The number of light periods and their duration governed caladium seed germination. Significant germination differences were found among the number of light periods, the durations, and the two-way interactions. Total absolute germination was greater with 20 than 10, five, or one light induction periods, while T_{50} and $T_{90} - T_{10}$ were shorter (Table 2). Increasing daily lighting from 0.5 to 12 hr progressively increased G and reduced T_{50} and $T_{90} - T_{10}$ (Table 2). Combining 20 lighting periods with 4- to 12-hr durations gave largest G and shortest T_{50} and $T_{90} - T_{10}$. Mayer and Poljakoff-Mayber (1979) classified seeds requiring light for germination into groups requiring brief periods and continuous light. Caladium seeds require light daily for 4 hr or longer for maximum G.

Caladium G declined if seeds remained in fruits after release from the spadix. Progressively lower G was found as the duration in the fruit after harvest was increased from 0 to 12 weeks (Fig. 2). Whether reduced G results from seeds in the fruit entering a secondary dormancy or is caused by lost viability is unknown. The rapid loss in seed viability reported by Hartman et al. (1972) and by commercial producers could be related to delayed cleaning of seeds after harvesting caladium fruit.

Caladium seeds were only moderately tolerant of desiccation. Total absolute germination was similar from 32% to 16% moisture contents, but 14% and 12% moisture levels caused statistically significant but small reductions (Fig. 3). Reducing seed moisture contents from 32% to 12% left T_{50} and $T_{90} - T_{10}$ unchanged (Fig. 3). Caladium seeds in this study were more tolerant of low moisture contents than reported by Hartman et al. (1972), and seed desiccation did not contribute to irregular germination, as found by Job et al. (1982).

Seeds were very cold-tolerant and G generally was similar among all temperature treatments (Fig. 4). Fifty percent relative germination and $T_{50} - T_{10}$ were unchanged by 7 days of storage of seeds with 18% moisture content at temperatures from 10 to -80°C (Fig. 4). Seeds were more cold-tolerant than caladium tubers or plants. Harbaugh (1983) reported 13C for 72 hr to cause 40% of caladium leaves to abscise, with 100% foliage loss below 10C. Marousky (1974) found tubers exposed to 5 to 15C for 10 days were inhibited from sprouting during a subsequent forcing period.

Seed storage for 6 months without reduction in G was possible at 15C and 22%, 33%, or 52% RH, but 5 or 25C storage at these relative humidities significantly reduced G (Table 3). Storage at 75% or 95% RH for periods exceeding 1 month caused losses in G, with smaller reductions at 15C than 5 or 25C. Total absolute germination progressively declined at all temperatures during 6 months of seed storage at 11% RH (Table 3). Seeds dehydrated at 105C after 6 months of storage at 11% RH contained 14% moisture, which the dehydration study showed reduced G (Fig. 3).

These studies provide information to ex-

plain caladium seed germination failure, irregular germination, and rapid loss of viability after seed drying and storage. Recommendations for seed germination, handling, and storage are necessary for the introduction of inbred lines as cultivars. Genetically uniform caladiums from direct seeding of cultivars from inbred lines would have potential as bedding plants. Harbaugh (1983) found bedding plant "plugs" with three to four leaves reached marketable size in 10-cm (0.8-liter) pots in 6 weeks after transplanting. Plants were uniform in size, disease-free, and had many small highly colored leaves.

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Growth and Transplantability of *Magnolia grandiflora* Following Root Pruning at Several Growth Stages

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Abstract. Roots of field-grown southern magnolia (*Magnolia grandiflora* L.) were pruned once during dormancy, following the first shoot growth flush or after the second growth flush or twice at the following times: during dormancy and following first growth flush, during dormancy and following second growth flush, following first and second growth flush before transplanting in the winter. By the end of the growing season, root pruning at all stages of growth reduced leaf number, tree height, trunk caliper, and total tree leaf area and weight compared with unpruned controls. Total root weight was less for trees pruned during dormancy or following the first growth flush. Root pruning increased the proportion of fine roots (0- to 5-mm-diameter class) to coarse roots (> 5- to 10-mm-diameter class). Shoot : root dry weight ratios at transplanting were not affected by root pruning. Root-pruned trees grew at a faster rate following transplanting than unpruned trees. Despite these initial differences, trees in all treatments were the same size 1 year after transplanting.

