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Chemical control of root deflection and tap root elongation in containerized nursery stock

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I am submitting herewith a thesis written by Randon J. Krieg entitled "Chemical control of root deflection and tap root elongation in containerized nursery stock." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Landscape Architecture.

Willard T. Witte, Major Professor

We have read this thesis and recommend its acceptance:

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Vice Provost and Dean of the Graduate School

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To the Graduate Council:

I am submitting herewith a thesis written by Randon J. Krieg entitled "Chemical Control of Root Deflection and Tap Root Elongation in Containerized Nursery Stock." I have examined the final copy of this thesis for form and content and 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.

Willard T Witte

Willard T. Witte, Major Professor

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CHEMICAL CONTROL OF ROOT DEFLECTION
AND
TAP ROOT ELONGATION
IN
CONTAINERIZED NURSERY STOCK

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

Randon J. Krieg
May 1994

To my wonderful wife Patricia and sparkling daughter Voletta,
for the joy and happiness you bring me.

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I would like to thank my parents for their constant love and kindness throughout my life Finally, I would like to thank my dear wife Patricia for her nourishing love, support, patience, understanding and encouragement during these last long two and a half years.

ABSTRACT

These studies were designed 1. to test the effectiveness of a 7% cupric hydroxide [$Cu(OH)_2$]/latex paint formulation (Spin Out™) to control root deflection in a wide assortment of containerized nursery stock, and 2. to control tap root elongation of selected coarsely rooted species by inserting six different types of materials painted with Spin Out™ or impregnated with Spin Out™ WP (wetable powder) at the bottom of the container.

Seedlings or rooted cuttings of 54 taxa of ornamental trees, shrubs, perennials and grasses were grown in plastic containers, half of which were painted inside with Spin Out™. Root deflection was measured subjectively by a panel of four judges using a scale from 1 to 5, with 1 indicating root deflection of less than 1.3 cm, (excellent control) and 5 indicating severe root deflection (no control). While excellent control of root deflection was not always achieved in treated containers, root deflection was consistently reduced compared to untreated containers. This eliminated the need for corrective root pruning. Treatment means ranged from 1.0 to 2.5 with 83% $\leq$ 1.5. Control means ranged from 1.8 to 5.0 with 85% $\geq$ to 3.0. No visual signs of copper toxicity were observed. Cupric hydroxide did not inhibit or restrict the growth of stem structures such as rhizomes, stolons or basal suckers.

Tap roots of three coarse rooted species, *Nyssa sylvatica* Marshall (black gum), *Quercus acutissma* Carruth. (sawtooth oak) and *Castanea mollissima* Bl. (Chinese chestnut) were subjected to six treatment materials which were either cut to fit or placed on the bottom of a 7.6 l container. Each treatment material (paint only, Styrofoam plug tray, 3M floor buffer mat, peat fiber sheet, stone and weed barrier fabric) was either painted with Spin Out™ or impregnated with Spin Out™ WP. Treatments that allowed the tap root to penetrate the material, i.e. weed barrier fabric, stone and 3M floor buffing mat, were more effective in controlling tap root elongation compared to controls. Weed barrier fabric significantly reduced tap root length of *Quercus acutissima* and *Nyssa sylvatica* by 80% and 67%, respectively, compared to controls and by 65% and 53%, respectively, compared to the paint only treatment. In some cases the 3M floor buffing mat and stone treatments were more effective than the weed barrier fabric but were impractical because of weight or expense. The interior walls of all treatment containers were painted with Spin Out™ which significantly inhibited lateral root deflection down the side of the container compared to controls.

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INTRODUCTION

The nursery container industry has experienced rapid growth over the last several decades. This is due to many benefits associated with producing plants in containers (Davidson et al., 1988) such as:

- plants are more uniform because more optimal conditions can be maintained.
- marketing and planting season is extended.
- container weighs less because artificial media is used instead of soil, which reduces transportation costs.
- less handling damage.
- easier for wholesale grower to assemble orders, no digging operation.
- more convenient for retailer and customer to handle.

There are also disadvantages in growing nursery stock in containers (Davidson et al., 1988) such as:

- need for special irrigation systems, i.e. drip irrigation,.
- container temperatures may become extremely high causing root death.
- production costs are relatively higher compared to field production.
- chemical supplements must be applied and monitored more closely.
- containerized plants require over-wintering storage in colder climates.
- roots may become deflected and matted along the wall of the container and limit growth and life expectancy of plants after transplanting.

Research on chemical root pruning with copper (Cu) compounds has shown promising results in controlling root deflection in containers. In almost all cases, Cu has been effective in preventing deflection of roots down the side of the container. Measurements of plant growth of plants grown in Cu-treated containers have shown both increases and reductions in parameters such as: plant height, caliper, growth rate, dry root and shoot weights and root/shoot ratios, but these were not of a high enough magnitude to be commercially significant. Usually no differences were observed compared to controls.

It was not the purpose of this study to evaluate different rates or sources of Cu. Work has been done with enough species to show both positive and negative effects in the above growth parameters, at effective rates, which are species dependent. The rate found most effective was approximately 100 g $Cu(OH)_2/l$ latex paint. This study was designed to test the effectiveness of Cu paint in controlling root deflection on a wide variety of container grown plant material. Most previous work has been done with coniferous forest seedlings, and only recently has attention been given to ornamentals. A small number of species relative to the total number of species produced by nurseries have been studied thus far. It also must be demonstrated that one rate of Cu will be effective on all species. If varying rates are required to control root deflection in different species then this root pruning method would probably not find acceptance in the nursery industry. It would be impractical for nursery growers to keep track of containers coated with different rates of Cu and which species required which rate.

Cu coated containers have been effective in reducing the growth of tap roots but coiling still occurs on some dominant rooted species. More work needs to be done to halt or control tap root growth so that coarse rooted species such as oaks and hickories can be produced in containers in such a way as to eliminate the need for mechanical root pruning later.

The objectives of this research were to: 1. Evaluate the effectiveness of one rate of cupric hydroxide, formulated as Spin Out™, on 54 taxa of ornamental trees, shrubs, perennials and grasses. 2. Study the effectiveness of different copper treated container inserts in controlling tap root development.

CHAPTER II

REVIEW OF LITERATURE

Changes in Root Morphology

Over the last twenty-five years foresters and ornamental horticulturists experimented with copper (Cu) compounds to control root deflection in nursery containers. Several forms of Cu have been used, i.e. cupric sulfate (Furuta et al., 1972; Flanagan, 1991), cupric carbonate (Arnold and Struve, 1989, 1989a; Burdett and Martin, 1982; McDonald et al., 1984, 1984a; Ruehle, 1985; Struve et al., 1987, 1987a; Wenny and Woollen, 1989), cupric naphthenate (Furuta et al., 1972) and cupric hydroxide (Arnold, 1992, 1993; Beeson and Newton, 1992; Flanagan 1991; Struve, 1990a; Svenson and Johnston, 1992). Cupric carbonate, sulfate and hydroxide have been effective on woody plant roots at rates between 50 - 300g/l latex paint. With herbaceous plants, Arnold (1993) found that 25-50 g $Cu(OH)_2$ /l latex paint was most effective. Other compounds, such as IBA, trifluralin, aluminum sulfate and barium sulfate, have been tried but are either phytotoxic or yield inconsistent results (McDonald et al., 1981 and 1984; Pellet et al., 1980). One of the earliest research efforts to control root growth with Cu used metallic Cu sheets, Cu-armored fiber and paint containing metallic Cu flakes, all of which controlled root deflection (Saul, 1968). Latex paint by itself appears to be somewhat phytotoxic to roots but when Cu is added the toxicity is masked (McDonald et al., 1984, Flanagan, 1991). Recent research has used a cupric hydroxide/latex paint formulation for two main reasons. One, it is more effective than other Cu compounds and two, Griffin Corporation (Valdosta, GA) received

EPA approval in 1993 for a cupric hydroxide/latex paint product called Spin Out™ containing 7% cupric hydroxide (Struve, 1990a). Cupric hydroxide is also less expensive, more flowable than cupric sulfate and is available in a finely powdered form which facilitates dispersion in paint.

When root tips reach the side of a Cu treated container, root elongation stops or decreases which inhibits root deflection down the side of the container (see above references). Higher order lateral roots develop approximately two centimeters back from the chemically pruned primary lateral (Arnold and Struve, 1989; Flanagan, 1991) and these are chemically pruned when they reach the container wall (McDonald et al., 1984; Burdett, 1978; Wenny and Woollen, 1989). Chemical pruning results in a more fibrous root ball (Arnold and Young, 1991; Burdett, 1978) with the lateral roots maintaining their natural horizontal orientation in the media (Burdett, 1978; Wenny and Woollen., 1989) (Fiqure 1). This control of root deflection has several benefits. When seedlings are transplanted, first order lateral roots resume lateral growth into the soil horizon, which resembles the root morphology of a natural seedling (Burdett, 1978; Wenny et al., 1988) (Fiqure 1). There are more lateral roots diverging from the entire length of the root ball into the soil (Burdett, 1978; McDonald et al., 1981). These benefits result in greater growth (McDonald et al., 1981, Arnold and Struve, 1989), greater mechanical stability (Burdett, 1978 and 1981) and faster establishment (Burdett, 1981; Struve et al.,1987a). These benefits may be due to the root system's ability to permeate more of the soil horizon and thus enhance water and nutrient absorption.

