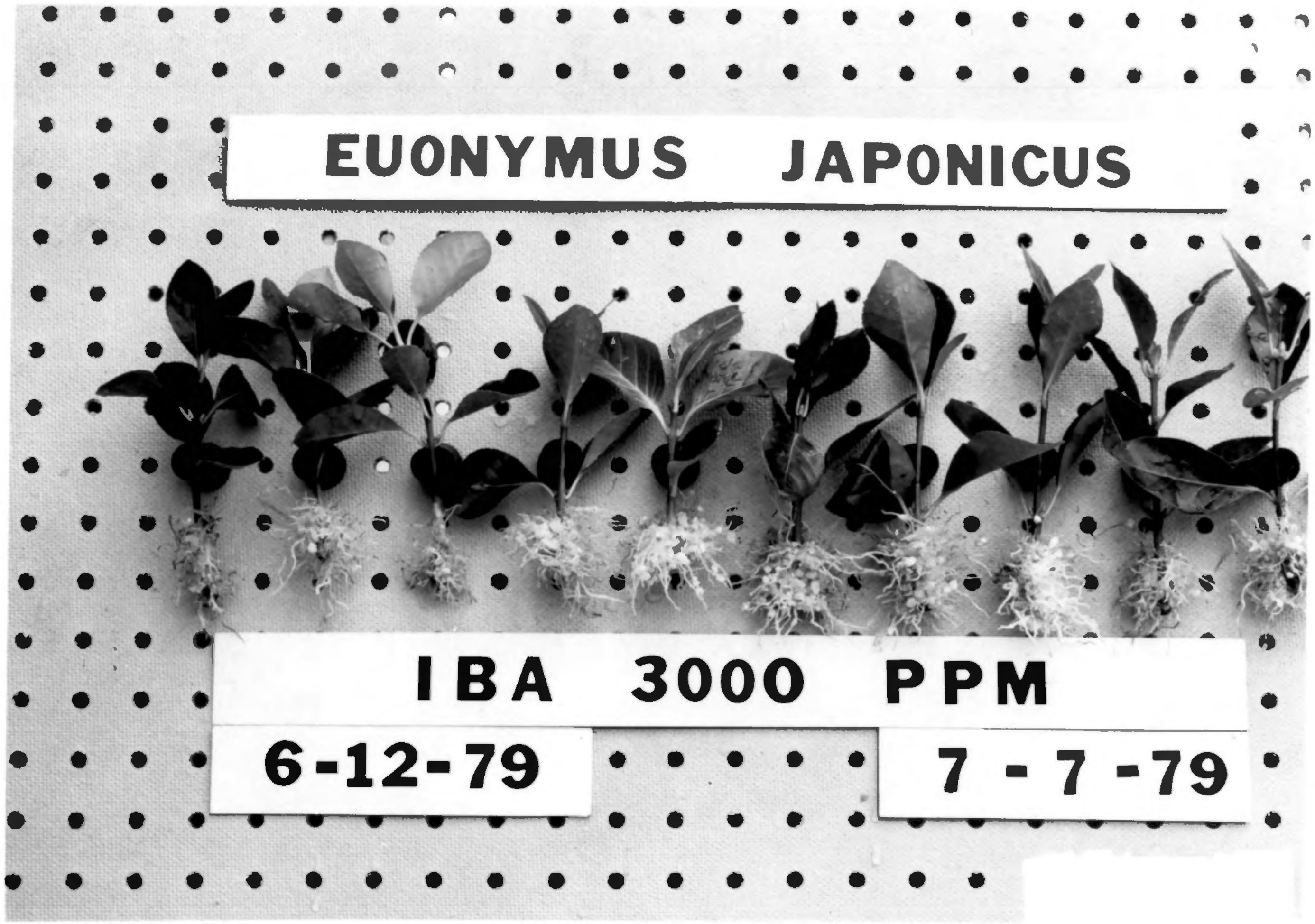

Figure 2. Single best treatment for Euonymus japonicus (Japanese euonymus) was 3,000 ppm IBA applied during the spring.

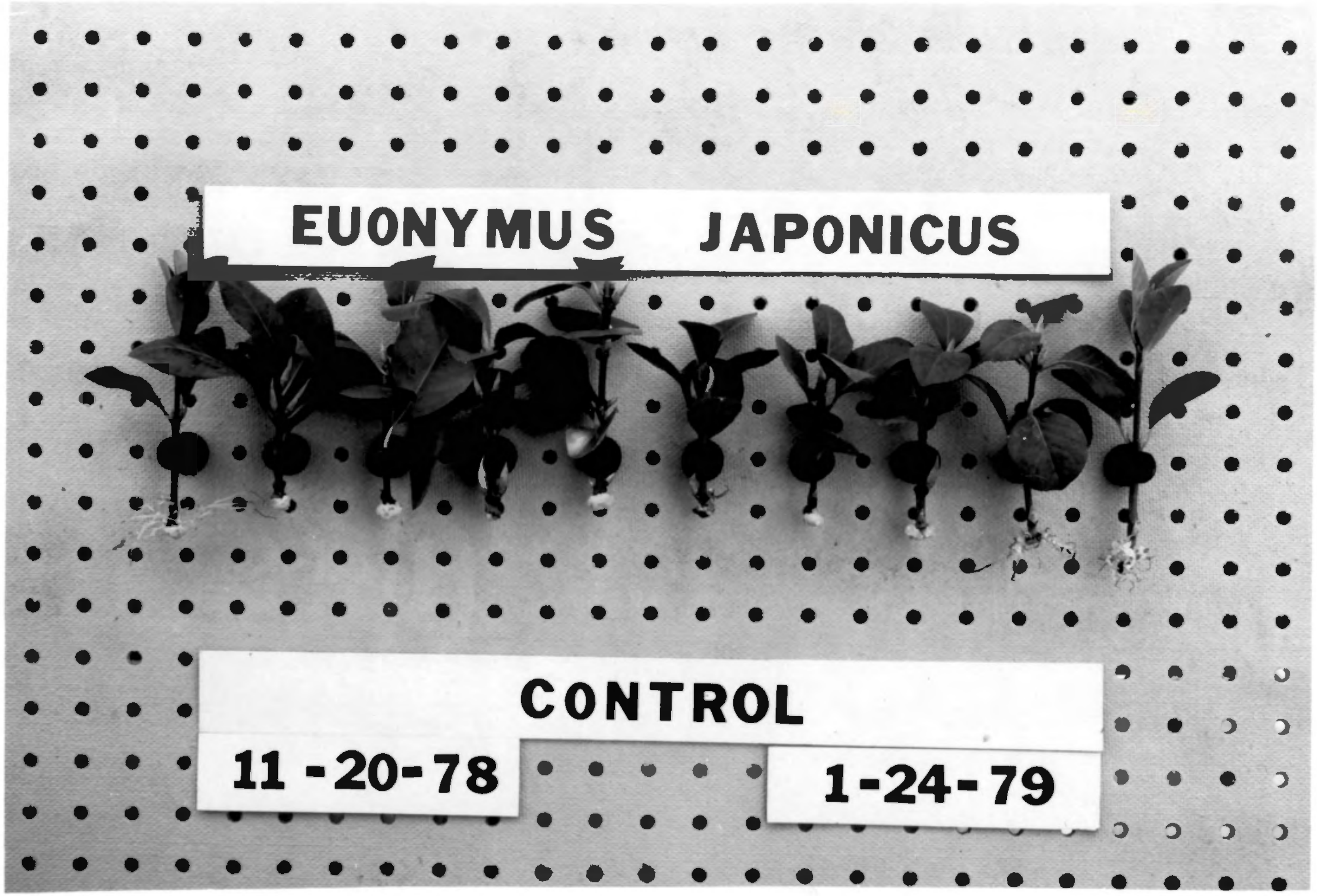

Figure 3. Single poorest treatment for Euonymus japonicus (Japanese euonymus) was the control (untreated cuttings) taken in the winter experiment.

2. Juniperus horizontalis ('Bar Harbor' Juniper)

'Bar Harbor' juniper rooted best in winter based on quality, percent rooting and root ball diameter while root dry weights were equally as high for fall cuttings (Tables 4.11 and 4.12, pages 48 and 49). Spring cuttings were consistently poorer rooting.