Root-pruning of trees in fruit, forest, and landscape tree nurseries is an old and varied practice (Hawley and Smith, 1954). It has been used as a horticultural tool to produce a sturdier tree; force development of a more

compact, fibrous root system; retard top growth; and increase transplant "survival and post-transplant growth (Mullin, 1966). The timing, frequency, severity, and location of root pruning are governed more by practical experience and tradition than by scientific studies. Only recently have the effects of root pruning on pre- and post-transplant tree growth been studied.

A recognized plant response to root pruning is reduction of shoot growth, an effect found in apple (*Malus domestica* Borkh.) (Maggs, 1965), orange [*Citrus sinensis* (L.) Osbeck] (Alexander and Maggs, 1971), and white spruce (*Picea glauca* Moench) (Mul-

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Table 1. Effect of time of root pruning on growth characteristics of southern magnolia trees (Jan. 1988).¹

Growth stage at pruning ²	No. leaves	Tree height (cm)	Trunk caliper (cm)	Total tree leaf area (cm ² /tree)	Total tree leaf wt (g/tree)
February	505 b	158 bc	3.2 bc	1935 bc	628 b
June	425 b	158 bc	3.4 b	1631 bc	558 bc
October	536 b	171 b	3.4 b	2389 ab	767 ab
June and October	356 b	148 c	2.9 c	1131 c	408 c
February and October	370 b	151 c	3.1 bc	1732 bc	514 bc
February and June	446 b	155 bc	3.1 bc	1824 bc	576 bc
Control	741 a	189 a	3.9 a	3067 a	946 a

¹Mean separation in columns by Duncan's multiple range test, $P = 0.05$. Means calculated on five trees.

²February = dormant, June = following first growth flush, October = following second growth flush, control = not pruned.

lin, 1966). Spring root pruning reduced shoot growth of 3-year-old apple 25% and of 4-year-old trees 40%. Early season root pruning reduced trunk expansion and shoot growth more than later-season pruning (Drinkard, 1914; Schupp and Ferree, 1987). The greatest reduction in white spruce height was caused by root pruning in mid-September, at the end of the growing season (Mullin, 1966). A single root pruning of 5-year-old blue spruce (*Picea pungens* Engelm.) reduced top growth so that 8-year-old unpruned plants were the same size as 10-year-old pruned plants (Watson and Sydnor, 1987). Reduced top growth may result from induced water stress, limited mineral absorption, or reduced hormone synthesis (Randolph and Wiest, 1981).

According to Kramer and Kozlowski (1979), each species has a characteristic root : shoot ratio. When the ratio is disturbed, plants respond by redirecting assimilates to replace the removed parts. Root pruning, while reducing shoot growth, stimulates root growth as the plant restores the pre-pruning root : shoot ratio (Richards and Rowe, 1977; Maggs, 1964). Roots regenerated in response to root pruning originate primarily at or just behind the cut (Carlson, 1974; Wilcox, 1955). However, a portion of regenerated roots can originate from at least 10 cm behind the cut, depending on species (Gilman and Yeager, 1988). This pattern likely accounts for the increase in fibrous roots within the root ball in response to root pruning reported for various species (Gilman and Yeager, 1987; Watson and Sydnor, 1987). Lower shoot : root ratios were induced by

root pruning (Tanaka et al., 1976; Bacon and Bachelard, 1978), and were associated with improved post-transplant tree seedling performance (Benson and Shepherd, 1977). However, others report no benefit to survival and post-transplant growth from pre-transplant root pruning seedling-sized forest species (Mullin, 1966; Duryea and Lavender, 1982).

