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Root System Modification of Container Stock for Arid Land Plantings

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ABSTRACT

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Root morphology is important for successful seedling establishment in semiarid lands. Production systems that improve root morphology, such as container volume, container configuration, and mycorrhizal inoculation influence root system development and ensure establishment success. Mycorrhizal inoculation has been enhanced by chemical root pruners that inhibit lateral root growth and promote short root development. These factors, when used in concert, ensure successful seedling establishment and rapid growth. This paper attempts to integrate these concepts into a production system.

INTRODUCTION

Containerization has many advantages over bareroot production. Most obvious is the opportunity to accelerate seedling growth in a greenhouse environment optimizing photoperiod, temperature, plant nutrition and pest control (Tinus, 1974a; Hanover et al., 1976). Containerized seedlings suffer little transplant shock because root disturbance is minimized (Kinghorn, 1972). In temperate climates, containerization can extend the planting season beyond bareroot nursery seedling availability. This is particularly important in arid regions, because containerized seedlings can be planted when soil moisture is optimum, rather than when bareroot seedlings are available.

Containerization offers unlimited opportunities for controlling seedling growth, form, hardiness and physiological condition. It follows that seedlings can be tailored to specifications that assure transplant success.

This paper examines practices and relationships potentially useful in modifying roots to maximize establishment.

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ROOTING VOLUME

Seedling size is directly related to container volume (Endean and Carlson, 1975; Carlson and Endean, 1976; Tinus and McDonald, 1979). An increase in container volume from 10 cm^3 to 131 cm^3 increased total dry weight and shoot length of *Picea glauca* (Carlson and Endean, 1976). Root dry weight, shoot dry weight and shoot length of 20-week-old *Pinus contorta* seedlings increased significantly as rooting volume was increased from 10 cm^3 to 524 cm^3. Seedlings grown in the largest container weighed 10 times more than those grown in the smallest container. Rooting volume did not become limiting until 14 weeks in the largest container. However, the smallest container (10 cm^3) was limiting by 4 weeks, and the 33 cm^3 container limited growth after 8 weeks.

A.E. Romero (unpubl. results) grew *Pinus caribaea* in various sized containers and found an increase in total seedling biomass with an increase in rooting volume (P=0.01). Shoot and root biomass were approximately 3.5 times higher for 20-week-old seedlings grown in the 740-cm^3 containers than for those grown in 165-cm^3 containers (Fig. 1).

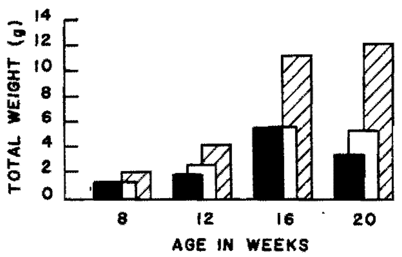

Fig. 1. Effect of container volume on total fresh biomass of *P. caribaea* over time. Solid bar = 165 cm^3, open bar = 350 cm^3, hatch bar = 740 cm^3 container (A.E. Romero, unpubl. results).

With rooting volume held constant, root growth is more responsive to container diameter than container length (Boudoux, 1972; Hocking and Mitchell, 1975). Tinus (1974b) showed *Pinus ponderosa* seedling size is strongly dependent upon container surface area. Hocking and Mitchell (1975) showed better plant growth in containers of greater diameter than in containers with similar or slightly larger volumes, but smaller diameters. Boudoux (1972) investigating container dimension, proposed a container 4 cm × 7 cm for optimum production of *Picea mariana* (Mill.) B.S.P. Recommendations were based on rooting intensity as well as shoot quality.

Container volume determines greenhouse growth and influences transplant survival. *Pinus taeda* and *P. palustris* seedlings grown in 131-cm^3 containers had survival rates 10% higher than those grown in 66-cm^3 containers, and 19% higher than those grown in 74-cm^3 containers (Amidon et al., 1981).

CHEMICAL ROOT PRUNING

The advent of chemical root pruners to modify containerized root systems has partially eliminated mechanical pruning before planting (Bell, 1978; McDonald et al., 1984a). Cupric carbonate ($CuCO_3$), silver nitrate, cupric sulfate, cobalt chloride and sodium borate effectively prune roots of container-grown plants (Pellett et al., 1980; McDonald et al., 1984a).