For fall and spring cuttings, NaOH at pH 10.5 gave best results while base + low IBA was equally as good in winter. The better treatments averaged over all seasons were base, high IBA, acid + IBA, base + low or high IBA and even control plants were nearly as good. Little significant difference occurred among these better treatments. Poor rooting usually occurred for acid alone or acid + low IBA. The best and poorest treatment response, NaOH pH 10.5 + low IBA during the winter and H_2SO_4 during the spring, are shown in Figures 4 and 5, respectively. Even during the best season (winter) only about 75 percent rooting of Bar Harbor juniper was realized with best treatments giving only 80 to 85 percent rooting.

3. Juniperus conferta (Shore Juniper)

Shore juniper, in contrast to 'Bar Harbor', rooted best in spring as measured by all parameters (Tables 4.13 and 4.14, pages 50 and 51). Fall and winter rooting were equally poor when measured by dry weight, quality, and root ball diameter, but percent rooting was significantly poorer in winter than fall.

Consistently good rooting, averaged over all seasons, occurred for both IBA treatments. Few significant differences were seen among acid, base, acid + low IBA, acid + high IBA, base + low IBA, base + high IBA

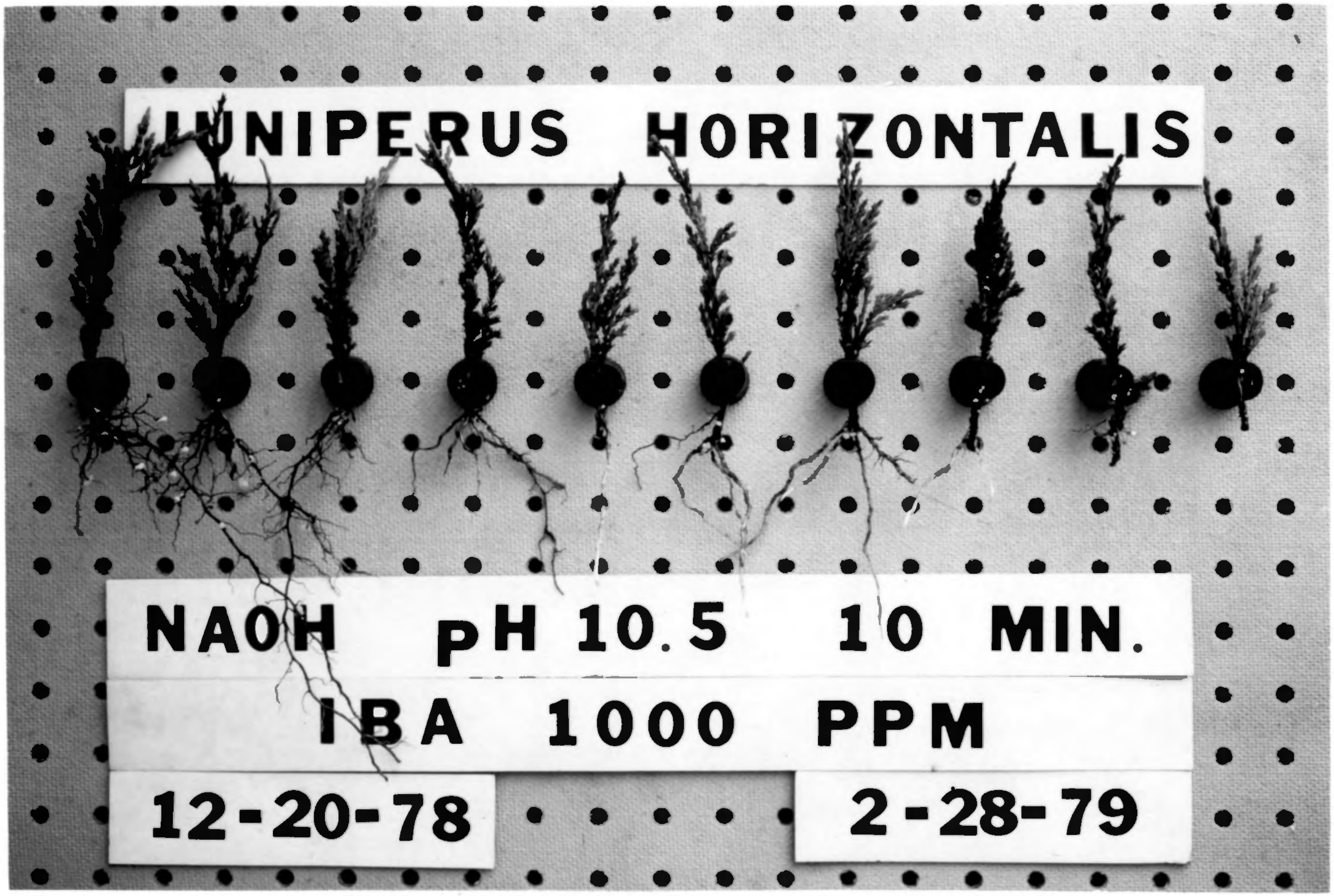

Figure 4. Single best treatment for _Juniperus horizontalis_ 'Bar Harbor' (Bar Harbor juniper) was NaOH pH 10.5 + low IBA during the winter experiment.

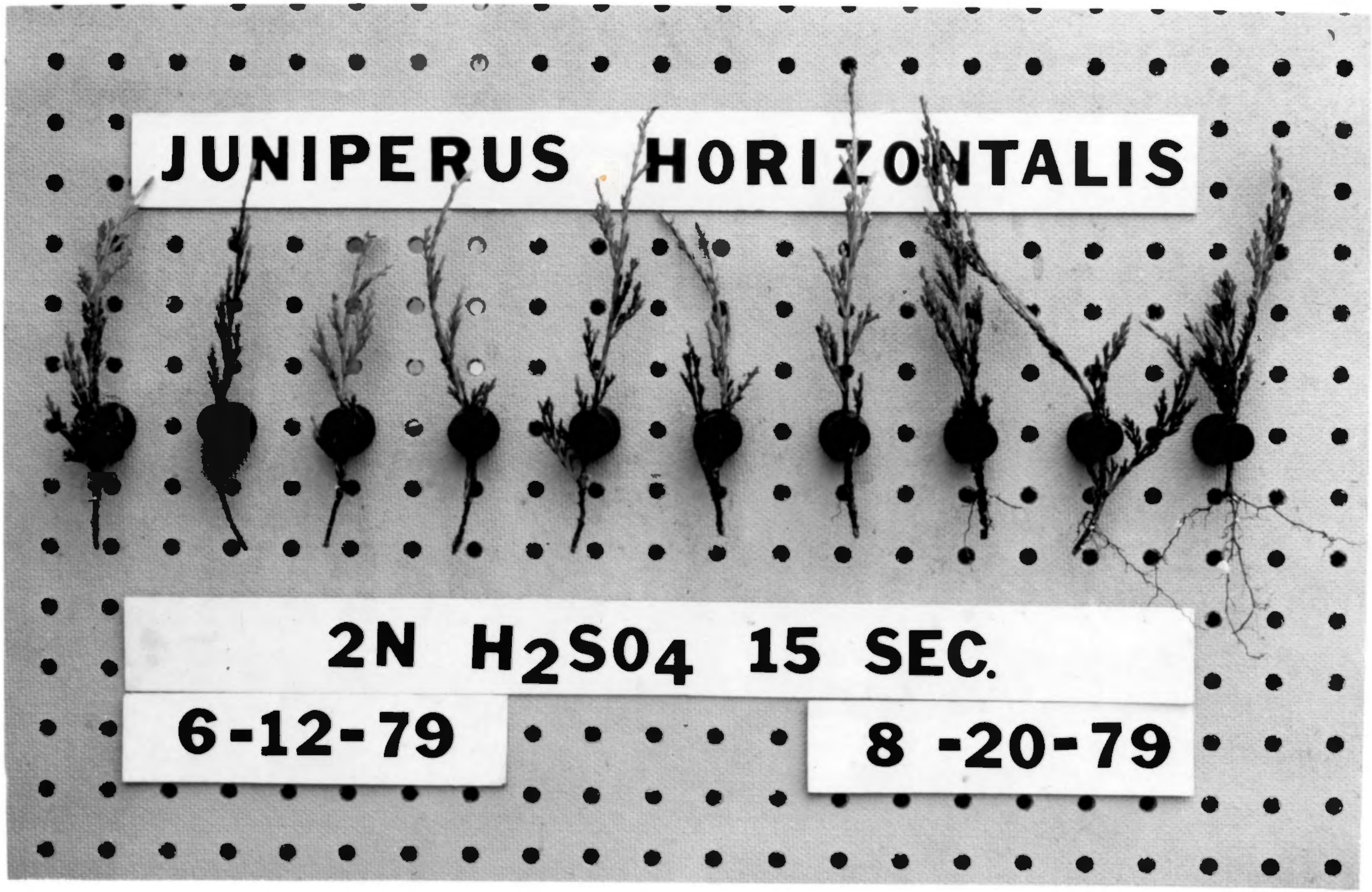

Figure 5. Single poorest treatment for Juniperus horizontalis 'Bar Harbor' (Bar Harbor juniper) was 2N H_2SO_4 during the spring experiment.

and even control plants during fall and winter, but treatments separated somewhat for spring rooting. The best treatment was high IBA applied to softwood cuttings (Figure 6) while the worst treatment was acid + high IBA applied to fall cuttings (Figure 7). Overall, Shore juniper rooted slightly better than 'Bar Harbor' juniper, however, the seasonal effect was almost reversed.