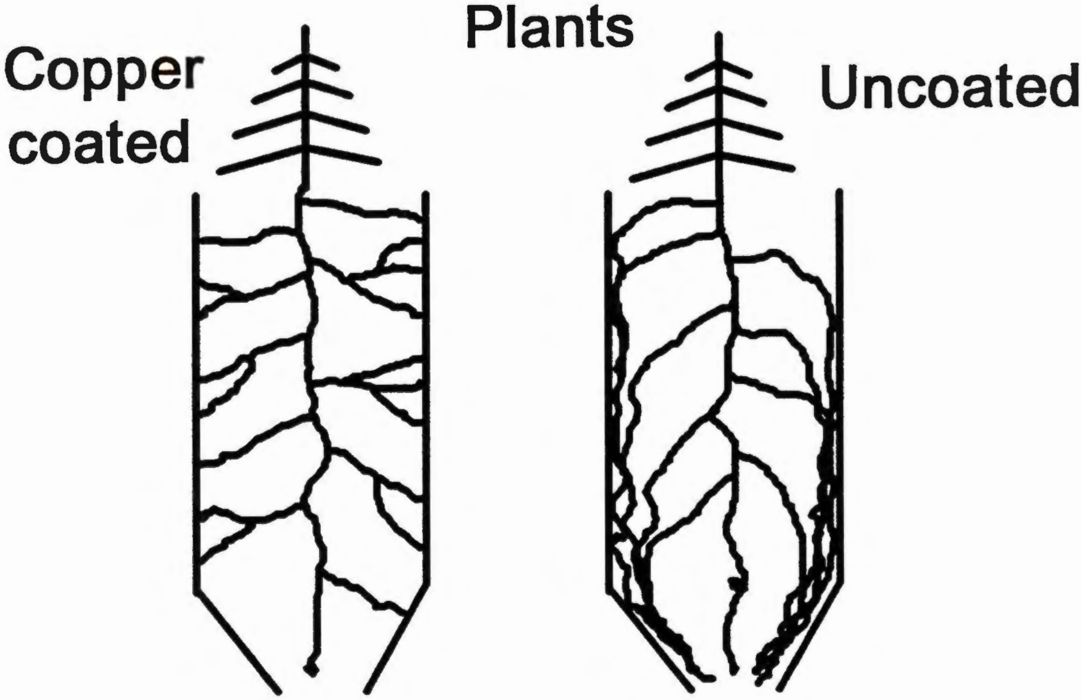
In an untreated container, the primary lateral roots reach the container wall and deflect downwards (Figure 1). When transplanted, lateral root development into the surrounding soil takes place at the bottom of the pot where all the primary lateral root tips are located (Figure 1). The taller the container, the deeper the lateral root tips will be from the nutrient rich A horizon when transplanted. Compared to plants from Cu treated containers, these plants establish more slowly and are more prone to wind throw (Burdett, 1981). Plants grown in untreated containers should be root pruned prior to transplanting to correct root deflection. This is typically done by making several vertical cuts down the side of the root ball and removing matted roots from the bottom (Bush-Brown and Bush-Brown, 1980). As a result, up to 37% of the root system may be removed (Arnold and Struve, 1989a). This practice severs any circling roots and stimulates lateral root development into the surrounding soil. This necessary practice may induce transplant shock which defeats one of the main benefits of producing plants in containers. Failing to correct a contorted root system may strangle the trunk of the tree resulting in stunted growth and possibly death.

Changes in Growth

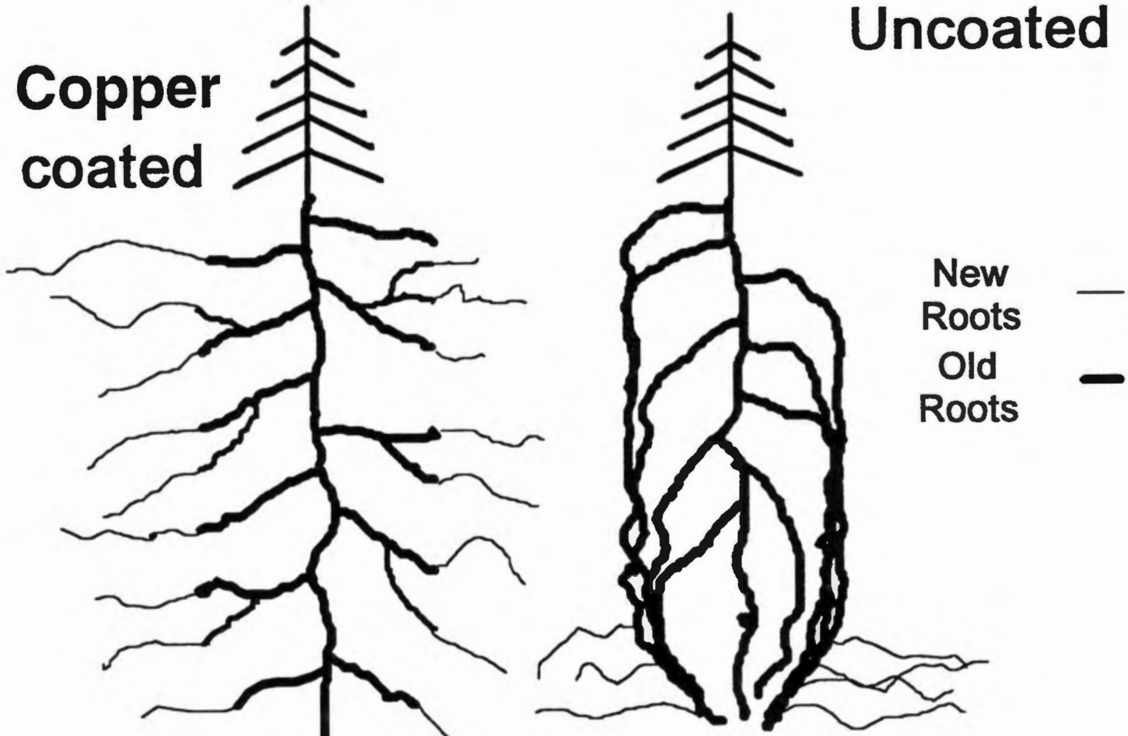
When measuring growth parameters (growth rate, root and shoot dry weights, root/shoot ratios, shoot length, regenerated roots, trunk caliper, plant height, transplant survival rate), plants grown in Cu treated containers perform equal to or better than controls. Arnold and Struve (1989a) found that red oak (*Quercus rubra*) and green ash (*Fraxinus pennsylvanica*) seedlings grown in Cu treated pots showed enhanced shoot growth for two growing seasons after transplanting compared to root pruned seedlings grown in untreated

Figure 1. Root deflection is inhibited when plants are grown in copper coated containers, whereas in uncoated containers root deflection is uninhibited. After transplanting, plants from copper coated containers develop a root morphology that resembles a normal seedling whereas the root tips in uncoated containers are located at the bottom of the root ball.

Containerized Plants



After transplanting



containers. New root growth (dry wt.) after transplanting was greater on plants from Cu treated containers. The same study found that shoot length and shoot dry weight of green ash were greater for plants from Cu treated pots and root/shoot ratio was less than controls, while total plant weight and root dry weight were unaffected. Results for red oak were not affected by Cu treatment except for root/shoot ratios where Cu treated plants had a lower ratio. Several researchers have observed that root/shoot ratios are lower in plants grown in Cu treated containers (Beeson and Newton, 1992; Romero et al., 1986) but Arnold and Struve (1989a) found that after taking corrective pruning measures on plants from Cu treated containers, root/shoot ratios were the same or differences were reduced.

In studying eighteen southeastern woody landscape species, Beeson and Newton (1992) observed few treatment effects due to Cu-treated containers when measuring height growth rate, final height, stem diameter, root and shoot dry weights, total weight and root/shoot ratios. Treatment effects were both positive and negative but were commercially insignificant.

Burdett and Martin (1982) studied different types of media used in conjunction with Cu treated pots (100 g $CuCO_3$/l latex paint). The Cu pruning effect was completely negated in seven conifer species when grown in a 3:1 sphagnum moss/vermiculite media amended with 3 kg/m^3 of dolomitic lime. When the same species were grown in a 1:3 sphagnum moss/vermiculite mix without lime, all roots that reached the container wall were pruned. The author speculated that the much higher calcium content in the limed mix may have inhibited Cu^{2+} uptake. In the same study, seedlings grown in Cu treated containers were marginally shorter than controls.

There was a concern that Cu painted containers would be detrimental to the development of mycorrhizal roots due to the direct fungicidal effect of Cu ions. McDonald et al., (1981) found the combination of Cu treated containers and mycorrhizal inoculation resulted in bigger trees, more lateral roots and more mycorrhizal infection than either treatment alone. Ruehle (1985), on the other hand, found that Cu treatment was not effective in increasing the number of mycorrhizal roots in loblolly (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.) seedlings, but did increase them in longleaf pine (*Pinus palustris* Mill.) seedlings and decreased them in eastern white pine (*Pinus strobus* L.) seedlings. Contrary to McDonald's findings, Ruehle did not observe significant changes in seedling height, root-collar diameter, or top and root fresh weight. *Saillus granulatus* (L. ex Fr) O. Kutze and *Pisolithus tinctorius* (Pers.) Coker and Couch, were used by both researchers.