Nursery operators growing trees in the field for the landscape trade have relied on guidelines generated for 1- to 3-year-old seedling-sized trees. The objectives of our two experiments were to measure the effects of root-pruning landscape-sized southern magnolia on tree morphology at transplanting and on post-transplant survival and growth.

Southern magnolia trees from #3 (1 l-liter) containers were planted in rows on 2.5 x 4 m spacing in Fall 1984 on a Chandler fine sand (hyperthermic, uncoated Typic Quartzpsamment) near Gainesville, Fla. Irrigation (3 liters/tree) was applied through microspray stakes generally daily, except during rainy periods and winter. Nitrogen was applied to a 1-m² circular area around each tree as NH₄NO₃ at 482 kg·ha⁻¹·year⁻¹ divided into five equal applications. Glyphosate was periodically applied to control weeds in a 1-m-wide strip centered on the tree line down each row.

Trees were root-pruned in 1987 at the following times: 1) mid-dormant season—February; 2) just following the first shoot growth flush, after a terminal bud formed—June; 3) following the second growth flush—October; 4) mid-dormancy and following first

flush—February and June; 5) mid-dormancy and following second growth flush—February and October; 6) following the first and second growth flush—June and October; and 7) non-root-pruned control. Immediately before initiating treatments in Feb. 1987, stem caliper 15 cm above the soil line and tree height to the base of the terminal bud on the central leader were recorded. Root pruning cuts were made with a sharpened hand-spade inserted to a 30-cm depth at 60° from the horizontal in a circle 38 cm in diameter centered around the trunk. Irrigation (8 liters/tree) was applied to all plants in the study for 7 days following root pruning. Treatments were arranged in a randomized complete block design with four-tree replications/treatment in each of eight blocks (rows), totaling 32 trees/treatment.

Root pruning, growth phase, and tree morphology (Expt. 1). Five trees (one from each of five randomly chosen blocks) from each of the seven treatments were dug on 20 Jan. 1988 with a 50-cm-diameter root ball according to established standards (American Association of Nurserymen, 1986). Soil was washed immediately from the root ball with a stream of water. Roots were separated into 3 diameter classes: 1) 0-2 mm, 2) > 2-5 mm, and 3) > 5-10 mm, and dried at 70C to constant weight.

All leaves were removed from each tree and counted. Leaf area was measured for each plant from a random sample of 20 current-year leaves with a LI-COR Model 3000 leaf area meter (LI-COR, Lincoln, Neb). Fifty current-year leaves were chosen from each tree and dried at 70C to constant weight. Total leaf dry weight and total leaf area for each tree were calculated from the above. A randomized complete block design analysis of variance (ANOVA) with five blocks and seven treatments was performed for each measured variable.

Root pruning and post-transplant growth (Expt. 2). Sixteen trees (two from each of the eight blocks) from the unpruned, and pruned February, June, and October treatments (total of 64 trees) were transplanted on 17 Feb. 1988 with a 50-cm-diameter root ball using a two-blade mechanical tree spade. Trees were lifted into the air ≈1 m to assure that all roots were severed, then lowered back into the original hole. A 10-cm-high soil ridge was constructed around each tree to retain water. Irrigation (3 liters/tree) was applied

Table 2. Effect of time of root pruning on root ball root weight and top : root ratios of southern magnolia (Jan. 1988).²