4. Juniperus virginiana (Eastern Red Cedar)

Red cedar, the third juniper species tested, in no way responded like the other two. Red cedar did not root in fall or spring and few cuttings (6 percent) rooted in winter (Tables 4.15 and 4.16, pages 52 and 53). Rooting was so poor, there was no significant average seasonal difference as measured by any parameter.

For the winter season, best rooting occurred where cuttings were treated with high IBA, or base + high IBA but only 23 to 26 percent rooting occurred. No significant difference was recorded for other treatments except in two cases control cuttings were as good as high IBA. The single best treatment was base + high IBA applied to hardwood cuttings. Many cuttings callused in the fall but failed to root during the 95 days in which they were in the mist beds.

5. Ilex cornuta (Burford Holly)

Burford holly consistently rooted best in winter with fall and spring rooting being equally poor as judged by all rooting parameters (Tables 4.17 and 4.18, pages 54 and 55). Averaged over all treatments,

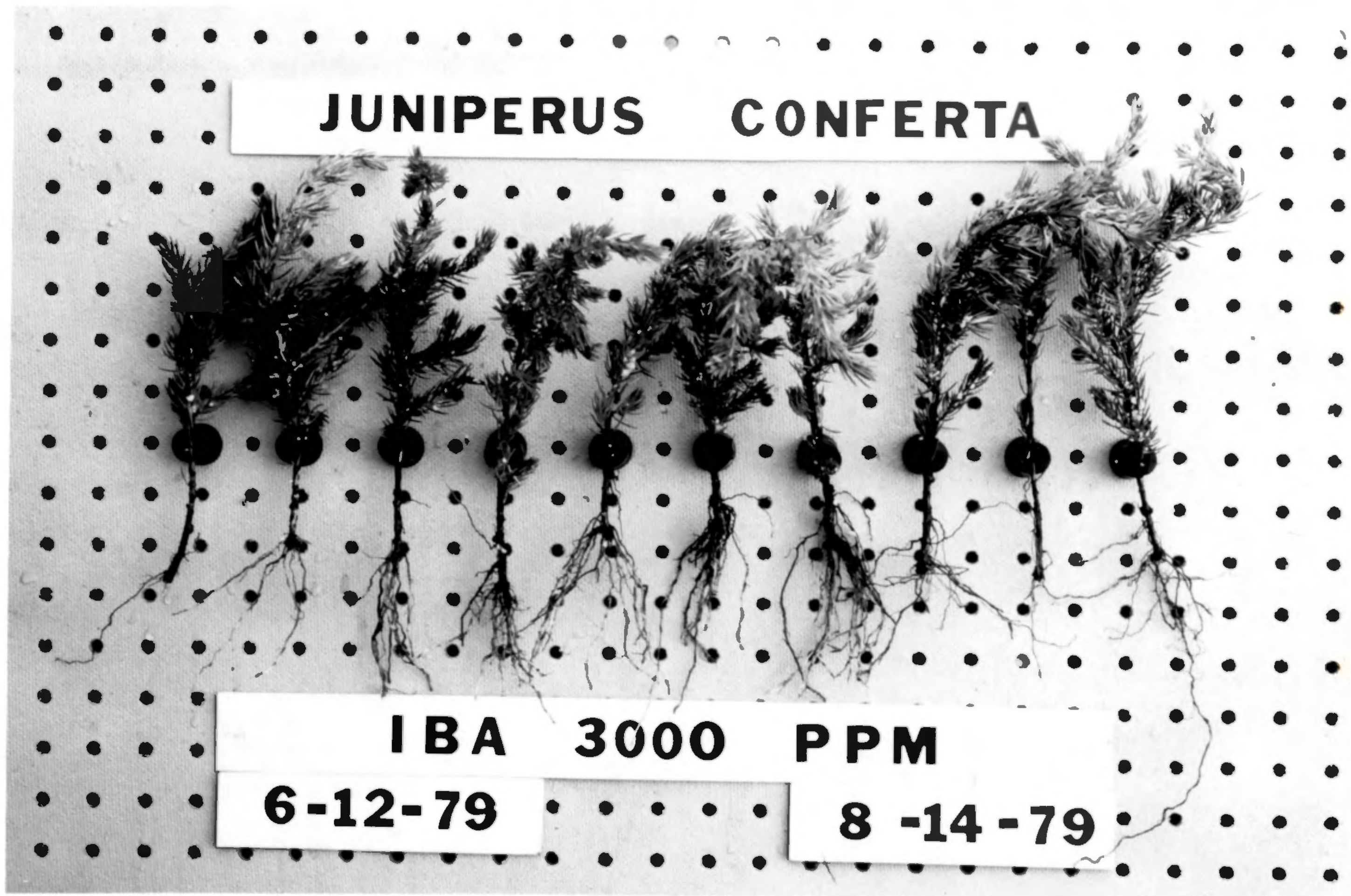

Figure 6. Single best treatment for Juniperus conferta (Shore juniper) was high IBA applied during the spring experiment.

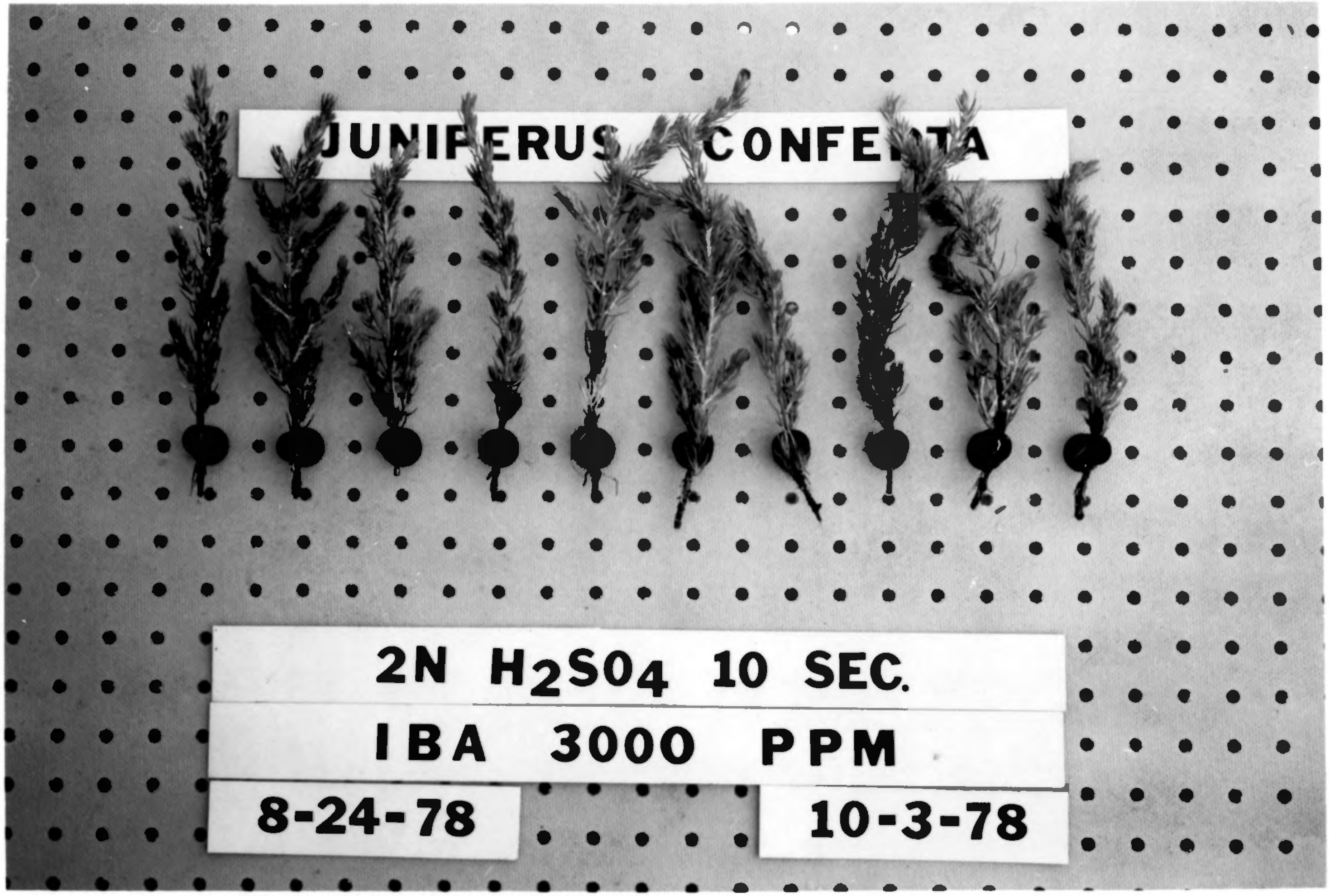

Figure 7. Single poorest treatment for Juniperus conferta (Shore juniper) was acid + high IBA applied during the fall experiment.