Chemical pruners inhibit lateral root growth (Burdett, 1978; McDonald et al., 1984a, b), thereby preventing root spiraling and growth down the container wall. This pruning promotes the development of higher order lateral roots, which in turn are pruned when they contact the chemical barrier. The absence of root spiraling or other deformities results in greater resistance to windthrow after transplanting (McDonald et al., 1984b). Lateral roots of *P. contorta* seedlings grown in $CuCO_3$-treated containers elongated or developed more rapidly following transplanting (Burdett, 1978).

Positive effects, such as increased caliper, weight and height, and reduced number of deflected roots have been achieved through the use of $CuCO_3$ (Burdett, 1978; McDonald et al., 1984a, 1984b). Seedlings of *P. ponderosa* and *P. contorta* generally had greater height, diameter and dry weight when subjected to $CuCO_3$ (Table 1). Seedlings were, on the average, 1.2 times taller and had 1.1 times larger diameters than untreated trees (McDonald et al., 1984a).

Similar results were found with greenhouse-produced *P. caribaea* seedlings grown in a factorial experiment. Treatments included three container volumes (165 cm^3, 350 cm^3 and 740 cm^3) and three $CuCO_3$ levels (control, 25 and 100 $g\,l^{-1}$ dissolved in exterior acrylic latex paint; A.E. Romero, un-

TABLE 1

Root/shoot (R/S) ratio of seven *Pinus* species as affected by $CuCO_3$

Species	Shoot weight		Root weight		R/S	
	Control	$CuCO_3$	Control	$CuCO_3$	Control	$CuCO_3$
P. ponderosa[2]	0.8a[1]	1.4b	0.5a	0.5a	0.60	0.36
P. contorta[2]	0.7a	1.1b	0.6a	0.6a	0.86	0.55
P. taeda[3]	4.4a	4.9a	1.6a	1.6a	0.36	0.33
P. echinata[3]	4.4a	5.8b	2.1a	2.2a	0.48	0.38
P. palustris[3]	9.1a	9.7a	2.3a	2.6a	0.25	0.27
P. strobus[3]	2.2a	2.3a	1.9a	2.0a	0.86	0.87
P. caribaea[4]	5.9a	8.6b	1.5a	1.9a	0.25	0.22

[1] Means within a row and variable followed by the same letter are not significantly different (P=0.5).
[2] McDonald et al., 1984a.
[3] Ruehle, 1985.
[4] A.E. Romero, unpubl. results.

publ. results). Control treatments consisted of no paint and no $CuCO_3$. Stunted lateral roots increased significantly from 25% to nearly 100% as $CuCO_3$ levels changed from 25 to 100 g l^{-1}. Primary lateral roots of control seedlings were as long as the container. In contrast, the primary lateral roots in the $CuCO_3$ treatments were usually no longer than the container width (Fig. 2). Lateral root number increased from 24 to 35 as container volume increased. Lateral root number increased from 28 for control seedlings to 32 for seedlings grown in containers treated with 25 g l^{-1} $CuCO_3$ (P=0.01).