In a study conducted by Arnold and Struve (1989a) with seedlings grown in Cu treated pots, transplanted to the field in July, August and September, growth was enhanced for two consecutive growing seasons compared to root pruned control seedlings. Total shoot growth after two seasons for red oak (*Quercus rubra* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) were 61 cm and 72 cm, respectively, for Cu treated trees vs. 47 cm and 60 cm, respectively, for controls. In a four year study, Struve and Rhodus (1990a) observed that red oak seedlings produced via the Ohio Production System (a production system which starts seedlings 10 weeks earlier in a greenhouse and uses Cu treated containers) produced 18 inches of new growth the first year after transplanting compared to 6 inches of growth by the conventional bare-root stock method. This trend continued over the entire 4 year period. Red oak trees from Cu treated containers experienced very low mortality, 1 of 240 seedlings died after a 3 year period while 12 of 30 of the bare-root trees died. Struve and Rhodus stated that, "the Cu treatment gives the Ohio Production System plants better resistance to transplant shock." Wenny et al. (1988) observed a statistical increase, compared to controls, in new roots generated in the upper and middle sections of the root plug in three types of conifer seedlings one year after transplanting to a forest site. Seedling stem diameter, height, shoot dry weight and total dry root weight was unaffected by treatment.

It was not until the third and forth year after transplanting to the field that Burdett (1981) observed 15% greater height in growth of copper treated lodgepole pine (*Pinus contorta*) compared to control seedlings. On excavation of 4 year old plants, it was evident that lateral roots of plants grown in Cu treated plugs emerged from the uppermost part of the root plug close to the soil surface. In contrast, lateral roots emerging from control trees were few except at the bottom of the plug. Even though the trees were not yet at the stage when wind throw is a problem, Burdett was confident to predict that if any toppling occurred it would be trees from untreated containers.

Cu - Its Importance, Deficiency and Toxicity

Cu is an essential micronutrient for plants and has several functions. Cu occurs as a co-factor in many enzymes which have vital functions in plant metabolism. These are chiefly oxidases such as ascorbic acid oxidase, tyrosinase, diamine oxidase and phenol oxidase. The main sites of Cu accumulation in the roots are in epidermal, endodermis and pericycle cells (Lepp, 1981).

Several other important physiological processes significantly affected by Cu are respiration, carbohydrate distribution, nitrgen reduction and fixation, protein metabolism and cell wall metabolism. Permeability of xylem vessels is influenced by Cu and hence effects water relationships. Disease resistance mechanisms are associated with Cu as well as the synthesis of DNA and RNA. (Kabata-Pendias and Pendias, 1991)

In photosynthesis, plastocyanin contains Cu as an essential component. This cyanin accounts for 50% of the Cu found in the chloroplast. Plastocyanin plays an important role in the electron transfer process linking photo system ll and l. It has been observed that Cu inhibits auxin transport in roots. Cu plays two roles in the production of ethylene: one, it acts as a catalyzer of ethylene from linolenic acid and two, it stimulates ethylene production from methionine (Lepp, 1981).

Deficiency of Cu results in a wide variety of symptoms which are species specific. Woody plants show progressive die-back of terminal shoots, and increased production of gummy outgrowth both within and on the surface of fruits and twigs. Correction of the deficiency can be obtained by application of Cu as a sulfate, oxide, chelate or a fungicide. Response varies with soil type and crop. One major cause of lack of availability of Cu in soils is organic matter content. It has been shown that 90% of the "available" soil copper reserve is fixed in the form of organo-copper complexes (Lepp, 1981).

Containerized plants grown in artificial media, e.g. pine bark, vermiculite, and domestic peats (all potentially low in Cu), may develop Cu deficiency symptoms. Cultivars of camellia, azalea, jasmine and privet developed the following foliage symptoms of Cu deficiency: dwarfing, chlorosis, cupping, tip and marginal burn of leaves and premature leaf drop. Shoots had shortened internodes, multiple buds, dieback of shoot tips and severe stunting. (Dickey et al., 1978)

Symptoms of toxicity are manifested as a general chlorosis, stunting of growth and root deformation. The effects of excess Cu can be summarized as follows:

1. Cell and tissue damage
2. Alteration of membrane permeability, causing root leakage of ions (e.g., K^+, PO_4^{3-}) and solutes
3. Peroxidation of chloroplast membrane lipids and inhibition of photosynthetic electron transport
4. Immobilization of Cu in cell walls, cell vacuoles, and in nondiffusible Cu protein complexes

As high levels of Cu increase, iron levels in chloroplasts decrease. This can be corrected by the application of iron. To ameliorate high levels of Cu in the soil, liming is recommended. (Kabata-Pendias and Pendias, 1991)

Lepp (1981) found no satisfactory explanation for the inhibitory effect of Cu on root elongation but speculated that it might be due to changes in IAA-oxidase activity. When roots of older plants reach a critical concentration of Cu, IAA-oxidase activity rapidly declines. Other studies have shown that Cu inhibits acropetal transport of IAA in roots (Mitchell and Davies, 1974) and is involved in ethylene production (Pennazio and Roggero, 1991). Both IAA and ethylene are known for their inhibitory effect on root tip growth (Davis, 1987; Mulkey et al., 1982).

Foliar toxicity symptoms have not been observed at 300g cupric sulfate/l latex paint (Witte, personal communication), a rate well above the effective level for chemically pruning roots. Flanagan (1991) measured Cu levels in root segments and foliage of plants grown in Cu treated containers with varying rates of Cu. The highest concentration of Cu was within the first 5 cm from the root tip and quickly decreased as distance from the root tip increased. Cu levels of the root collar and foliage were at control levels. Dry weight measures of P, K, Ca, and Mg were within acceptable levels in all plant parts sampled and at different rates of Cu. There was an increase in Mn and Zn in the root sections and a decrease in Fe. Flanagan did not observe any foliar toxicity symptoms when Cu was used at 90g $Cu(OH)_2$/l of latex paint. Root growth resumed 2-6 days after transplanting. Root tips, on contact with the Cu paint, became bulbous, thicker and brown. A similar study conducted by Arnold and Struve (1989) showed similar results. Burdett (1982) observed that Cu concentrations of 500g $CuC0_3$/l latex paint appreciably reduced height, dry weight and in one species killed the majority of the tree seedlings.

CHAPTER III

$Cu(OH)_2$/LATEX PAINT FORMULATION (SPIN OUT™) CONTROLS ROOT DEFLECTION IN 54 TAXA OF CONTAINERIZED ORNAMENTAL TREES, SHRUBS, PERENNIALS AND GRASSES

Introduction

Many papers have been published recently on the effect of copper (Cu) as a root pruning compound. Several formulations of Cu/latex paint compounds have been used, such as cupric sulfate (Furuta et al., 1972; Flanagan, 1991), cupric naphthenate (Furuta et al., 1972), cupric carbonate (Arnold and Struve, 1989, 1989a; Burdett and Martin, 1982; McDonald et al., 1984 and 1984a; Ruehle, 1985; Struve et al., 1987, 1987a; Wenny et al., 1988) and cupric hydroxide (Arnold 1992, 1993; Beeson and Newton, 1992; Flanagan, 1991; Struve, 1990; Svenson and Johnston, 1992). For several years, greater attention has been given to cupric hydroxide because it is less expensive, more effective, mixes well in latex paint. EPA approval was given in 1993 to Griffin Corporation for a 7% cupric hydroxide/latex paint formulation called Spin Out™.

When roots reach the interior wall of containers painted with Cu, elongation is inhibited. This prevents root deflection down the side of the container and prevents the development of matted and contorted root systems which are typical of plants grown in untreated containers.

The following is a list of observations from previous research on the use of Cu as a root pruning compound.

- Cu prevents root deflection in containers alleviating the need to root prune prior to transplanting (see above citations).
- Root systems are more dense and fibrous (Arnold and Struve, 1989; Flanagan, 1991; McDonald et al., 1984; Burdett, 1978).
- Cu does not interfere with the development of mycorrhizal roots but actually enhances mycorrhizal root development (McDonald et al., 1981; Ruehle, 1985).
- Root morphology is much like a natural seedling in that lateral roots are oriented more horizontally rather than vertically as in untreated containers (Burdett, 1978; Wenny et al., 1988). This enhanced mechanical stability (Burdett 1981).
- Faster establishment of plants (Arnold and Struve, 1989a; Burdett, 1981; Struve et al., 1987a).
- Foliage toxicity has not been observed at effective rates [7% $Cu(OH)_2$/l latex paint) (Beeson and Newton, 1992; Flanagan, 1991)].
- Root growth resumes within 3-6 days after transplanting (Arnold and Struve, 1989; Flanagan, 1991).
- Growth responses, such as shoot length, root and shoot ratios, dry root and shoot weights, trunk caliper, height, rate of growth, regenerated roots, and transplant survival are species dependent and have been both positive (Arnold and Struve, 1989), negative (Burdett and Martin, 1982) and indifferent (Ruehle, 1985) compared to controls.
- Only a relatively small number of species have been studied.

In a study of 18 woody landscape species, Beeson and Newton (1992) observed that growth parameters varied statistically amoung species but the differences were commercially unimportant.

The objective of this study was to determine whether one rate of cupric hydroxide would be effective in controlling root deflection in 54 species of ornamental trees, shrubs, perennials and grasses (Table 1).

Methods and Materials - Experiment One

Forty-one taxa of ornamental trees, shrubs, perennials and grasses were used in this experiment which started during June and July 1992 as plants were received (Table 1.). Plants were procured from several nurseries in the south east United States.as one year old seedlings or rooted cuttings. Thirty-two uniform plants were selected from each taxon. Sixteen plants were potted in treated plastic bands and sixteen potted in untreated bands. Plastic 9 x 9 x 15 cm bands were used (Anderson Die and Manufacturing Co., Portland, OR). The interior of treated containers were spray painted with a formulation of 7% cupric hydroxide in latex paint (Spin Out™, Griffin Corp. Valdosta, GA) using a Wagner Sprayer model 330 (Wagner Sprayer Tech Corporation Minneapolis, MN). Potting media was pine bark amended with dolomitic limestone, 4.17 kg/m^3; treble super phosphate (20.2P), 1.19 kg/m^3; 10N-4.4P-8.3K granular fertilizer, 1.19 kg/m^3; gypsum ($CaSO_4$), 1.33 kg/m^3 and Micromax™ (Grace-Sierra Horticultural Products Milpitas, CA) 0.89 kg/m^3.