the 60 percent rooting in winter far exceeded the poor 15 to 23 percent rooting measured in other seasons.

The consistently best treatments averaged over all three seasons were base + high IBA, base + low IBA, base, and high IBA. Few significant differences occurred among acid, low IBA, acid + low IBA, acid + high IBA, and even control plants. Base did seem to generally improve rooting of this acid-tolerant species especially when combined with IBA, however, high IBA alone was almost as good. The single best treatment was winter use of base + 3000 ppm IBA (Figure 8) while the poorest results were found for the acid treatment applied in fall (Figure 9).

6. Philadelphus coronarius (Mockorange)

Spring rooting of Philadelphus was much superior to the other two seasons which were equally poor (Tables 4.19 and 4.20, pages 56 and 57). Softwood cuttings showed rooting percentages of 73 to 90 percent as compared to hardwood averages of 30 to 46 percent. Fall cuttings were erratic, varying highly among treatments.

High IBA and base + high IBA gave best rooting especially when averaged over all three seasons. Low IBA, acid + low IBA, and base + low IBA were nearly as good. Poor rooting occurred for acid and base alone, base + high IBA during the spring was overall the best treatment (Figure 10) while low IBA + base in fall was the poorest treatment (Figure 11).

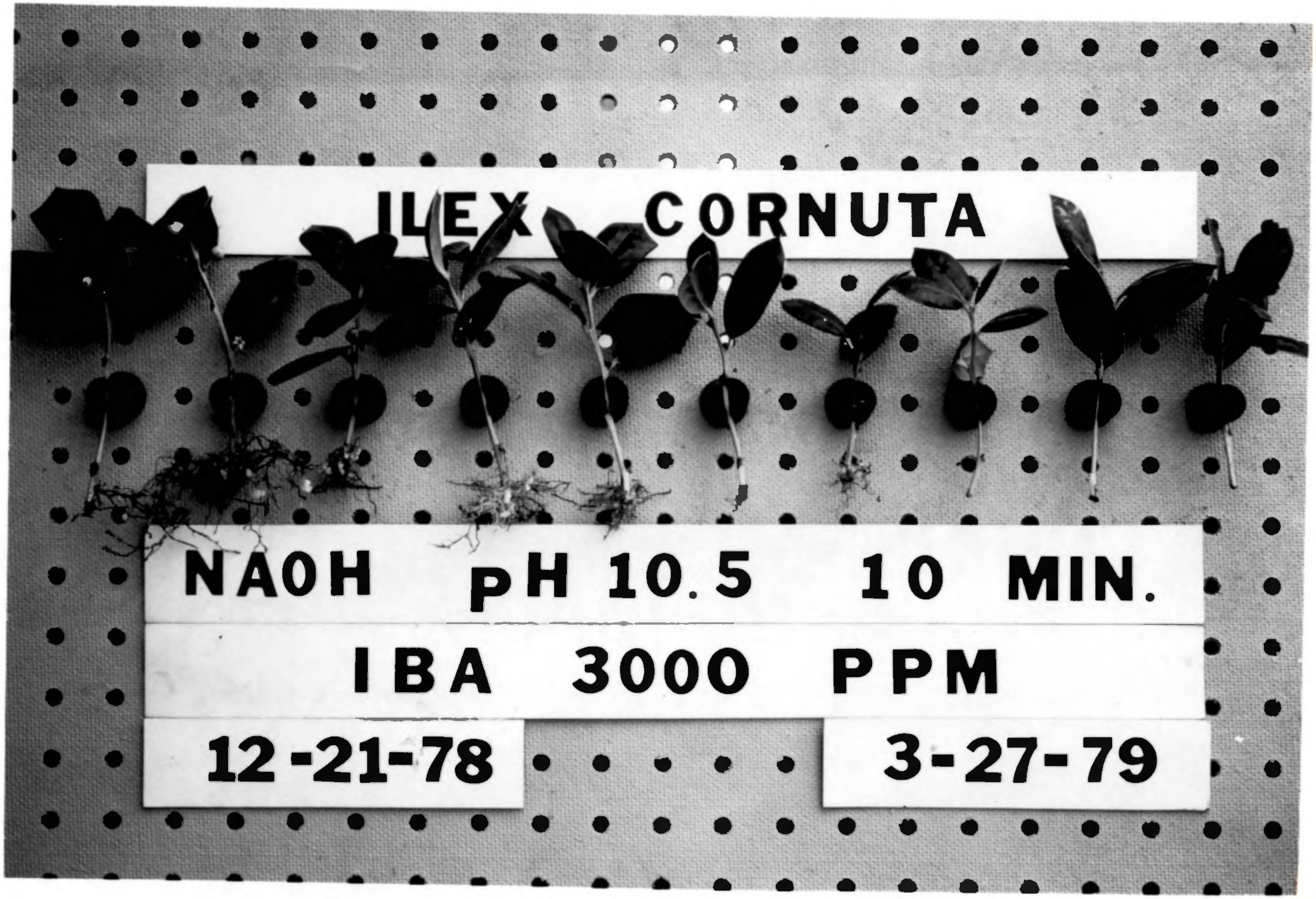

Figure 8. Single best treatment for _Ilex cornuta_ 'Burfordii' (Burford holly) was base + 3,000 ppm IBA applied during the winter experiment.

