# Timing, Acclimation Period, and Cupric Hydroxide Concentration Alter Growth Responses of the Ohio Production System[1]

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## Abstract

Northern red oak (*Quercus rubra* L.) was used as a model system to determine the effects of reduced greenhouse and acclimation phases of the Ohio production system for use in the mid-southern portion of the U.S. Initiation of the greenhouse phase could be delayed from early February to early March without reducing end-of-season growth. Eliminating the acclimation phase reduced seedling survival, but extending the acclimation phase beyond 7 days did not improve growth. In another experiment, common baldcypress (*Taxodium distichum* (L.) Rich.) were grown in straight-walled round plastic containers painted with 25, 50, or 100 g $Cu(OH)_2$/l (0.83, 1.67, or 3.34 oz/qt) Spin Out™ carrier, in nontreated straight-walled round containers, in nontreated stepped-pyramid pots, or in stepped-pyramid pots painted with 100 g $Cu(OH)_2$/l (3.34 oz/qt). Either container type treated with 100 g $Cu(OH)_2$/l effectively controlled root deformation. Nontreated stepped-pyramid pots reduced root circling, but did not control kinking and matting of roots at container surfaces.

**Index words:** Northern red oak (*Quercus rubra*), common baldcypress (*Taxodium distichum*), Spin Out™, root regeneration, container production



### Significance to the Nursery Industry

The Ohio Production System (7, 19), OPS, offers nursery managers a method of rapidly producing high quality container-grown trees while avoiding root deformation, resulting in plants physiologically adapted to withstand the rigors of transplanting into either landscape or field situations. The first two experiments explored the effect of reducing the greenhouse and acclimation phases on plant growth. In a third experiment the effectiveness of cupric hydroxide ($Cu(OH)_2$) and stepped-pyramid pots on controlling root deformation were studied. Results indicated that the greenhouse and acclimation phases and the accompanying costs can be reduced, but not eliminated. Cupric hydroxide, formulated as Spin Out™, may provide an economical alternative to cupric carbonate ($CuCO_3$) for control of root deformation. Also, Spin Out™ dries to a light gray color, a more pleasing contrast with the black pots than white paint formulated with $CuCO_3$ previously used.

### Introduction

Containerized production of nursery stock offers numerous production and marketing advantages compared to field production (8). However, root system deformation, i.e. circling, kinked, and matted roots at container surfaces, is inherent in conventional container production. Root system deformation in can adversely affect plant establishment following transplanting (13, 15, 18). Recommended corrective root pruning of deformed roots at transplanting (10, 18) removes large portions of the lateral roots, decreases shoot growth, reduces photosynthetic gas exchange, and hastens leaf senescence (2, 3, 4, 5).

The most conventional containers are round with straight walls. In recent years, various new containers have been designed to alleviate root deformation. Poly bags, square containers, and stepped-pyramid containers have produced mixed results (20). None of the newer designs were found to consistently produce superior growth to conventional straight-walled round containers, although root circling was reduced (20). Successful control of root deformation in containers has been achieved by applying root growth inhibiting substances. Copper compounds have been found to control root growth in conifers (6, 11, 12, 14, 16, 21) and deciduous woody species (2, 3, 4, 5) when applied to interior container surfaces. A new container production system, the Ohio Production System, combines cupric carbonate ($CuCO_3$) to control root deformation, a greenhouse phase to extend the growing season, and near optimum growth conditions to reduce rotation times and produce trees that exhibit reduced transplant shock when field planted (7, 19).

While attempting to adapt the Ohio Production System to mid-south conditions several questions arose. Could the greenhouse phase be reduced to save fuel costs? Could the acclimation phase between greenhouse and container yard be eliminated or shortened? Could cupric hydroxide ($Cu(OH)_2$) be substituted for $CuCO_3$? Cupric hydroxide is already labeled for use as an active ingredient in a fungicide (Kocide 101, Griffin Corp., Valdosta, Ga.) used on agricultural crops. Extending the label for use as a root growth control substance should be less difficult than obtaining labeling of a nonlabeled compound.

Therefore, the objectives of this study were to: (A) determine the effect of reducing the greenhouse phase on plant growth, (B) determine the duration of the shaded acclimation phase, (C) determine the effects of $Cu(OH)_2$ concentrations in a preformulated latex-carrier applied to interior

[1]Received for publication January 30, 1992; in revised form March 25, 1992. Tennessee Technological University (TTU) College of Agriculture and Home Economics Manuscript Number 44. The author thanks W. Edgar Davis for technical assistance.

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container surfaces on root deformation and plant growth, and (D) determine root development and plant growth in stepped-pyramid containers with and without coating interior container surfaces with $Cu(OH)_2$.