Growth stage at pruning ²	Root weight				0-5 mm roots : >5-10 mm roots dry wt ratio	Total tree leaf area : total root dry wt ratio	Total tree leaf weight : total root dry wt ratio
	0-2 mm diam (g)	> 2-5 mm diam (g)	> 5-10 mm diam (g)	Total (0-10mm) (g)			
February	31.3 b	37.2 b	49.8	118 b	1.37 bc	16.4 a	5.3 a
June	28.8 b	48.4 ab	54.9 b	132 b	1.41 bc	12.3 ab	4.2 ab
October	55.5 a	66.2 a	76.1 ab	198 a	1.60 ab	12.1 ab	3.8 ab
June and October	43.0 ab	59.0 ab	51.3 b	153 ab	1.99 a	7.9 b	2.7 b
February and October	43.9 ab	46.6 ab	69.3 b	160 ab	1.31 bc	9.4 ab	3.0 ab
February and June	41.6 ab	50.3 ab	57.7 b	150 ab	1.59 ab	12.9 ab	3.8 ab
Control	40.3 ab	63.5 a	105.0 a	208 a	0.99 c	14.7 ab	4.5 ab

¹Mean separation in columns by Duncan's multiple range test, $P = 0.05$. Means calculated on five trees.

²February = dormant, June = following first growth flush, October = following second growth flush, control = not pruned.

Table 3. Effect of time of root pruning on height and caliper of transplanted southern magnolia (Jan. 1988).^a

Growth stage at pruning ^b	Height at transplanting (cm)	Height 1 year later (cm)	Increase in height (%)	Caliper at transplanting (cm)	Caliper 1 year later (cm)	Increase in caliper (%)
February	155 b	177 a	14	3.1 b	3.9 a	26
June	160 b	187 a	17	3.2 b	4.0 a	25
October	165 b	198 a	20	3.4 b	4.4 a	29
Control	185 a	204 a	10	3.9 a	4.4 a	13

^aMean separation in columns by Duncan's multiple range test, $P = 0.05$. Means calculated on 16 trees.

^bFebruary = dormant, June = following first growth flush, October = following second growth flush, control = not pruned.

daily, except when it rained, during 1988 to assure adequate water supply to the transplants. Tree height and stem caliper were measured at transplanting and at the end of the post-transplant growing season in Dec. 1988. A randomized complete-block design ANOVA with eight blocks and four treatments was performed for each measured variable. Mean separation in both experiments was accomplished with Duncan's multiple range test at $P = 0.05$.

Experiment 1. Root pruning at all stages of growth had reduced leaf number, tree height, and trunk caliper by the end of the growing season compared with the control (Table 1). Reduction in shoot growth from late-season root prunings was not reported in most previous studies, which was reasonable because top growth ceases late in the season (Maggs, 1964, 1965). In this study, late-season pruning (October) resulted in smaller trees than unpruned controls because a warm fall apparently stimulated budbreak in the unpruned trees after the October pruning. Schupp and Ferree (1988) showed a similar response in unpruned apple that flushed following a mid-summer rainy period. None of the root-pruned trees in either study grew new shoots during this later growth period.

Plants pruned late in the season (October) were taller than the February-October and June-October double-pruned trees, but there were no other differences among pruning treatments (Table 1). Trees pruned once in June or October had greater trunk caliper than the June-October double-pruned trees, and there were no other caliper differences among root-pruned treatments. Findings from similar studies in seedling nurseries and in orchards have been contradictory: our results support those of some (Hobbs et al., 1987; Mullin, 1966), but not others (Schupp and Ferree, 1987; Drinkard, 1914). These contrasting effects may reflect cultural or tree size differences among studies or species-dependent responses to timing of root pruning.

Area per leaf (70 to 92 cm²/leaf) and leaf weight (1.1 to 1.4 g) were unaffected by root pruning; however, total tree leaf area and leaf weight for all root pruning times, except October, were significantly less than for the controls (Table 1).

Single root prunings during dormancy (February) and following the first growth flush (June) reduced the 0-to 10-mm-diameter class root dry weight within the root ball compared to the unpruned control (Table 2). Dry

weight (0- to 10-mm-diameter class) was not affected by pruning in October or in any double root-pruned treatment. Root weight in the 0- to 2-mm and >2- to 5-mm-diameter classes was not significantly affected by root pruning, except that the >2- to 5-mm root weight class was reduced by dormant pruning (February) compared with the control. Root weight in the >5- to 10-mm-diameter class was reduced by root pruning at all stages of growth, except after the second growth flush (October).