Table 1. List of scientific names, common names and families used in this experiment

SCIENTIFIC NAME AND AUTHORITY*	COMMON NAME+	FAMILY
Acer rubrum 'October Glory' L.	'October Glory' Red Maple	Aceraceae
Acorus gramineus 'Variegatus' Ait.	Variegated Sweet Flag	Araceae
Artemisia ludoviciana 'Silver King' Nutt.	'Silver King' Artemisia	Compositae
Betula nigra L.	River Birch	Betulaceae
Buxus microphylla Sieb. & Zucc.	Littleleaf Boxwood	Buxaceae
Buxus sempervirens 'Vardar Valley' L.	'Vardar Valley' Boxwood	Buxaceae
Calluna vulgaris (L.) Hull	Scotch Heather	Ericaceae
Carex morrowi variegata Boott.	Japanese Sedge Grass	Cyperaceae
Ceratostigma plumbaginoides Bunge	Blue Leadwort	Plumbaginaceae
Cercis canadensis L.	Eastern Redbud	Leguminosae
Chionanthus retusus Lindl.	Chinese Fringe Tree	Oleaceae
Cornus florida L.	Flowering Dogwood	Cornaceae
Cornus kousa (Buerger ex Miq.) Hance.	Kousa Dogwood	Cornaceae
Cortaderia selloana (Schult. & Schult. f.) Asch. & Gräbn.	Pampas Grass	Gramineae

Table 1. (continued)

SCIENTIFIC NAME AND AUTHORITY*	COMMON NAME+	FAMILY
Diospyros virginiana L.	Common Persimmon	Ebenaceae
Euonymus fortunei 'Coloratus' (Turcz) Hand.-Mazz.	'Coloratus' Wintercreeper Euonymus	Celastraceae
Festuca cinerea 'Solling' Vill.	'Solling' Blue Fescue	Gramineae
Ginkgo biloba L.	Maidenhair Tree	Ginkgoaceae
Hibiscus syriacus 'Aphrodite' L.	'Aphrodite' Rose-of-Sharon	Malvaceae
Hydrangea paniculata 'Grandiflora' Sieb.	Pee Gee Hydrangea	Saxifragaceae
Hypericum x 'Hidcote'	'Hidcote' St. Johnswort	Hypericaceae
Iberis sempervirens L.	Candytuft	Cruciferae
Ilex (*aquifolium x cornuta*) x 'Nellie R. Stevens'	'Nellie R. Stevens' Holly	Aquifoliaceae
Juniperus horizontalis 'Blue Rug' Moench.	'Blue Rug' Creeping Juniper	Cupressaceae
Kerria japonica 'Pleniflora' (L.) DC.	'Pleniflora' Japanese Kerria	Rosaceae
Koeleria glauca Coleman ex.Willk. & Lange.	Large Blue Hair Grass	Gramineae
Ligustrum japonicum Thunb.	Japanese Privet	Oleaceae
Liquidambar styraciflua L.	Sweet Gum	Hamamelidaceae

Table 1. (continued)

SCIENTIFIC NAME AND AUTHORITY*	COMMON NAME+	FAMILY
Lythrum virgatum 'Morden's Pink' L.	'Morden's Pink' Loosestrife	Lythraceae
Magnolia grandiflora L.	Southern Magnolia	Magnoliaceae
Magnolia liliiflora 'Ann' Desr.	'Ann' Lily Magnolia	Magnoliaceae
Magnolia liliiflora 'Jane' Desr.	'Jane' Lily Magnolia	Magnoliaceae
Nandina domestica Thunb.	Heavenly Bamboo	Berberidaceae
Nyssa sylvatica Marshall	Black Gum	Nyssaceae
Pennisetum alopecuroides (L.) Spreng.	Fountain Grass	Gramineae
Photinia x fraseri Dress.	Fraser Photinia	Rosaceae
Pinus thunbergii Parl.	Japanese Black Pine	Pinaceae
Prunus laurocerasus 'Schipkaensis' L.	'Schipkaensis' Cherry Laurel	Rosaceae
Prunus subhirtella 'Autumnalis' Miq.	'Autumnalis' Higan Cherry	Rosaceae
Quercus falcata var. *pagodifolia* Ellis.	Cherrybark Oak	Fagaceae
Salix gracilistyla 'Melanostachys' (Mak.) C. Schneid.	Black Pussy Willow	Salicaceae
Spiraea japonica 'Little Princess' L.f.	'Little Princess' Japanese Spirea	Rosaceae

Table 1. (continued)

SCIENTIFIC NAME AND AUTHORITY*	COMMON NAME[+]	FAMILY
Spiraea nipponica 'Snowmound' Maxim.	'Snowmound' Nippon Spirea	Rosaceae
Syringa vulgaris 'Michael Buchner' L.	'Michael Buchner' Common Lilac	Rosaceae
Taxodium distichum var. *distichum* (L.) Rich.	Bald Cypress	Taxodiaceae
Taxus x *media* 'Densiformis' Rehd.	'Densiformis' Anglojap Yew	Taxaceae
Taxus x *media* 'Hicksii' Rehd.	'Hicksii' Anglojap Yew	Taxaceae
Thuja occidentalis 'Pyramidalis' L.	'Pyramidalis' Arborvitae	Cupressaceae
Thuja occidentalis 'Techny' L.	'Techny' Arborvitae	Cupressaceae
Viburnum plicatum var. *tomentosum* 'Mariesii' (Thunb.) Rehd.	'Mariesii' Double File Viburnum	Caprifoliaceae
Viburnum x *rhytidophylloides* 'Alleghany' Suring.	'Alleghany' Lantanaphyllum Viburnum	Caprifoliaceae
Vitex agnus-castus L.	Chaste Tree	Verbenaceae
Wisteria floribunda 'Rosea' Willd.	'Rosea' Japanese Wisteria	Leguminosae

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* Authorship was substantiated by the New Royal Horticultural Society Dictionary of Gardening [Huxley et al. (eds)].

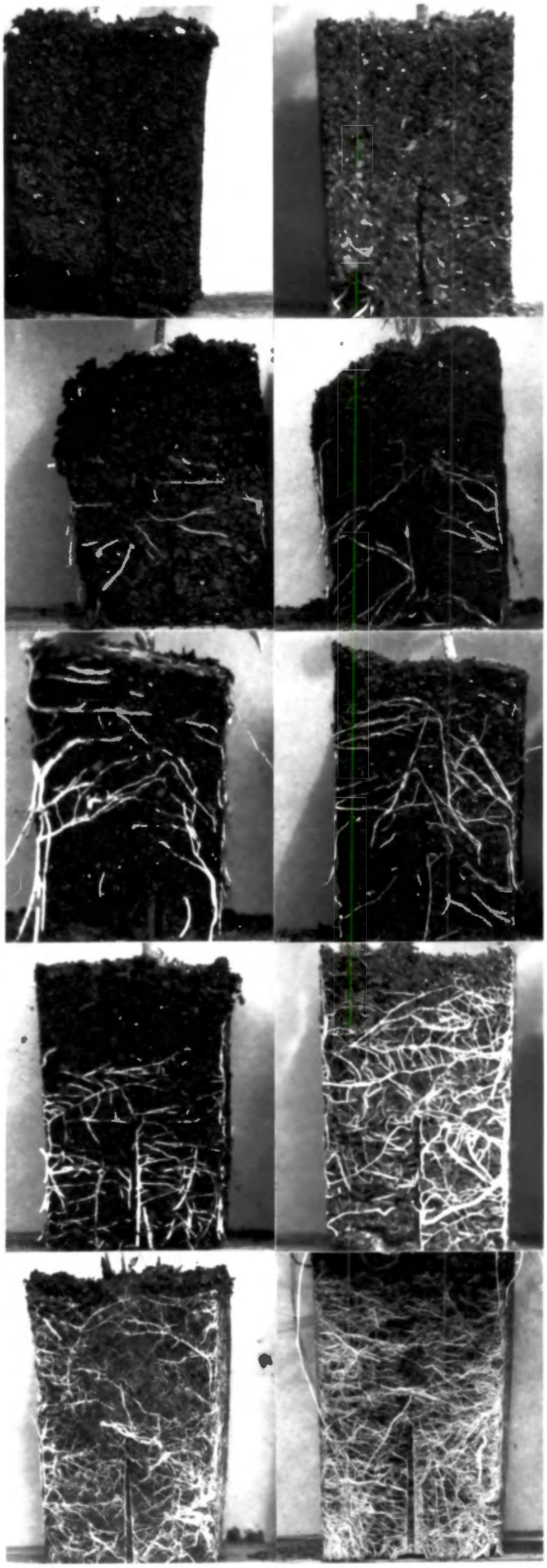
[+] Common names were substantiated by the Manual of Woody Landscape Plants by Dirr and Kurt Bluemel Inc. 1991. Wholesale Price List. Baldwin, Maryland.

Plants were arranged in a randomized complete block design on greenhouse benches with each taxon being a block. Plants were evenly spaced on 16 cm centers. Greenhouse temperatures ranged from 31°C day to 18°C night. Plants were watered as needed and fertigated weekly with Peters Professional (20N-4.4P-16.6K) general purpose fertilizer at 473 ppm N (Grace-Sierra Horticultural Products Milpitas, CA). A 50% shade cloth covered the double layer polyhouse. Pests, such as aphids, spider mites, and white flies, were controlled using standard insecticidal products and application rates. *Chionanthus retusus* required two applications of Liquid Iron™ (Vigoro Industries, Fairview Heights, IL). as a soil drench to correct iron chlorosis which occurred uniformly in plants from treated and untreated containers.