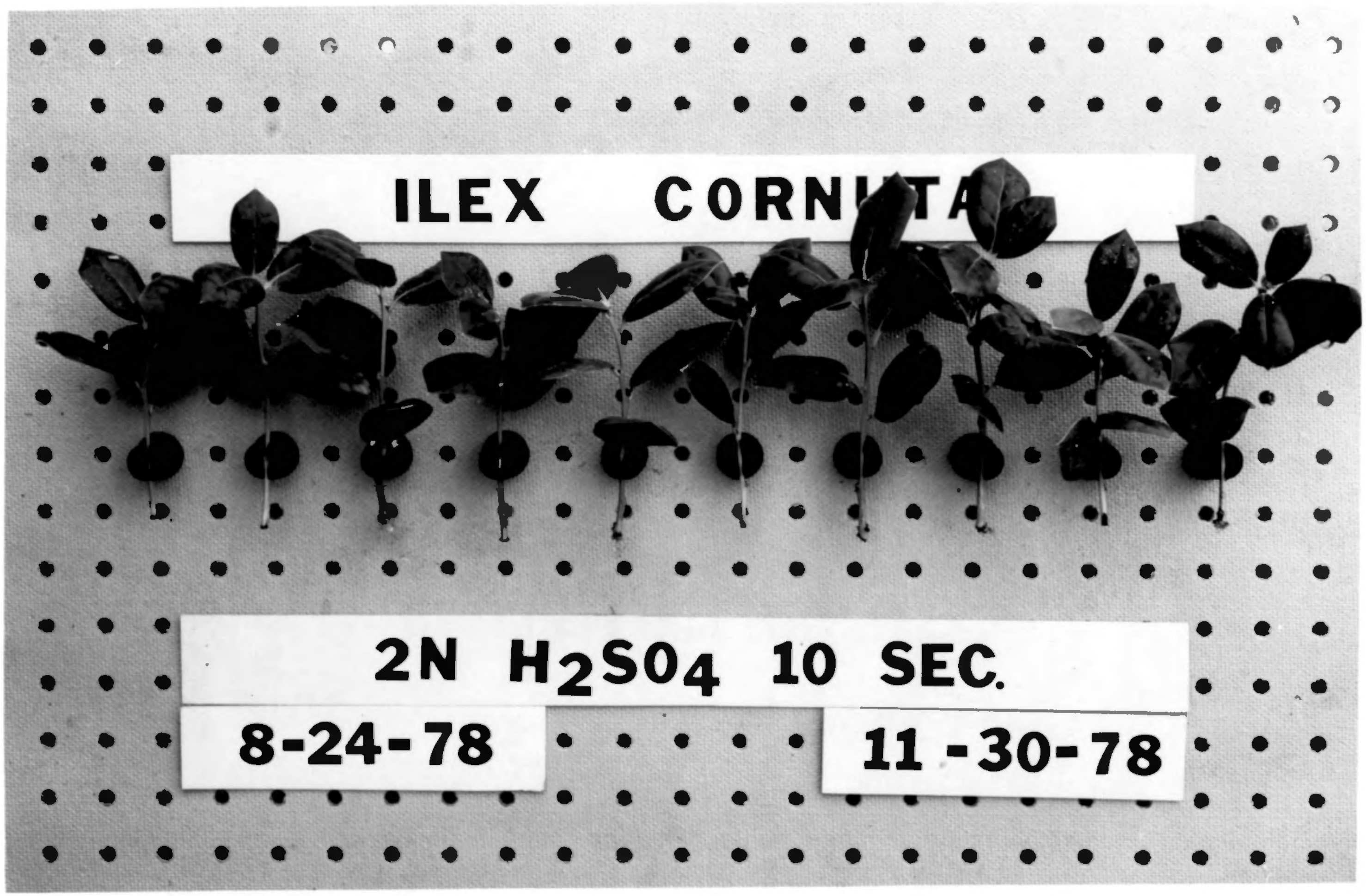

Figure 9. Single poorest treatment for Ilex cornuta 'Burfordii' (Burford holly) was 2N H_2SO_4 applied during the fall experiment.

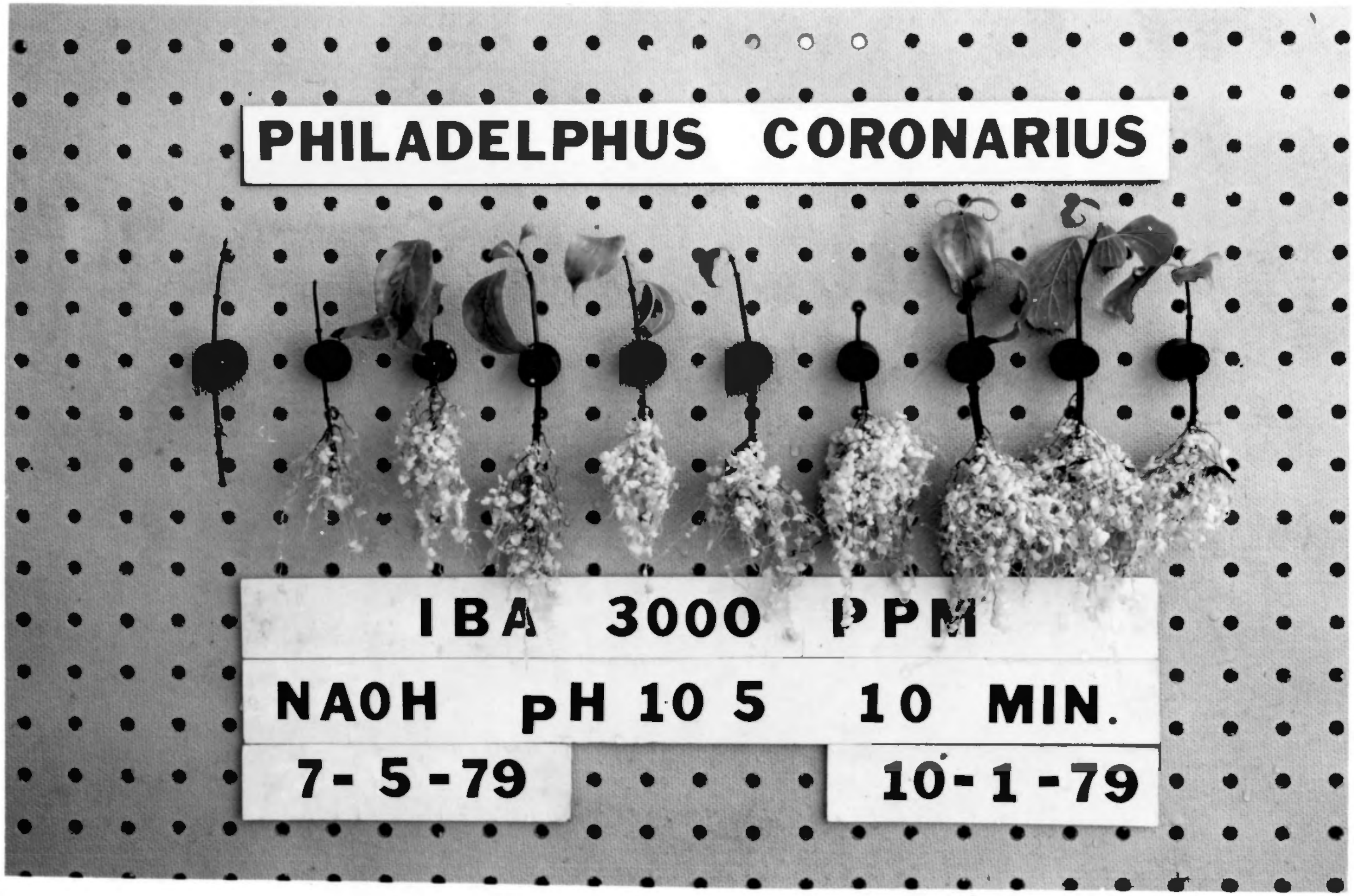

Figure 10. Single best treatment for Philadelphus coronarius (Mockorange) was base + high IBA during the spring experiment.