## Materials and Methods

*Effects of seeding date, Expt. 1.* On February 11, March 4, and March 25, 1991, stratified seeds of northern red oak (*Quercus rubra*) were sown in flats and the flats placed in a greenhouse set at 75/65°F day/night covered with 55% shade cloth. As the first true leaves began to expand, 15 seedlings were gently uprooted, tap roots pinched in half or at the point of deflection by the germination flat bottom, and planted in no. 1 (2.2 l, 2.3 qt) plastic containers (Zarn Inc., Reidsville, N.C.). The plants were returned to the greenhouse and placed in a randomized complete block design. On April 16, 1991, a fourth group of seeds was similarly sown, but was placed directly outdoors under 55% shade cloth. On May 8, 1991, 15 seedlings of the April 16 group were planted directly in no. 3 (11.0 l, 3 gal.) containers (Zarn, Inc., Reidsville, N.C.) while the greenhouse grown seedlings were transplanted to no. 3 (11.0 l, 3 gal.) containers. Prior to planting the interior surfaces of all containers were painted with 100 g $Cu(OH)_2$/l (3.34 oz/qt) of flat interior white latex paint in keeping with the Ohio Production System (19).

After 14 days under shade, all potted seedlings were moved to the container yard (under full sun) and placed in randomized complete block design with three blocks containing five seedlings from each sowing date. Container production conditions were as previously described (19) with the following exceptions; no peat was included in the medium, 16 g (0.56 oz) 18N-3.1P-8.3K-1Fe (18-7-10-1) Sierrablen Nursery Mix 8-9 month formulation (Sierra Chemical Co., Milpitas, Ca.) was applied to each container 2 weeks after potting in the greenhouse, 48 g (1.7 oz) of the same fertilizer was applied at transplanting to 11.0 l (3 gal.) containers, and overhead irrigation was supplemented by hand watering as needed. Height, caliper at 2 inches (5 cm) above the medium, and the number of flushes were recorded at transplant. Height, caliper, number of flushes, and shoot and root fresh and dry (2 weeks at 70°C) weights were recorded and total plant fresh and dry weights calculated after harvest on November 11, 1991.

*Acclimation duration, Expt. 2.* On February 20, 1991, seeds of northern red oak (*Quercus rubra*) were germinated as in expt. 1. Cultural conditions were the same as expt. 1 except during the acclimation phase. On May 9, 1991, 15 seedlings were transplanted from the no. 1 (2.2 l, 2.3 qt) containers to no. 3 (11.0 l, 3 gal.) containers and placed directly in the container yard. The remaining 45 seedlings were placed under 55% shade cloth. At 7, 14, and 21 days after transplanting, 15 seedlings were moved from the shade area to the container yard. Data collected at transplanting were the same as in expt. 1. The experimental design was a randomized complete block with three blocks containing five plants per shade treatment. At noon on a typical sunny day (August 23, 1991) light levels in the greenhouse, shade area, and container yard averaged 569 ± 12, 962 ± 22, and 1949 ± 22 $\mu molm^{-2}s^{-1}$, respectively, in the 400 to 700 nm range (Grant 1200 series Squirrel meter/logger, Grant Instruments Ltd., Cambridge, England, with Terrestrial Type SA LI-190SA Quantum Sensor, Li-Cor, Inc., Lincoln, Neb.). On October, 25, 1991, expt. 2 was harvested as in expt. 1.

*Pot type and $Cu(OH)_2$ concentration, Expt. 3.* Seedlings of common baldcypress (*Taxodium distichum*) seedlings were chosen to test the effectiveness of $Cu(OH)_2$ treatments as root growth of this species is more difficult to control than that of several tree species (author's unpublished data). On March 11, 1991, stratified seeds of common baldcypress were sown in flats of milled pine bark and the flats placed in a greenhouse set at 75/65°F day/night covered with 55% shade cloth. On March 25, 1991, uniform seedlings with fully expanded cotyledons, but no expanded true leaves, were planted in 3 qt straight-walled round plastic containers (Zarn Inc., Reidsville, N.C.) or No. 1 pyramid pots (round containers with stepped-pyramid indentations, Imperial Plastics, Evansville, Ind.) each containing 1.9 l (2 qt) of media (equal volume of media in each container). Prior to planting, the straight-walled round containers were painted with Spin Out™ (Griffin Corp., Valdosta, Ga.) containing 25, 50, or 100 g $Cu(OH)_2$/l (0.83, 1.67, or 3.34 oz/qt) or left nontreated as a control. Stepped-pyramid pots were either painted with Spin Out™ containing 100 g $Cu(OH)_2$/l (3.34 oz/qt) or left nontreated. The experimental design was a randomized complete block with three blocks containing five plant replications of each container and $Cu(OH)_2$ treatment. Cultural conditions were as described in expt. 1, except the seedlings were not transplanted to larger containers following the acclimation phase. On August 22, 1991, the seedlings were harvested as described in expt. 1. Also, root ratings were assigned with 0 = no control of root deformation, 1 = slight to moderate control of root deformation (several to many escaped roots elongating ≥ 1 inch (2.5 cm) after contacting a container surface), 2 = good control of root deformation (few escaped roots), 3 = complete control of root deformation (no escaped roots). All three experiments were analyzed using analysis of variance and means declared significant by Fisher's least significant difference test (17).