A pictorial rating scale was constructed to aid a panel of four judges in evaluating the degree of root deflection. The scale (Plate 1) ranged from 1 to 5. For each level of the scale two color photographs of root balls depicted the range of root deflection for that level. Level one indicated root deflection < 1.3 cm in length (excellent control). Level two indicated root deflection > 1.3 cm and < 15 deflected roots, level three 16 - 27 deflected roots, level four 28 - 38 deflected roots and level five > 38 deflected roots (severe root deflection).

Videotaped images (Canon VM-E2 8mm videocamera and recorder, Canon Inc., Japan) from which root deflection data were derived were recorded from 15 October to 10 November 1992. Each plant was removed from the square container and an 8 second color videotape image was recorded of a randomly chosen face of the root ball (Plate 2.1). Four judges simultaneously viewed a playback of the

Plate 1. Pictorial rating scale used by judges to score the degree of deflection of root balls, The scale ranged from 1 to 5. For each level of the scale two color photographs of root balls depicted the range of root deflection for that level. Level one indicated root deflection < 1.3 cm in length (excellent control). Level two indicated root deflection > 1.3 cm and < 15 deflected roots, level three 16 - 27 deflected roots, level four 28 - 38 deflected roots and level five > 38 deflected roots (severe root deflection).



videotape recording and subjectively scored each root ball based upon the rating scale. Each judge had a copy of the pictorial scale to facilitate accurate scoring. Data were analyzed with a GLM procedure using SAS and means were separated using LSD at the 5% level of significance (Table 2). Judges were analyzed as a second factor to validate whether scoring between judges was uniform.

Methods and Materials - Experiment Two

After collecting data from Experiment One (10 November 1992) the deflecting roots of every plant were sheared off from all four sides of the root ball. Plants were potted up into 15 x 15 x 15 cm plastic containers (Lerio Corporation, Mobile, AL) using the same media as in Experiment One. Plants were maintained in their respective treatments from Experiment One to Experiment Two. Thirteen additional taxa were added to this experiment. These plants were originally to be a part of Experiment One but the root balls were too large to fit in the 9 x 9 x 15 cm bands. Plants were placed outside and allowed to harden off, then stored over winter in an unheated polyhouse. In early May 1993, plants were placed on the open gravel area of the nursery. Each taxon was arranged in a single row from replication one through sixteen with treatments randomized within replications. On center spacing within a row was 30 cm and 56 cm between rows (Plate 2.2). All pots were marked on the east side with white paint. Each plant was fertigated once with Peters Professional 20N-4.4P-16.6K general purpose fertilizer (Grace-Sierra Horticultural Products, Milpitas, CA) at 470 ppm nitrogen and then top dressed with 9 g/pot of Osmocote 14N-6.2P-11.6 (Grace-Sierra Horticultural Products Milpitas, CA). Larger plants were attached to a wire to hold them upright. Plants

Table 2. Mean scores of root deflection in 54 taxa of containerized plants. Interior of treated containers (+Cu) were spray painted with Spin Out™. Control containers (-Cu) were not painted. Column A and B show the difference in root scores between Experiment One (1992) and Experiment Two (1993) for +Cu and -Cu (control) respectively.

	MEAN ROOT CONTROL SCORES *^{z}					
		Exp. 1 (1992 DATA)		Exp. 2 (1993 DATA)		
SPECIES	A	+Cu	-Cu	+Cu	-Cu	B
Acer rubrum 'October Glory'	-	-	-	1.4	4.0	-
Acorus gramineus 'Variegatus'	+0.5	1.0	2.6	1.5	3.7	+1.1
Artemisia ludoviciana 'Silver King'	+0.4	1.0	4.0	1.4	4.0	0
Betula nigra	+0.7	1.3	3.4	2.0	4.3	+0.9
Buxus sempervirens 'Vardar Valley'	-1.0	2.1	2.9	1.1	2.9	0
Buxus microphylla	0	1.0	2.8	1.0	3.0	+0.2
Calluna vulgaris	+0.2	1.0	4.6	1.2	4.7	+0.1
Carex morrowi variegata	+0.3	1.0	3.3	1.3	4.6	+1.3
Ceratostigma plumbaginoides	+0.4	1.0	3.1	1.4	3.5	+0.4
Cercis canadensis	0	1.0	3.3	1.0	3.4	+0.1
Chionanthus retusus	+0.1	1.0	1.9	1.1	3.3	+1.4
Cortaderia selloana	-0.4	1.5	4.6	1.1	5.0	+0.4
Cornus florida	-	-	-	1.2	3.7	-
Cornus kousa	-	-	-	1.0	3.0	-
Diospyros virginiana	-	-	-	1.0	3.7	-
Euonymus fortunei 'Coloratus'	0	1.0	3.8	1.0	4.9	+1.1
Euonymus fortunei 'Variegatus'	+.1	1.1	2.4	1.2	5.0	+2.6
Festuca cinerea 'Solling'	+0.5	1.0	2.8	1.5	4.4	+1.6
Ginkgo biloba	-	-	-	1.9	3.2	-

Table 2. (continued)

	MEAN ROOT CONTROL SCORES *z					
		Exp. 1		Exp. 2		
		(1992 DATA)		(1993 DATA)		
SPECIES	A	+Cu	-Cu	+Cu	-Cu	B
Hibiscus syriacus 'Aphrodite'	+0.4	1.5	4.7	1.9	4.3	-0.4
Hydrangea paniculata 'Grandiflora'	-0.1	1.1	3.6	1.0	4.8	+1.2
Hypericum x 'Hidcote'	0	1.0	2.8	1.0	4.6	+1.8
Iberis sempervirens	+0.1	1.1	4.4	1.2	3.2	-1.2
Ilex x 'Nellie R. Stevens'	0	1.0	2.1	1.0	4.1	+2.0
Juniperus horizontalis 'Blue Rug'	-	-	-	1.3	3.0	-
Kerria japonica 'Pleniflora'	0	1.0	4.8	1.0	4.0	-0.8
Koeleria glauca	-	-	-	1.0	4.9	-
Ligustrum japonicum	0	1.1	2.5	1.1	4.6	+2.1
Liquidambar styraciflua	-	-	-	1.3	3.8	-
Lythrum 'Morden's Pink'	0	1.0	4.8	1.0	3.5	-1.3
Magnolia grandiflora	-	-	-	1.5	3.7	-
Magnolia liliiflora 'Ann'	+0.3	1.8	3.6	2.1	4.1	+0.5
Magnolia liliiflora 'Jane'	+0.4	1.5	3.3	1.9	4.1	+0.8
Nandina domestica	+1.4	1.0	2.6	2.4	4.7	+2.1
Nyssa sylvatica	0	1.0	2.8	1.0	4.5	+1.7
Pennisetum alopecuroides	+0.2	1.4	4.9	1.6	5.0	+0.1
Photinia x *fraseri*	0	1.0	3.1	1.0	4.4	+1.3
Pinus thunbergii	+0.1	1.0	2.2	1.1	2.4	+0.2
Prunus laurocerasus 'Schipkaensis'	-	-	-	1.0	2.7	-
Prunus subhirtella 'Autumnalis'	-0.1	1.1	3.1	1.0	2.5	-0.6
Quercus falcata var. *pagodifolia*	-	-	-	1.0	1.8	-

Table 2. (continued)

	MEAN ROOT CONTROL SCORES *^{z}					
		Exp. 1		Exp. 2		
		(1992 DATA)		(1993 DATA)		
SPECIES	A	+Cu	-Cu	+Cu	-Cu	B
Salix gracilistyla 'Melanostachys'	+0.1	1.0	2.4	1.1	4.0	+1.6
Spirea japonica 'Little Princess'	+0.1	1.0	4.7	1.1	5.0	+0.3
Spirea nipponica 'Snowmound'	+0.1	1.0	3.3	1.1	4.6	+1.3
Syringa vulgaris 'Michael Buchner'	0	1.0	3.3	1.0	3.6	+0.3
Taxodium distichum	-	-	-	1.7	3.5	-
Taxus x *media* 'Densiformis'	-0.2	1.2	2.8	1.0	2.0	-0.8
Taxus x *media* 'Hicksii'	-0.7	1.7	2.0	1.0	2.2	+0.2
Thuja occidentalis 'Pyramidalis'	0	1.1	3.4	1.1	4.2	+0.8
Thuja occidentalis 'Techny'	+1.1	1.4	4.3	2.5	4.8	+0.5
Viburnum plicatum tomentosum 'Mariesii'	-0.1	1.1	3.1	1.0	2.8	-0.3
Vitex agnus-castus	0	1.0	4.6	1.0	4.7	0.1
Viburnum x *rhytidophylloides* 'Alleghany'	+0.1	1.0	2.7	1.1	4.1	+1.4
Wisteria floribunda 'Rosea'	-	-	-	1.2	3.4	-

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* Comparisons within all taxa were significantly different at $P \leq 0.05$ by Duncan's multiple range test.

^{z} Based on root control scoring scale: 1 = complete control, 5 = no control of root deflection.

were irrigated by overhead impact sprinklers about every other day during spring and every day during the summer to the point of media saturation.