Root pruning following the second growth flush (October) increased the ratio of fine roots (0- to 5-mm-diameter class) to coarse roots (> 5- to 10-mm-diameter class) compared to the control (Table 2). This ratio ranged from 1.31 to 1.99 for root-pruned plants, compared with 0.99 for unpruned plants. Root pruning had no significant effect on the ratios total tree leaf area : total root dry weight and total tree leaf weight : total root dry weight (Table 2).

Experiment 2. All 64 transplanted trees survived and grew following transplanting. Root-pruned plants were shorter and had less caliper at transplanting than the unpruned controls (Table 3). However, height (14% to 20%) and stem caliper (25% to 29%) increased more for root-pruned than unpruned trees (10% and 13%, respectively) in the first year following transplanting (Table 3). As a result, there was no significant difference in height or stem caliper among pruned and unpruned transplanted trees one growing season following transplanting (Dec. 1988).

The 0- to 5-mm-diameter root class : > 5- to 10-mm root class dry weight ratio was significantly correlated with post-transplant height ($r = +0.90$) and stem caliper growth ($r = +0.99$). Post-transplant height and stem caliper growth were not significantly correlated with any other top or root measurements or top to root ratios. This result indicates that post-transplant tree growth may be related to the distribution of roots among diameter classes and that trees may benefit from treatments encouraging a high fine root : coarse root dry weight ratio.

Top growth of double-pruned plants in this study was not significantly less than trees in the single-pruned treatments (Table 1). In general, there was no difference in the top : root ratios (Table 2) between single and double pruning treatments. This finding agrees with a similar study by Hobbs et al. (1987), in which double-root-pruned conifer seedlings grew no differently than single-pruned

plants. Bacon and Bachelard (1978) and Benson and Shepherd (1977) showed that shoot : root ratio and shoot growth were both reduced as the number of root prunings increased during a growing season. In one study, increasing the number of root prunings enhanced post-transplant growth (Bacon and Bachelard, 1978), while, in another, growth was reduced by multiple pre-transplant root prunings up to 5 years after transplanting (Benson and Shepherd, 1977). There does not appear to be a clear advantage to multiple root prunings.

Despite enhanced growth rate following transplanting, tree height and stem caliper in all three transplanted root-pruning treatments were statistically similar to those in the unpruned controls one growing season after transplanting on this well-irrigated site. Root pruning before transplanting corresponded to better post-transplant growth, but did not produce trees that were larger 1 year later. These results do not support the often-discussed, sometimes implemented, practice of root pruning previously unpruned landscape-sized trees before transplanting. Future studies should address the effect of post-transplant water stress on growth following transplanting.

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Competitive Effects of Weeds on the Growth of Container-grown Plants

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Abstract. A 2-year study evaluated the effects of three weed species: eclipta [*Eclipta alba* (L.) Hasskarl], prostrate spurge (*Euphorbia supina* Raf.), and wood sorrel (*Oxalis stricta* L.) on growth of container-grown 'Gumpo White Sport' azalea (*Rhododendron eriocarpum*), *R. x 'Fashion'*, and *Berberis thunbergii* DC. var. *atropurpurea* 'Crimson Pigmy'. Competitiveness among weed species as ranked from greatest to least was eclipta, prostrate spurge, and wood sorrel. Greater populations of eclipta and prostrate spurge resulted in decreased shoot dry weight of 'Fashion' and 'Gumpo White Sport' azalea. Prostrate spurge had a similar effect on 'Crimson Pigmy' barberry in both small (3.8-liter) and large (15.2-liter) containers, while eclipta reduced shoot dry weight of barberry only in large containers. Wood sorrel had little effect on shoot dry weight of 'Fashion' and 'Gumpo White Sport' azalea.