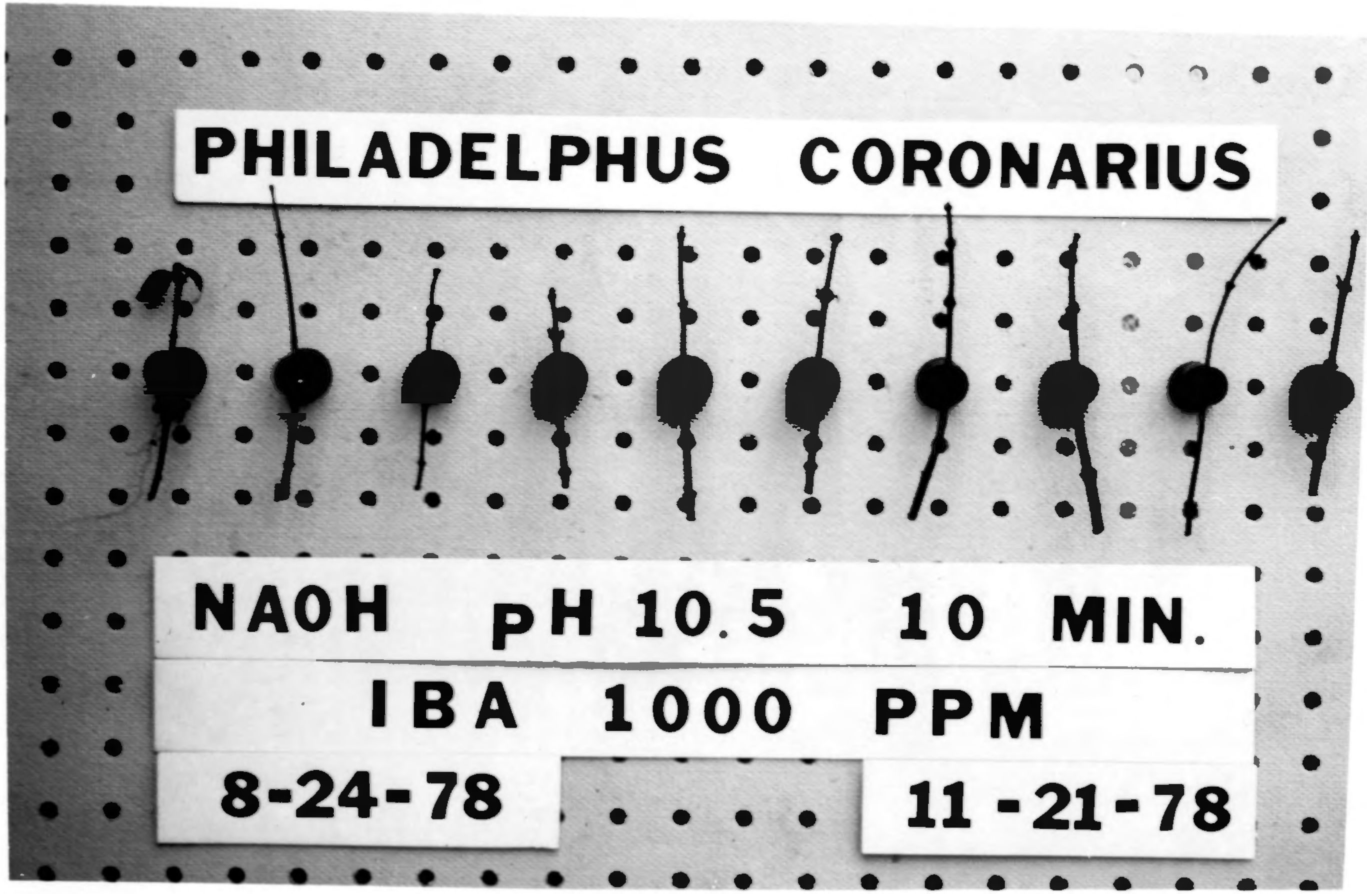

Figure 11. Single poorest treatment for Philadelphus coronarius (Mockorange) was base + low IBA during the fall experiment.

7. Rhododendron obtusum ('Coral Bells' Azalea)

'Coral Bells' azalea rooted best in fall as judged by dry weight and root ball diameter but spring was equally as good if using quality grade and percent rooting as a response measure (Tables 4.21 and 4.22, pages 58 and 59). Winter rooting was consistently inferior regardless of chemical treatments.

Treatment effects were not obvious on azalea. No or only slight difference due to treatments was recorded for root dry weights in any season; root quality in winter and spring; root ball diameter in fall and winter; and percent rooting at any season. Azalea appeared to respond very little to chemical rooting treatments.

Treatments producing slightly better rooting were high IBA, acid + high IBA and base + high IBA. The single best chemical treatment was fall application of base + high IBA (Figure 12). A consistently poor treatment was acid along, especially in winter (Figure 13).

8. Cornus florida (Flowering Dogwood)

Seasonal response of dogwood was highly significant. Spring rooting was excellent, averaging 87 percent over all treatments (Tables 4.23 and 4.24, pages 60 and 61). Fall rooting was a poor second to spring and no rooting occurred for winter hardwood cuttings.

Chemical treatments had a very significant effect on rooting of softwood and semi-hardwood cuttings of Cornus. Root quality, root ball diameter, percent rooting and dry weight data showed high IBA and base + high IBA to be superior treatments. Acid with either low or high IBA and

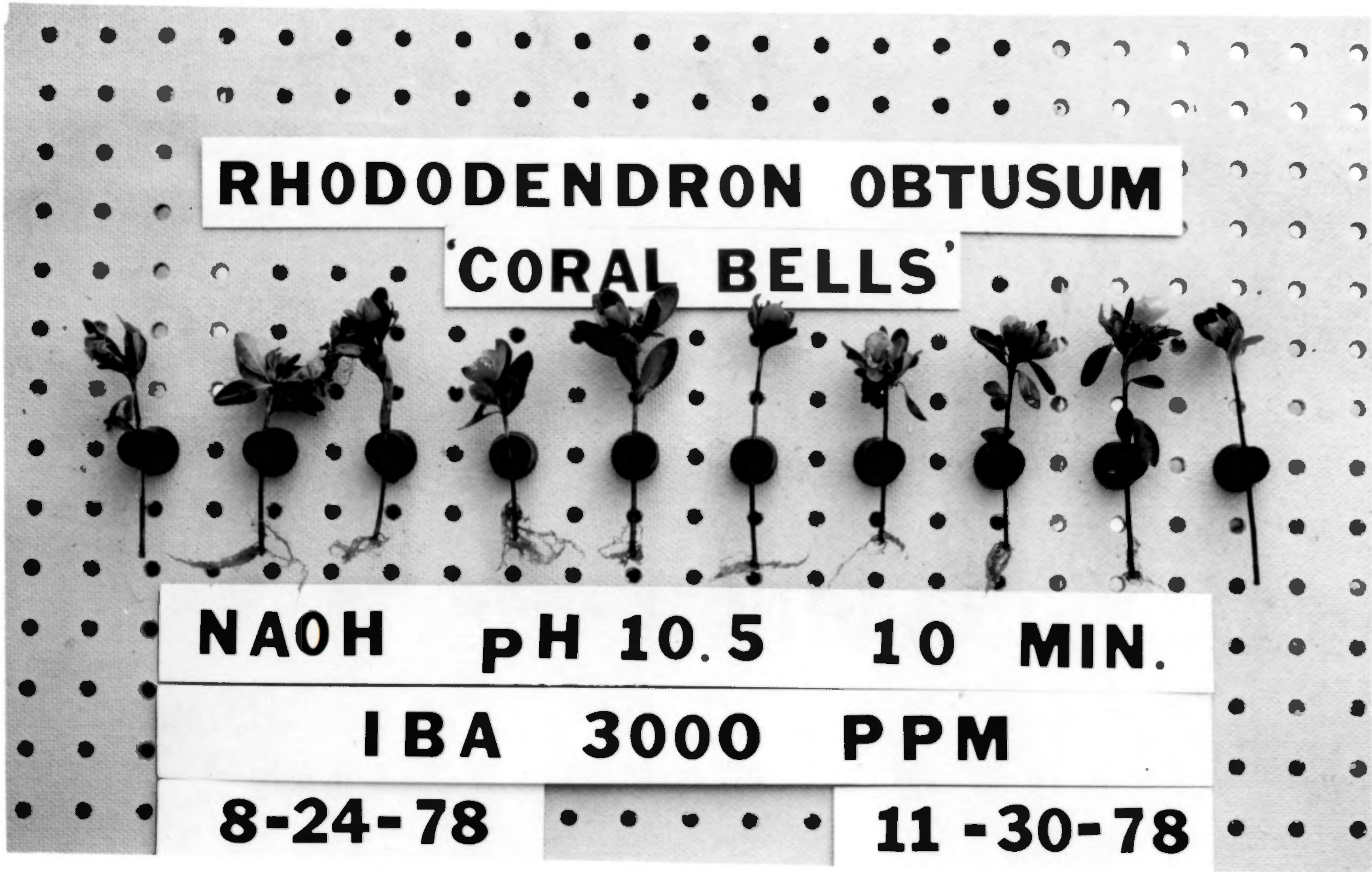

Figure 12. Single best treatment for Rhododendron obtusum 'Coral Bells' (Coral Bells azalea) was base + high IBA in the fall experiment.