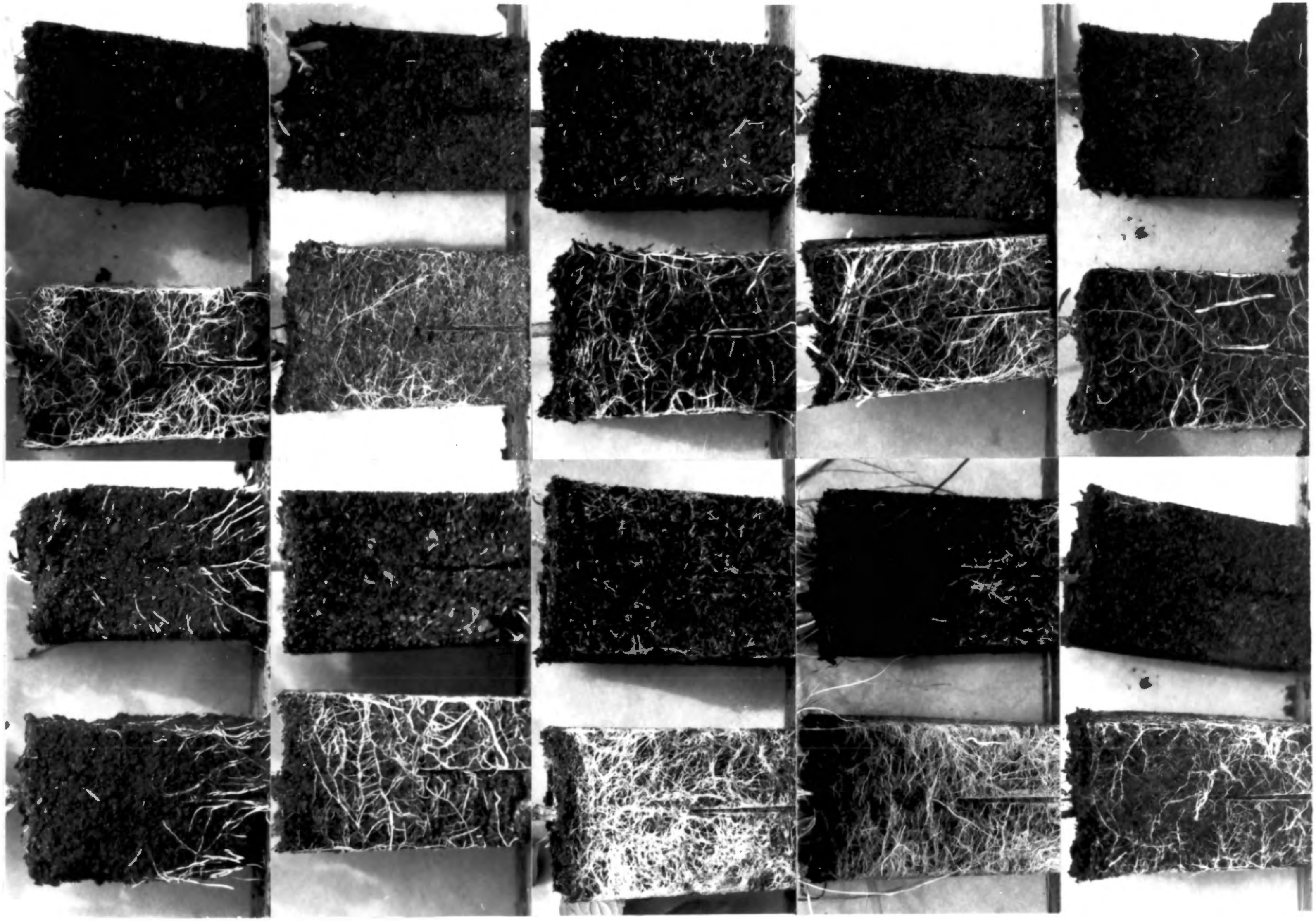
Data collection began September 1993, following the same procedures in Experiment One, except the east side of the root ball was evaluated. It was anticipated that the east side of the container would have greater root development because of lower maximum media temperatures compared to the south and west facing sides.

Results and Discussion

In Experiment One and Two, Spin Out™ was effective in controlling root deflection in all species tested (Table 2 and Plate 3). In both experiments the treatment was significantly different from the control ($P = 0.05$) and in many cases the difference was by two to four points based on the five point rating scale. While 100% control of root deflection was not always achieved in treated containers, root deflection was consistently reduced compared to untreated containers. The results of the Experiment Two strengthened the results of the Experiment One (Table 1). More of the controls in the Experiment One, that had control scores from 2 to 4, attained a score of 4 to 5 in Experiment Two while treatment scores remained low, 1.0 to 2.5. e.g. *Calluna vulgaris*, *Carex morrowi variegata, Euonymus fortunei* 'Variegatus', Ilex x 'Nellie R. Stevens', *Liquidambar styraciflua* and *Salix gracilistyla* 'Melanostachys'.

The rationale behind Experiment Two was to allow more time for the slower growing taxa to develop a heavier root system. Taxa that had control

Plate 3. Each set of photographs contains a representative root ball from a copper treated container (right) and from an untreated container (left). The ten species are, 1, *Buxus sempervirens* 'Vardar Valley', 2.*Euonymus fortunei* 'Coloratus', 3. *Acer rubrum* 'October Glory', 4. *Spiraea nipponica* 'Snowmound', 5. *Hydrangea paniculata* 'Grandiflora', 6. *Hibiscus syriacus* 'Aphrodite', 7. *Artemisia ludoviciana* 'Silver King', 8. *Pennisetum alopecuroides*, 9. *Lythrum virgatum* 'Morden's Pink', 10. *Magnolia liliiflora* 'Jane'.



means < 3 for Experiment One were allowed to develop a more extensive root system in the control containers (Table 3). This more adequately tested the ability of Spin Out^{TM} to halt root deflection under greater growing pressure from the plant. Taxa with a control score of < 3.0 in Experiment One decreased or increased up to 2.1 points in Experiment Two, while Cu treatment scores decreased or increased up to 1.4 points (Table 3). In faster growing taxa, Experiment 2 also tested how well Cu controlled root deflection in severely root bound conditions. In one taxon, *Cortaderia selloana*, the root ball exerted so much pressure that the plastic container walls started to split, but root deflection was minimal in the Cu treated container.

Visual observations of the root balls showed maximum root development in the control container occured on the east side. This minimized variation due to temperature extremes. Plants grown in Cu treated containers may experience less stress due to high media temperatures because roots are not deflecting down the side of the container.

The judges scored the treatments of each taxa consistently. For most of the taxa in Experiment One and Experiment Two there were no judge/treatment interactions (61% and 80%, respectively) at $P = 0.05$. Even when judge/treatment interactions were significant, ($P \leq 0.05$) judges consistently scored the Cu treatment lower than the control. What they disagreed upon was the magnitude of difference (Table 4). There were fewer judge/treatment interactions in Experiment Two, probably due to experience in grading the images of the root systems. Three of the judges were the same in both Experiments.

Table 3. Mean scores of root deflection in containerized plants that had a control (-Cu) mean in Experiment One (1992) that was < 3.0 (Table 1). Interior of treated pots (+Cu) were spray painted with Spin Out™ and controls (-Cu) were unpainted. Column A and B show the difference in root scores between Experiment One (1992) and Experiment Two (1993) for +Cu and -Cu (control) respectively.

	MEAN ROOT CONTROL SCORES *^{z}					
		Exp. 1 (1992 DATA)		Exp. 2 (1993 DATA)		
SPECIES	A	+Cu	-Cu	+Cu	-Cu	B
Acorus gramineus 'Variegatus'	+0.5	1.0	2.6	1.5	3.7	+1.1
Buxus sempervirens 'Vardar Valley'	-1.0	2.1	2.9	1.1	2.9	0
Buxus microphylla	0	1.0	2.8	1.0	3.0	+0.2
Chionanthus retusus	+0.1	1.0	1.9	1.1	3.3	+1.4
Euonymus fortunei 'Variegatus'	0.1	1.1	2.4	1.2	5.0	2.6
Festuca cinerea 'Solling'	+0.5	1.0	2.8	1.5	4.4	+1.6
Hypericum x 'Hidcote'	0	1.0	2.8	1.0	4.6	+1.8
Ilex x 'Nellie R. Stevens'	0	1.0	2.1	1.0	4.1	+2.0
Ligustrum japonicum	0	1.1	2.5	1.1	4.6	+2.1
Nandina domestica	+1.4	1.0	2.6	2.4	4.7	+2.1
Nyssa sylvatica	0	1.0	2.8	1.0	4.5	+1.7
Pinus thunbergii	+0.1	1.0	2.2	1.1	2.4	+0.2
Salix gracilistyla 'Melanostachys'	+0.1	1.0	2.4	1.1	4.0	+1.6
Taxus x *media* 'Densiformis'	-0.2	1.2	2.8	1.0	2.0	-0.8
Taxus x *media* 'Hicksii'	-0.7	1.7	2.0	1.0	2.2	+0.2
Viburnum x *rhytidophylloides* 'Alleghany'	+0.1	1.0	2.7	1.1	4.1	+1.4

* Control and treatment means within a species in each column are significantly different as determined by Duncan's multiple range test, P =0.05.

^{z} Based on root control scoring scale: 1 = complete control to 5 = no control of root deflection.

Table 4. In Experiment One and Two there was a judge/treatment interaction ($P < 0.05$) with some of the taxa (39% and 20% respectively). Even when the interaction was significant the Cu treatment (+Cu) was always scored lower than the control (-Cu). This point demonstrated by data from *Buxus microphylla*, (Pr = 0.0068).