## Results and Discussion

*Effects of seeding date, Expt. 1.* Eliminating the greenhouse phase entirely, i.e. planting directly outdoors (April 16, 1991), for seedlings of northern red oak significantly reduced all shoot growth indices except end of season height (Table 1). Lengthening the greenhouse phase from 0 days (4/16/91) to 43 days (3/4/91) significantly increased caliper, number of growth flushes, shoot dry weight and total plant dry weight, and survival (Table 1). However, initiating the greenhouse phase on February 11 did not significantly improve plant growth or survival over the March 4 initiation date (Table 1). Shorter day length and/or reduced solar irradiance at the earlier initiation dates may explain lack of an increase in growth responses to beginning the greenhouse phase on February 11 versus March 4. Many woody plant species, including northern red oak, have been reported to respond to extended photoperiods (9). More information is needed to determine the cost effectiveness of extended photoperiods and supplemental high intensity light on nursery crop production. Survival improved by 20% with a greenhouse phase compared to germinating directly outdoors (Ta-

Table 1. **Effects of initiation date of the greenhouse phase on performance of seedlings of northern red oak in the Ohio Production System (Expt. 1).[z]**

| Measured characteristic | Seeds sown in flats on | | | |
|---|---|---|---|---|
| | 2/11/91 | 3/4/91 | 3/25/91 | 4/16/91 |
| **At transplant:** | | | | |
| Height (cm) | 23.7 b[y] | 30.7 a | 16.1 c | 8.6 d |
| caliper (mm) | 3.2 a | 3.7 a | 2.1 b | 1.4 c |
| Number of flushes | 2.6 b | 2.9 a | 1.9 c | 1.0 d |
| **End of Season** | | | | |
| Height (cm) | 110.9 a | 114.3 a | 86.8 a | 88.3 a |
| Caliper (mm) | 11.0 ab | 12.0 a | 9.4 b | 9.7 b |
| Number of flushes | 5.3 a | 5.6 a | 5.7 a | 4.4 b |
| Survival (%) | 100.0 a | 93.3 ab | 93.3 ab | 73.3 b |
| Shoot dry wt. (g) | 52.04 ab | 65.94 a | 33.10 b | 37.74 b |
| Root dry wt. (g) | 49.64 a | 60.17 a | 42.20 a | 53.04 a |
| Total dry wt. (g) | 104.09 ab | 131.89 a | 66.19 b | 75.48 b |

[z]Values are means of 15 observations.

[y]Mean separation within rows by Fisher's least significant difference test, 5% level.

ble 1), perhaps due to the smaller transplant size of seedlings germinated directly in the shade area (Table 1).

*Acclimation duration, Expt. 2.* Acclimation under 55% shade did not significantly increase seedling growth compared to moving seedlings directly to the container yard (Table 2). In fact, root growth was significantly reduced by 14 days of acclimation (Table 2). However, survival was increased to 100% by all shade treatments (Table 2). Many of the seedlings moved directly to the container yard from the greenhouse exhibited a chlorotic or scalded appearance in some of their leaves a few days after being moved, apparently in response to increased irradiance. Leaves in new flushes initiated after moving appeared normal.

Data in this experiment suggest a need for a brief acclimation phase, perhaps 7 to 10 days for northern red oak under mid-south conditions, but no additional benefit from the longer acclimation phases was seen, as in earlier studies (19). More information is needed before recommendations for other species can be refined. Variations in responses due to seed source or provenance differences within a species should be investigated. Weather conditions during the days immediately following movement to the container yard may alter responses to the acclimation phase, so yearly variation and site differences are possible. Mid-day atmospheric temperatures (sampled at container height between noon and 3:00 pm in an adjacent study), on all but three dates, during the four week period beginning with the moving of seedlings receiving 21 days of acclimation averaged from 20.5 to 26.5°C (69 to 80°F). The means outside this range on the remaining three dates were 32.5, 31.8, and 18.3°C (90, 89 and 65°F), with the last occurring immediately after a rain event.