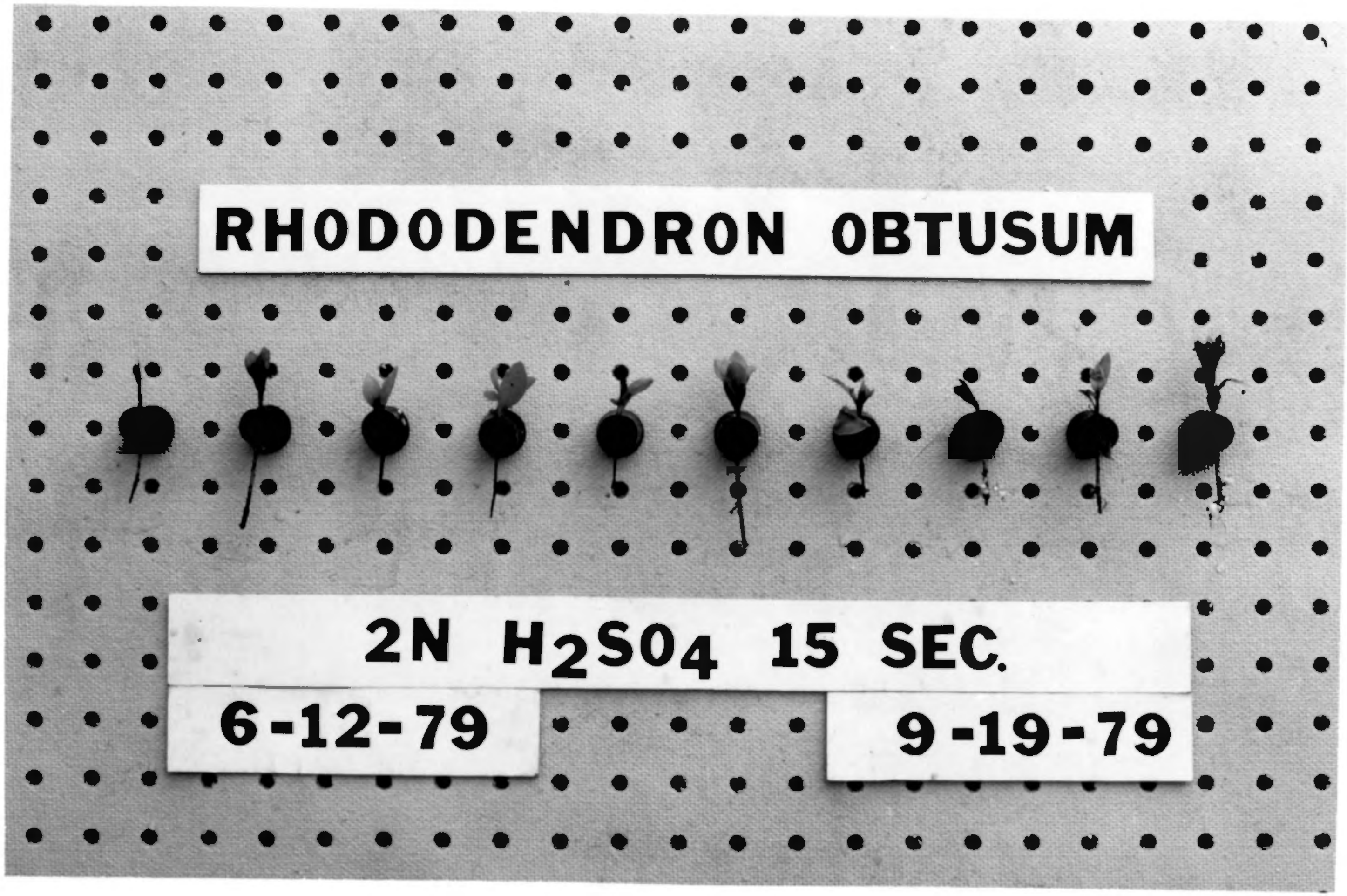

Figure 13. Single poorest treatment for Rhododendron obtusum 'Coral Bells' (Coral Bells azalea) was 2N H_2SO_4 applied during the winter experiment.

base + low IBA were nearly as good especially if looking at average response over both seasons. Dogwood rooted well (86 to 100 percent) for all treatments which included IBA during the spring. Even 63 percent rooting of softwood cuttings was seen for control plants. Best roots were produced by base + high IBA in spring (Figure 14), while base alone which allowed some fall rooting produced poorest quality roots (Figure 15). No treatments, however, produced roots in winter.

9. Tsuga canadensis (Canadian Hemlock) and Cercis canadensis (Eastern Redbud)

Both hemlock and redbud failed to root at any season regardless of chemical treatment.

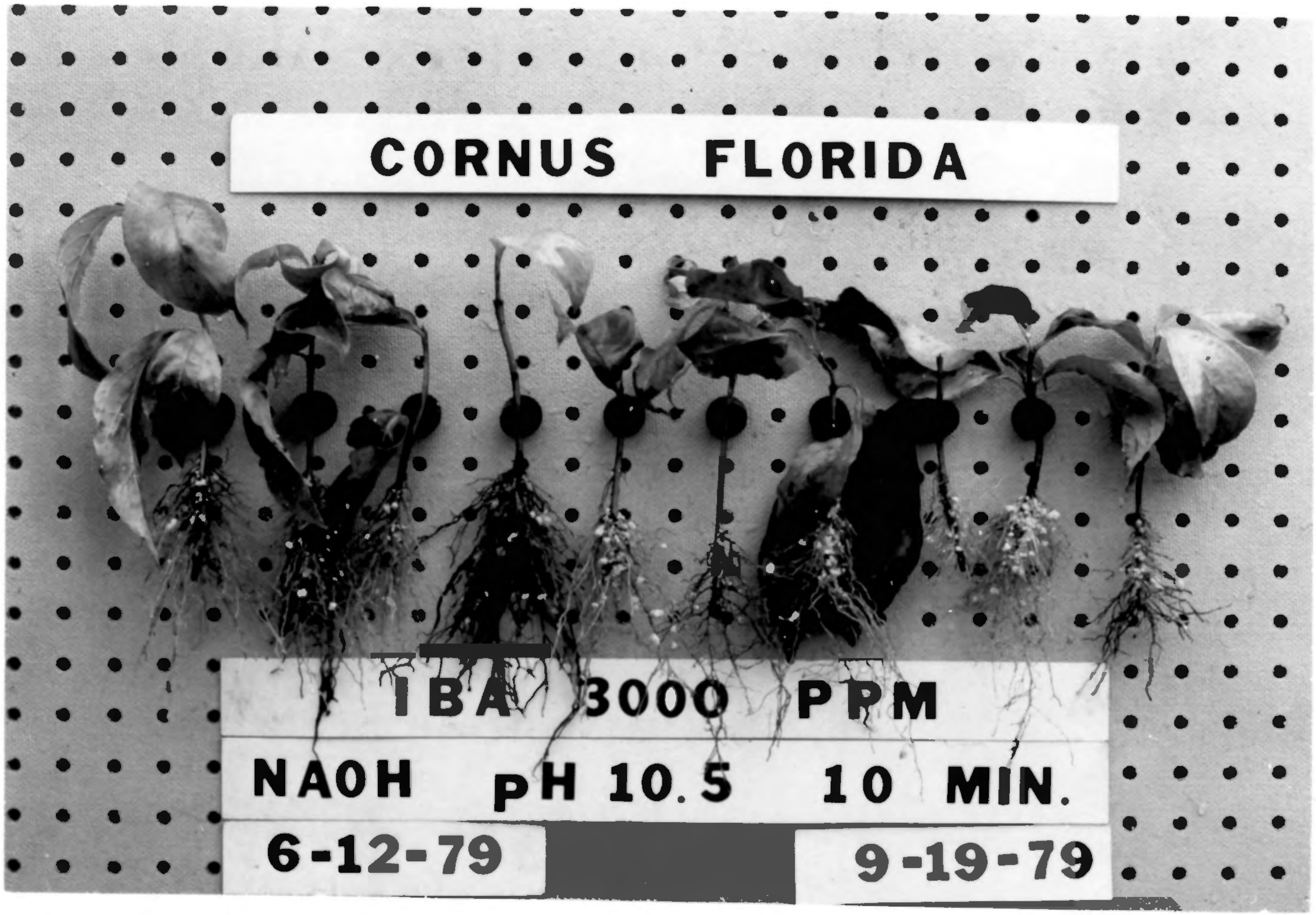

Figure 14. Single best treatment for Cornus florida (Flowering dogwood) was base + high IBA applied during the spring experiment.