Judge	Treatment	Mean
1	+Cu	1.0
	-Cu	2.8
2	+Cu	1.0
	-Cu	2.5
3	+Cu	1.0
	-Cu	3.4
4	+Cu	1.0
	-Cu	3.1

The main benefit of using Cu as a root pruning compound was that root deflection was greatly reduced. This eliminated the need for corrective root pruning which can induce transplant shock. Symptoms of foliar Cu toxicity were not observed. Spin Out™ did not inhibit or restrict the growth of stem structures such as rhizomes, stolons or basal suckers which grew unabated. This research agrees with the work of previous research showing that Cu compounds are very effective in controlling root deflection in containers, and extends it to many more taxa of ornamental plants.

Presently, long term experiments are being conducted by various researchers to determine how well plants from Cu treated containers establish in the field or landscape. If results are positive, then nursery growers will have a proven means of improving the quality of containerized plants.

CHAPTER IV

INHIBITION OF TAP ROOT ELONGATION IN CONTAINERS BY SIX DIFFERENT MATERIALS COATED WITH SPIN OUT™

Introduction

Coarsely rooted trees, such as many species of oak, black walnut, black gum, etc., are not commonly used in the landscape industry because field grown trees do not transplant well. The tap roots, when produced in containers, circle at the bottom and require corrective pruning prior to transplanting. This may severely stunt or kill the tree.

A few copper (Cu) compounds such as cupric sulfate (Furuta et al., 1972; Flanagan, 1991), cupric naphthenate (Furuta et al., 1972), cupric carbonate (Arnold and Struve, 1989, 1989a; Burdett and Martin, 1982; McDonald et al., 1984 and 1984a; Ruehle, 1985; Struve et al., 1987, 1987a; Wenny et al., 1988) and cupric hydroxide (Arnold 1992, 1993; Beeson and Newton, 1992; Flanagan, 1991; Struve, 1990; Svenson and Johnston, 1992) have been used successfully to chemically prune roots of container-grown plants. The compound most widely used in current research is 7% $Cu(OH)_2$ in a latex paint formulated as Spin Out™ (Griffin Corporation, Valdosta, GA). It was hoped that the tap root of coarsely rooted trees could be checked by these Cu compounds and allow container production of many beautiful taxa that are currently available only as field produced balled and burlapped plants.

It has been the author's observation that Cu is very effective in controlling lateral root growth but the tap root still circles at the bottom of the treated container. As a result, corrective pruning is required which may reduce transplant success. The objective of this experiment is to see if trapping the tap root into a material coated with a Cu compound would enhance absorption of Cu and halt elongation. The purpose of this study was to test seven different types of Spin Out™ coated materials in their ability to control tap root growth in *Nyssa sylvatica* Marshall. (black gum), *Quercus acutissima* Carruth. (sawtooth oak) and *Castanea mollissima* Bl. (Chinese chestnut).

Methods and Materials

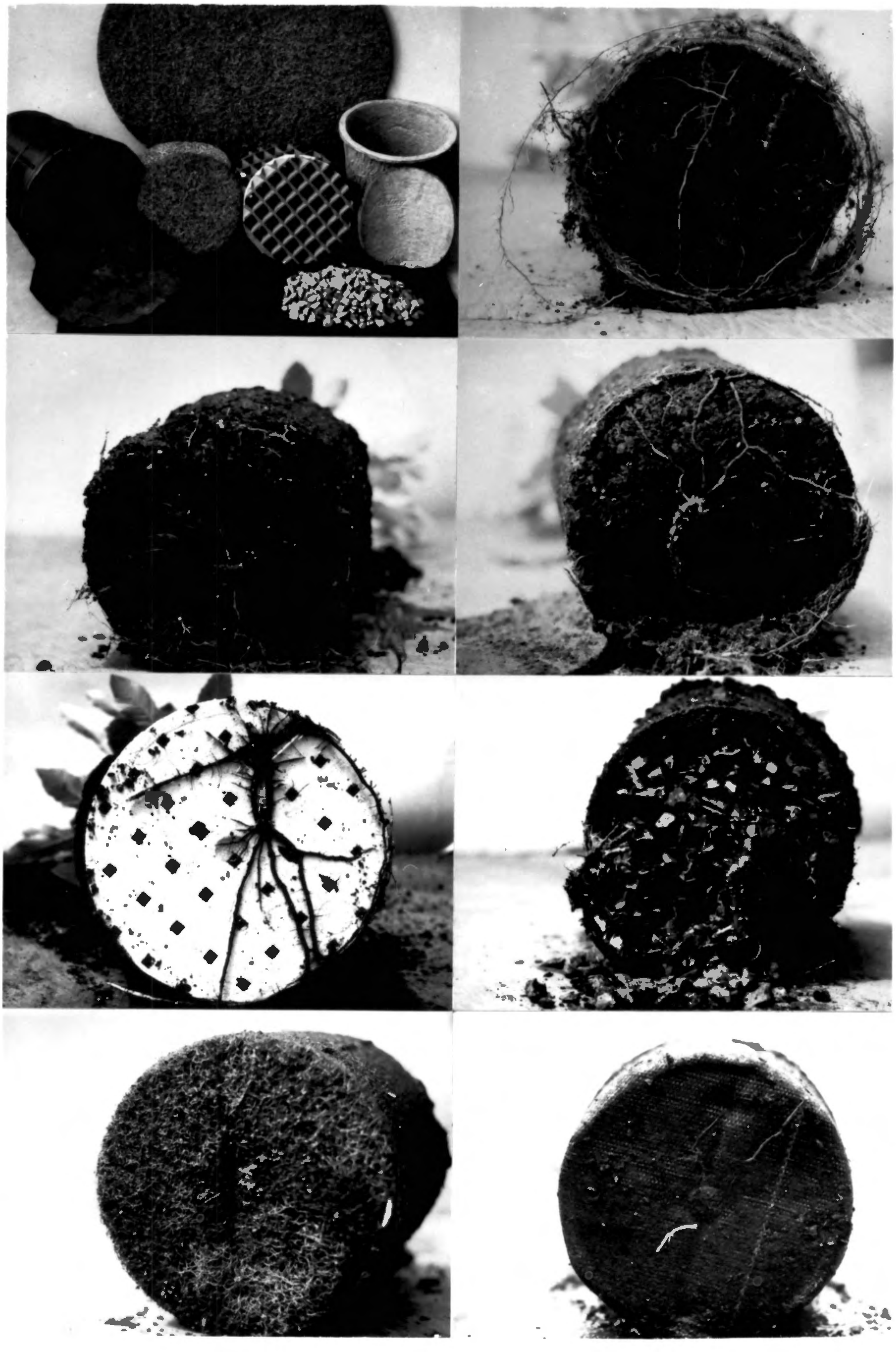
Treatments consisted of six types of inserts or modifications to the bottom of Zarn 800 containers (Zarn, Inc., Atlanta, GA) (Plate 4.1): Treatment #1, the control, had no modification; The modification treatments (inserts) were: #2) painted container; #3) washed pea gravel applied to a depth of 3.8 cm, enough to cover the drain holes; #4) Styrofoam seedling plug trays with a cell size of 2 x 2 x 4.5 cm (Todd Planter Flats, Speeding Inc., Sun City, FL); #5) Weed Barrier cut to cover the bottom and drain holes (DeWitt Co. Sikeston, MO; #6) medium coarse (15 mm thick) floor buffing mat, (3M mat) (3M, St. Paul, MN); #7) copper treated fiber pots (Keiding Inc., Milwaukee, WI). Spin Out WP™, a dry formulation of Spin Out.™ was incorporated into the fiber pot by the manufacturer. Circular disks were cut from the side of the container wall and placed in the bottom of the Zarn container. All inserts were placed or cut to tightly fit the bottom of the containers and the surfaces were painted with Spin Out™ using a Wagner Sprayer Model 330 (Wagner Sprayer Tech Corporation, Minneapolis, MN) except for the

Plate 4. Effect of inserts on tap root (*Quercus acutissima*) inhibition at bottom of container compared to control treatment.

- Unpainted control container (not shown), root ball A4.2

Following treatments were painted with Spin Out.™

- painted container A4.1B, root ball A4.3
- Spin Out™ WP impregnated fiber A4.1C, root ball A4.4
- Styrofoam plug tray A4.1D, root ball A4.5
- Pea gravel A4.1E, root ball A4.6
- 3M mat A4.1F, root ball A4.7
- Weed barrier A4.1G, root ball A4.8



3M mat and pea gravel which were drenched in Spin Out™. The interior walls of all containers except controls were also painted with Spin Out™.

The experimental design was a randomized complete block design which consisted of three species (*Nyssa sylvatica*, *Quercus acutissima* and *Castanea mollissima*), seven treatments, two trees/treatment and ten blocks. *Quercus acutissima* had seven replications. Treatments were randomized within a species.

Seeds of *Nyssa sylvatica*, and *Quercus acutissima* were planted in deep flats (approx. 32 cm) filled with bark media. When the seeds germinated they were removed and placed into the treatment containers. Seedlings were used for *Castanea mollissima* and were also planted in Zarn 800 containers. Potting media was pine bark amended with dolomitic limestone, 4.17 kg/m^3; treble super phosphate (20.2P), 1.19 kg/m^3; 10N-4.4P-8.3K granular fertilizer, 1.19 kg/m^3; gypsum ($CaSO_4$), 1.33 kg/m^3 and Micromax™ (Grace-Sierra Horticultural Products, Milpitas, CA) 0.89 kg/m^3. After planting, containers were placed on benches spaced pot to pot under 50% shade cloth for one month and then placed outdoors under 50% shade cloth. Greenhouse temperatures ranged from 31^{o}C day to 18^{o}C night.