Weed competition in agronomic crops is well-documented (Buchanan et al., 1980; Dawson, 1965; Hill and Santlemann, 1969; and Lawson, 1974). Limited research has been done in the area of weed competition in container-grown nursery stock (Fretz, 1972). Wilbourn and Rauch (1972) showed that coffeeweed suppressed growth of pyracantha, Andorra juniper, and Japanese holly, while cocklebur suppressed the two former species. Bittercress had no significant effect on any of the plants. Walker and Williams (1989) reported that *Potentilla fruticosa* L. 'Gold Drop' is very sensitive to weed interference and the grassy weed economic threshold density in these container-grown plants may be < 1. Fretz (1972) reported that one redroot, pigweed or large crabgrass plant

per container reduced the growth of Japanese holly grown in 2.4-liter nursery containers by 47% and 60%, respectively. His data reflect the detrimental effects of weeds in container-grown ornamental production. Limited information is available on weed suppression from troublesome weeds currently infesting container-grown ornamental nurseries. The objective of this study was to evaluate the interference of three pernicious weed species in container-grown ornamental in the southern United States.

On 5-8 Apr. 1985, uniform rooted cuttings of 'Fashion' azalea, 'Gumpo White Sport' azalea, and 'Crimson Pigmy' barberry were planted in 3.8-liter plastic containers (1-year-old plants, small containers) containing a 6 pine bark :1 sand medium (v/v) amended with (all in kg·m⁻³) 3.5 dolomitic limestone, 1.2 gypsum, 1.2 superphosphate, 0.6 AquaGro, 8.3 Osmocote "fast start" (18N-2.5P-10K), and 0.9 Micromax (micronutrients). Seeds of yellow wood sorrel, eclipta, and prostrate spurge were sown on 19 Apr. 1985 into flats containing 1 peat : 1 perlite (v/v) and were placed under a mist system. Weed seed had been collected the

previous season and stored at 4C during the winter. On 2-7 May 1985, weed seedlings were transplanted at the four to eight true-leaf stage (≈ 3.5 cm tall) into the containers with the woody plants. Each weed species was evaluated individually with each ornamental species. Twelve single-pot replicates per treatment were used in a complete randomized block design within each ornamental species. Treatments included weed densities of 0, 1, 3, 6, and 9 weeds per pot for each species. Plants were maintained in a 47% shadehouse (9.74 × 10³ μmol·s⁻¹·m⁻² at 1100 AM), with the exception of 'Crimson Pigmy' barberry, which were in full sun (19.62 × 10³ μmol·s⁻¹·m⁻² at 11:00 AM). Plants were maintained with normal nursery cultural practices. Uniform weed populations within treatments were maintained by hand-weeding. Weeds and ornamental were harvested after 90 days from one-half of the pots within each ornamental species and shoot dry weights were obtained. Growth indices (height + width + width/3) were taken on the remaining plants.

In 1986, the experiment was continued with experimental methods similar to those previously mentioned, with the following exceptions: 7 Apr. 1986, ornamental species were transplanted from the 3.8-liter containers into 15.2-liter containers (2-year-old plants, large containers). Weed seedlings were transplanted 3 weeks later and all plants were maintained in a 47% shadehouse.

Due to similar results with 'Gumpo White Sport' azalea and 'Fashion' azalea, only results from the latter are presented.

Shoot dry weights of 'Fashion' azalea grown in both small (3.8-liter) and large containers (15.2-liter) were significantly suppressed by weed densities of one through nine eclipta per container relative to the weed-free containers (Table 1). A 43% reduction in 'Fashion' azalea shoot growth with one eclipta per pot is similar to the growth reduction reported by Fretz (1972) for one redroot pigweed in Japanese holly. Growth indices of 'Fashion' azalea in small containers demonstrated similar results to those observed with shoot dry weight evaluations (Table 2); however, results for growth indices and shoot dry weights were dissimilar for large containers. In these, plants in high competition situations lacked vigor and were spindly in appearance.

In small containers, shoot dry weight of

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