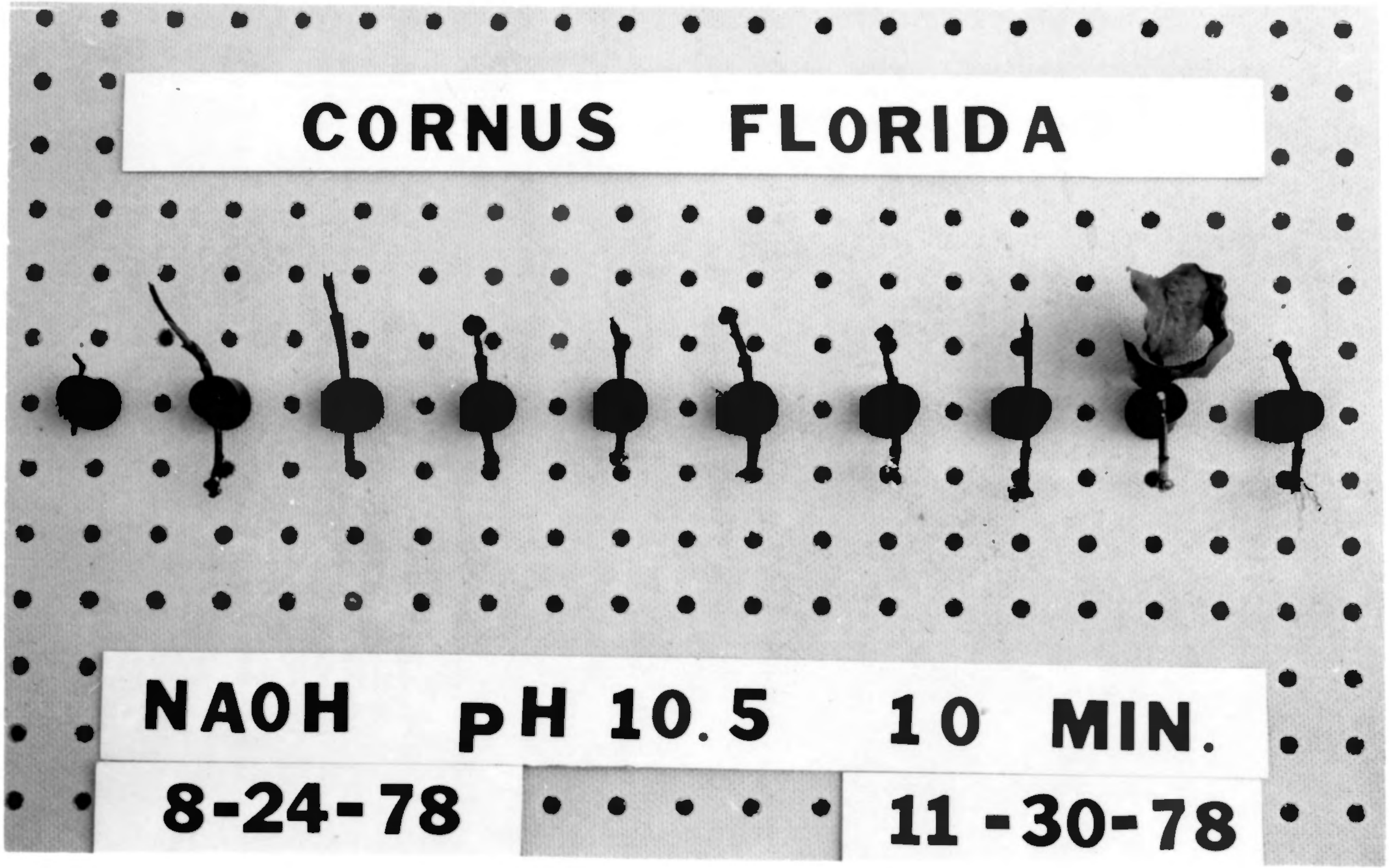

Figure 15. Single poorest treatment for <u>Cornus florida</u> (Flowering dogwood) was NaOH 10.5 pH applied during the fall experiment.

CHAPTER V

SUMMARY AND CONCLUSIONS

Much research in plant propagation has been concerned with the use of auxins like indolebutyric acid (IBA) and naphthalene acetic acid (NAA) to enhance rooting of cuttings. Less attention has been given to the effects of other chemicals such as bases and nonhormonal acids on rooting.

A recent study (17) has demonstrated the possibility of using simple chemicals like H_2SO_4 and NaOH to increase rooting. It was suggested that a short exposure to acid would increase rooting in base-tolerant plants, while base pretreatments would increase rooting in acid-tolerant plants.

A study of the vegetative propagation of ten species of ornamentals was conducted at three different seasons (fall, winter, and spring) to determine differences in rooting following treatment with combinations of acid or base and IBA.

Pretreatments consisted of a control in which no treatment was applied, a 15 second dip in 2N H_2SO_4, a 10 minute dip in NaOH, a 1,000 and 3,000 ppm (or 8,000 ppm) treatment of IBA and combinations of acid and base dips with low and high IBA. The experiment began on August 25, 1978, and concluded on October 1, 1979. The objectives were to determine (1) which chemical treatment or treatment combination would produce best rooting, (2) to find optimum seasons for rooting, (3) to determine if a correlation of acid- or base-tolerant species with a particular treatment existed, and (4) to determine if rapid methods for measuring rooting, quality, root ball diameter, and percent rooting, were as good as standard root dry weight.

I. ROOT DEVELOPMENT (ROOTING PARAMETERS)

Root dry weight, considered the standard rooting parameter by researchers, was compared to root quality grade, percent rooting, and root ball diameter. Data showed that the majority of the species had highest correlation coefficients between root quality grade and root ball diameter. Root quality grade and percent rooting correlated almost as well. Parameters correlating highest with root dry weight were root quality grade and root ball diameter. However, percent rooting showed very low correlation with dry weight.

The best measures of rooting after root dry weight, assuming weight as the standard of comparison, were quality grade and root ball diameter. Correlation, however, varied from season to season, species to species, and even among treatments within a species. With such variation it is difficult to speculate on which rooting parameter might be best for tested species under different growing conditions or for additional species. If correlation coefficients of 0.70 are acceptable for the optimum season of rooting in this study, root quality grade could be substituted for dry weight of 'Bar Harbor' juniper, Shore juniper and mockorange. Root ball diameter rather than dry weight could be accepted for 'Bar Harbor' juniper, Burford holly, Shore juniper, mockorange, and 'Coral Bells' azalea.

II. SEASONAL COMPARISON OF ROOTING

Seasonal variation in rooting occurred but based on root dry weight and quality grade seasonal trends were obvious. Euonymus was easily rooted at any season; Shore juniper, mockorange, and dogwood rooted best in spring; Burford holly and 'Bar Harbor' juniper in winter; and azalea in the fall. Red cedar rooted very poorly and redbud and hemlock not at all. Averaged over all species, rooting was generally better in spring followed by fall and then winter with little difference between fall and winter.

III. TREATMENT COMPARISON OF ROOTING

In the fall experiment, treatments giving best rooting were high IBA followed closely by low IBA then acid or base + high IBA. Best treatments for winter hardwood cuttings were again IBA at either rate and combinations of IBA + base. Softwood cuttings taken in the spring rooted best when treated with high IBA, base + high IBA, base + low IBA and, usually, low IBA.

Much variation occurred in treatment effects on acid-tolerant plants but the better treatments included base + high IBA, high IBA and base + low IBA. However, there was no obvious trend where base alone significantly increased rooting of acid-tolerant species. IBA appeared to be more important than base.

Base-tolerant species reacted much the same as acid-tolerant plants. Best response occurred with high IBA, base + high IBA, low IBA and base + low IBA. Acid treatment did not cause increased rooting of the base-tolerant plants tested.

Contrary to results in California, this study gave no indication that acid-tolerant species rooted best when treated with base nor did base-tolerant plants root best under acid treatment. Treatment comparison of rooting indicated that high and low IBA and acid or base + high IBA gave best results, while acid alone or base alone generally gave poor results. This suggests that high IBA may be causing most of the beneficial rooting response. Five of the species tested responded well to NaOH + high IBA.

IV. ANALYSIS OF ROOTING FOR INDIVIDUAL SPECIES

Treatments which gave consistently best results for Euonymus japonicus were low or high IBA, acid + high IBA and base + high IBA. Best treatments for Juniperus horizontalis 'Bar Harbor' were base, high IBA, acid + high IBA, base + low or high IBA and even control plants were acceptable. Consistently good rooting occurred for Juniperus conferta treated with IBA. Juniperus virginiana rooted poorly in the winter with best results obtained from high IBA, or base + high IBA. Best treatments for Ilex cornuta were base, base + high IBA, low IBA and high IBA. For Philadelphus coronarius high IBA and base + high IBA gave best results. No or only slight difference due to treatments were recorded for Rhododendron obtusum 'Coral Bells'. However, acid and base + high IBA and high IBA appeared best. For Cornus florida high IBA and base + high IBA were found to be superior treatments.

The single best treatment for Juniperus virginiana, Philadelphus coronarius, Rhododendron obtusum 'Coral Bells,' Ilex cornuta 'Burfordii,' and Cornus florida was base + high IBA. Euonymus japonicus and Juniperus conferta rooted best under high IBA. For Juniperus horizontalis 'Bar Harbor' base alone was the single best treatment. Both Tsuga canadensis and Cercis canadensis failed to root at any season regardless of chemical treatment.

Additional research should consider acid and base rates and treatment times as they influence rooting of these or additional species; further interaction studies on acid, base, and IBA; and, perhaps more refined studies on the effect of in vivo, as well as medium pH, on rooting of cuttings. Further research is also needed to explain the obviously beneficial combination of base + high IBA on rooting of five of the species tested.

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