During the growing season, plants were fertigated weekly with Peters Professional (20N-4.4P-16.6K) general purpose fertilizer at 473 ppm N (Grace-Sierra Horticultural Products, Milpitas, CA). After leaf drop, plants were top dressed with 9 g/pot of Osmocote 14N-6.2P-11.6 (Grace-Sierra Horticultural Products, Milpitas, CA). At the end of November, the shade house was covered with a double layer of polyethylene and inflated to protect plants from subfreezing temperatures. Data were recorded at the end of May 93. The following parameters were measured; plant height, caliper (taken 15 cm above media,) and number of deflected roots per container (>1.3 cm in length). Tap root length was measured from the point of contact with the treatments to the root cap. Data were analyzed by SAS software and means were separated using Tukey's HSD at $P \leq 0.05$.

Results and Discussion

Table 5 shows treatment effects on mean height, caliper, root deflection and tap root length. Height and caliper of *Castanea mollissima* and *Quercus acutissima* were unaffected by treatment, indicating that Spin Out™ was not detrimental to vegetative growth. Height and caliper varied with treatments in *Nyssa sylvatica*. This may have been due to mild Cu toxicity or genetic variation. None of the species showed visual foliar symptoms of Cu toxicity. There was no treatment effect, except for the control, with regards to root deflection in *Quercus acutissima.* This was expected because the interior wall of all treatment containers was painted with Spin Out™ except for controls. Differences in root deflection were observed in *Nyssa sylvatica* and *Castanea mollissima*. The main effect was that treatments had fewer deflected roots than the controls.

The treatments that were most effective (Table 5 and Plate 4.6 - 4.8) in controlling tap root elongation in *Nyssa sylvatica* were stone, 3M mat and weed barrier and in *Quercus acutissima* were stone and weed barrier. Tap roots penetrated these materials and as a result the root tip became completely surrounded by Spin Out™ coated material. Taproot diameter was greatly reduced

Table 5. Effect of tap root control treatments on three species of container grown plants[z]. The interior of all containers, except control containers, were painted with Spin Out™. All treatments were painted with Spin Out™ except the peat fiber disk which was impregnated with Spin Out™ WP and the control. Each treatment was cut to fit the bottom of the container except stone which was applied to a depth of 38 mm (1.5 in.).

Treatment	Ht. (mm)	Caliper (mm)	Root deflections[+]	Tap root length (mm)
	Nyssa sylvatica			
control	390 a*	4.14 a*	>50.0 a*	290 a*
paint only	320 ab	3.41 ab	2.6 c	205 a
Styrofoam plug tray	270 b	2.96 b	4.2 bc	197 ab
3M mat	340 ab	3.57 ab	7.0 b	54 c
peat fiber sheet	350 ab	4.08 a	6.9 b	188 ab
stone	300 ab	3.16 b	1.8 c	50 c
weed barrier fabric	360 ab	3.69 ab	2.4 c	96 b
	Castanea mollissima			
control	679 a*	5.68 a*	14.0 a*	160 a*
paint only	721 a	5.15 a	3.1 bc	136 a
Styrofoam plug tray	794 a	6.92 a	5.6 bc	192 a
3M mat	774 a	6.72 a	5.6 bc	140 a
peat fiber sheet	819 a	6.50 a	7.3 b	163 a
stone	810 a	6.96 a	5.0 bc	109 a
weed barrier fabric	804 a	6.89 a	1.2 c	89 a
	Quercus acutissima			
control	606 a*	5.57 a*	16.0 a*	452 a*
paint only	617 a	5.52 a	3.4 b	255 bc
Styrofoam plug tray	574 a	5.40 a	2.4 b	332 ab
3M mat	671 a	6.06 a	6.3 b	169 bc
peat fiber sheet	672 a	6.10 a	6.3 b	308 ab
stone	638 a	5.55 a	1.9 b	108 c
weed barrier fabric	648 a	6.09 a	2.5 b	89 c

[z] Values are means of 20 observations for *Nyssa sylvatica* & *Quercus acutissima* & 14 observations for *Castanea mollissima*.

*Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ using Tukey's HSD test..

[+] Total number of roots deflecting down the side of the container > 1.3 cm.

as the root penetrated the above treatments compared to its diameter prior to contacting the treatments. This was most striking with the 3M mat in which the tap root diameter of one black walnut specimen was reduced by 70% by the time it exited the 15 mm thick pad (data not shown). Occasionally penetration occurred with the 3M mat. Tap roots rarely penetrated through the weed barrier treatment. In the stone treatment, the tap root became very contorted. Compared to the above three treatments, the paint treatment was not as effective in inhibiting elongation in *Nyssa sylvatica*. The tap root deflected when it reached the bottom of the container which exposed it to Spin Out on only the lower side of the root.

The Styrofoam cell treatment effectively funneled the tap root toward the bottom of the cell but due to air space between the flat and the bottom of the container, the tap root had little contact with the Spin Out^{TM} and elongation continued (Plate 4.5). When the tap root contacted the peat fiber sheet treatment it deflected and began to coil. The flat and relatively smooth surface of the peat fiber sheet did not trap the tap root (Plate 4.3) Also, the sheet did not lie flat on the bottom of the pot and created an air space problem as with the Styrofoam. This air space problem occurred with the other species as well. Plants from all species grown in the control containers exhibited the typical massive coiling of the tap root and lateral root deflection.

The results for *Nyssa sylvatica* were similar to *Quercus acutissima*. Treatments which allowed the tap root to become entangled greatly reduced tap root elongation, i.e. weed barrier, stone and 3M mat treatments.

Tap root length of *Castanea mollissima* was not significantly affected by any treatment. This may be because the tap roots had already been air pruned as seedlings prior to being potted up into the respective treated containers. At the base of each primary tap root, multiple secondary roots developed, all of which were of similar length. This created difficulties in collecting data. Also, the root system did not fill the container sufficiently to keep the root ball intact. As a result root balls would occasionally break up and data were lost.

It is speculated that the tap root responds less to Spin Out™ compared to lateral roots because its rate of growth is faster. Cells of the root cap, the site of highest Cu accumulation, may slough off before absorption into the root can take place resulting in less control of elongation. It has been well documented that the roots of plants without tap roots are effectively pruned by Cu and that the effect is localized to a few centimeters of the root tip (Arnold and Struve, 1989; Beeson and Newton, 1992; Flanagan, 1991).

The weed barrier was the most promising treatment because tap root length was greatly reduced and rarely grew through the fabric. This would considerably reduce the problem of roots escaping out the drainage hole. It was easier to paint the fabric with Spin Out™ as compared to other effective treatment materials. Stone, although effective, was heavy and would hamper production and cause increased shipping costs. The 3M mat was more expensive than the weed barrier and hence not economical.

Treatment response could probably be improved by increasing the rate of $Cu(OH)_2$. Rates as high as 260 g/l of latex paint have not induced visual symptoms of foliar Cu toxicity (Flanagan, 1991). If the air space that existed with the

Styrofoam plug tray and fiber disk treatments were eliminated the results could possibly be improved, especially with the Styrofoam plug tray treatment. Once the tap root reached the bottom of the plug it would be surrounded by Cu. A more solid material would be more suitable because the tap root, in a few cases, grew through a thick section of the Cu painted Styrofoam.

Even though tap root length was reduced by the paint treatment, the tap roots of *Nyssa sylvatica* and *Quercus acutissima* would probably be coiled by the time the plants were potted up in a normal nursery production schedule. Corrective pruning would be required which tends to stunt the growth of coarsely rooted trees. Further research is needed to test the effective treatments over a longer period of time during container production and after transplanting.

CHAPTER V

SUMMARY AND CONCLUSIONS

General Summary

$Cu(OH)_2$/Latex Paint Formulation (Spin Out™) Controls Root Deflection In 54 Taxa Of Containerized Trees, Shrubs, Perennials And Grasses.

$Cu(OH)_2$ formulated as Spin Out™ was effective in reducing the number of deflected roots in all 54 taxa surveyed. The level of control varied from species to species but in every case the treatment gave substantial results compared to controls and would eliminate the need for corrective pruning.

Inhibition Of Tap Root Elongation In Containers By Six Different Material Inserts Coated With Spin Out™

The most effective treatments in reducing tap root elongation in *Nyssa sylvatica* were the 3M mat, stone and weed barrier inserts and for *Quercus acutissima*, stone and weed barrier inserts. The peat fiber sheet and the Styrofoam plug tray treatments were less effective because air spaces existed underneath the insert. Once the tap root entered the air space, growth was less inhibited. Lateral root deflection was substantially reduced in all three taxa compared to controls. There was no treatment interaction with respect to height and caliper in *Quercus acutissima* although there was with *Nyssa sylvatica*. These interaction may be due to genetic variability.

Conclusion

$Cu(OH)_2$ formulated as Spin Out,™ was very effective in inhibiting root elongation whether lateral roots or tap roots. This inhibiting effect prevents the formation of matted roots along the outer edge of the root ball and at the bottom of the container. In both studies foliage toxicity due to Cu was not observed.

The 54 taxa surveyed greatly adds to the total number of taxa studied so far with respect to Cu compounds as root growth inhibitors. From this study and previous work of other researchers, nursery growers should feel confident that $Cu(OH)_2$ is effective in controlling root deflection of many ornamental crops. More long term studies are needed to determine whether this production method will enhance establishment after transplanting. If the results are positive it will be necessary to see if the production method will be economical and if the public will pay the extra cost.

In the second study it was demonstrated that tap root elongation could be substantially reduced by inserting certain materials which had been treated with Spin Out™ in the bottom of the container. Further research is needed to determine the best type of material and the most effective rate of $Cu(OH)_2$. With time it should be possible to produce coarsely rooted trees in containers without lateral or tap root deflection.

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VITA

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