Table 2. **Effects of duration of acclimation under 55% shade on first year performance of seedlings of northern red oak in the Ohio Production System (Expt. 2).[z]**

| Measured characteristic | Days under 55% shade | | | |
|---|---|---|---|---|
| | 0 | 7 | 14 | 21 |
| Height (cm) | 118.5 a[y] | 127.2 a | 101.3 a | 111.3 a |
| Caliper | 12.5 a | 13.2 a | 11.0 a | 11.5 a |
| Number of flushes | 4.9 a | 5.5 a | 5.6 a | 5.3 a |
| Survival | 87.7 a | 100.0 b | 100.0 b | 100.0 b |
| Shoot dry wt. (g) | 81.78 a | 80.06 a | 51.79 a | 62.92 a |
| Root dry wt. (g) | 65.59 ab | 80.22 a | 44.30 b | 52.94 ab |
| Total dry wt. (g) | 147.37 a | 160.28 a | 96.08 a | 115.85 a |

[z]Values are means of 15 observations.

[y]Mean separation within rows by Fisher's least significant difference test, 5% level.

*Pot type and $Cu(OH)_2$ concentration, Expt. 3.* In common baldcypress root deformation decreased with increasing $Cu(OH)_2$ concentration in straight-walled round containers, with acceptable levels of control obtained at 100 g $Cu(OH)_2$/l (3.34 oz/qt) (Table 3, Fig. 1). Stepped-pyramid pots did reduce root circling, as previously reported (1, 20, 22), but did not stop the growth of roots contacting the container wall resulting in kinked and matted roots at container surfaces (Table 3, Fig. 1). Treating the stepped-pyramid pots with 100 g $Cu(OH)_2$/l (3.34 oz/qt) provided adequate root control (Table 3, Fig. 1) and was the only treatment to significantly increase height and shoot fresh weight over

Table 3. **Effects of growing seedlings of common baldcypress for 150 days in containers with $Cu(OH)_2$ applied to interior surfaces (Expt. 3).[z]**

| Container type | $Cu(OH)_2$ concentration | Root rating[y] | Height (cm) | Shoot fresh weight (g) |
|---|---|---|---|---|
| Straight-walled | 0 | 0.0 d[x] | 76.9 b | 52.16 b |
| Straight-walled | 25 | 1.0 c | 81.1 ab | 55.99 ab |
| Straight-walled | 50 | 1.9 b | 78.4 b | 59.92 ab |
| Straight-walled | 100 | 2.5 a | 82.7 ab | 58.80 ab |
| Stepped-pyramid | 0 | 1.1 c | 82.6 ab | 60.99 ab |
| Stepped-pyramid | 100 | 2.4 a | 86.5 a | 62.35 a |

[z]Values are means of 15 observations.

[y]Root ratings varied between 0 = no control of root deformation and 3 = complete control of root deformation.

[x]Mean separation within columns by Fisher's least significant difference test, 5% level.

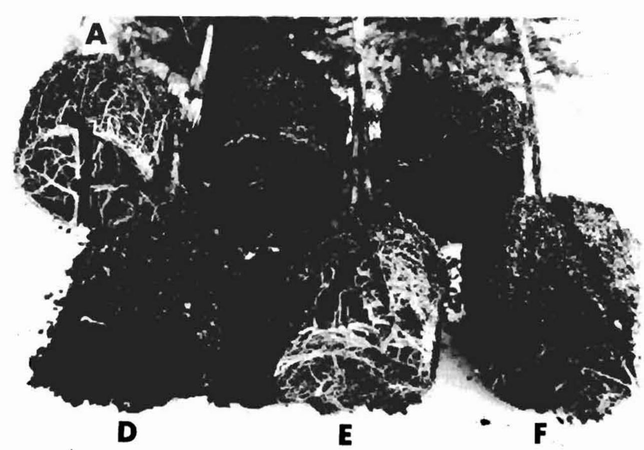


Fig. 1. **Seedlings of common baldcypress grown for 150 days in straight-walled round plastic containers (A–D) or stepped-pyramid pots (E, F) painted with 25 (B), 50 (C), or 100 (D, F) g $Cu(OH)_2$/liter of Spin Out™ carrier, or left nontreated (A, E) (Expt. 3).**

nontreated straight-walled round containers (Table 3). Neither the $Cu(OH)_2$ treatments or stepped-pyramid pots reduced growth (Table 3). Increased growth has been reported for some species grown in stepped-pyramid containers (20, 22) and copper treated containers (2, 3, 5, 11, 12).

In previous studies, root elongation was inhibition when roots contacted $CuCO_3$ treated container surfaces via a mild copper toxicity. Toxic copper levels were confined to within a few centimeters of the root tips (2, 3). Root tips of plants treated with $Cu(OH)_2$ either in a paint carrier (expts. 1 and 2) or in Spin Out™ exhibited a similar bulbous and slightly darker colored appearance, similar to $CuCO_3$ treated plants. Cupric hydroxide treated plants also appeared to have a more fibrous root system than those in nontreated containers. Similar increases in root system fibrosity have been reported for plants grown in $CuCO_3$ treated containers (2, 3, 4, 5). No foliar copper toxicity symptoms were observed in any seedlings treated with $Cu(OH)_2$.

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