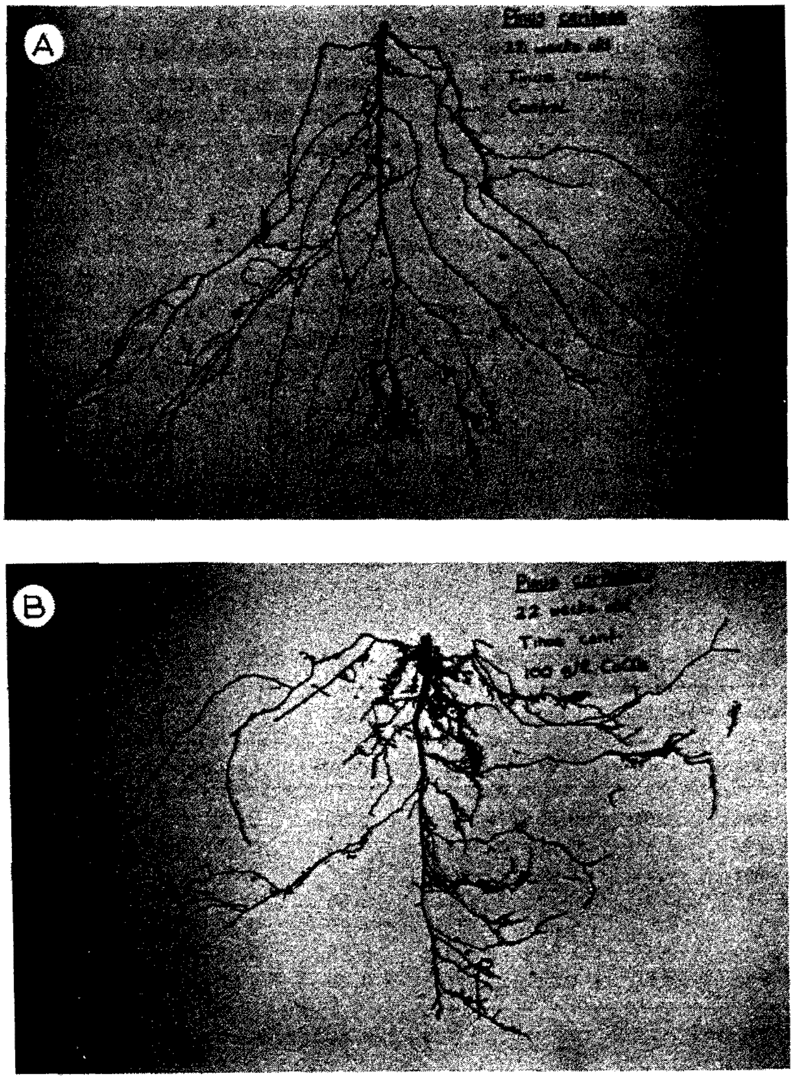

Fig. 2. Root morphology of *P. caribaea* at 22 weeks in the 350 cm^3 container without $CuCO_3$ (A) and with 100 g l^{-1} $CuCO_3$ (B) (A.E. Romero, unpubl. results).

Root collar diameter was significantly increased (P=0.01) with $CuCO_3$ treatments. Both levels (25 and 100 g l^{-1} $CuCO_3$) produced seedlings with significantly greater root collar diameters (3.17 and 2.94 mm, respectively) than those in the control treatment (2.45 mm).

Shoot fresh weight of seedlings grown in the largest container was twice that of seedlings grown in the smaller containers (P=0.01). Cupric carbonate significantly increased shoot weight over the control treatment (P=0.01). Among treatment combinations, shoot weight was greatest for the largest container with 25 g l^{-1} $CuCO_3$ (Fig. 3).

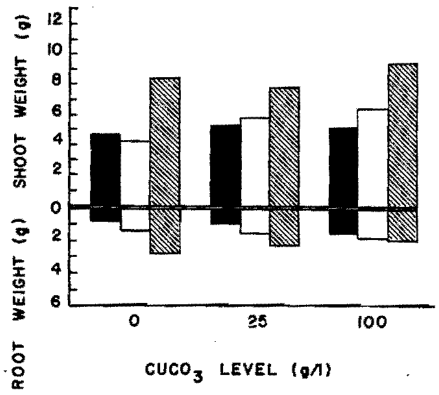

Fig. 3. Interaction between container volume and $CuCO_3$ level on *P. caribaea* biomass after 16 weeks of growth. Solid bar = 165 cm^3, open bar = 350 cm^3, hatch bar = 740 cm^3 container (A.E. Romero, unpubl. results).

Seedlings in the two largest containers had significantly greater root weight than those in the smallest container size (P=0.01). However, $CuCO_3$ did not affect root weight when compared to that of control seedlings, regardless of container size (Fig. 3).

Root/shoot (R/S) ratio on a w/w basis increased as container volume increased; however, $CuCO_3$ decreased the R/S ratio. The decrease in R/S ratio by $CuCO_3$ reflects a change in root morphology. Most long and heavy, primary lateral roots were changed to shorter and lighter primary roots with more development of secondary and higher order lateral roots (Fig. 2).

MYCORRHIZAL FORMATION

Ectomycorrhizal development is essential for successful tree establishment on adverse arid sites (Marx, 1980; Ruehle and Brendemuehl, 1981). Inoculation of container-grown pines before planting may further enhance seedling establishment (Ruehle, 1981). Success of inoculated, container-grown seedlings is attributed to maintenance of a relatively undisturbed ectomycorrhizal root system that can function in nutrient and water absorption quickly after transplanting (Ruehle, 1982).

Mycorrhizas ameliorate the effects of nutrient deficiencies and water stress (Reid, 1979; Brownlee et al., 1983). However, the benefit of mycorrhizas during periods of moisture stress is not completely understood. Mycorrhizas enhance nutrient uptake, resulting in healthier plants that are less susceptible to moisture stress (Reid, 1979). In addition, mycorrhizal plants may be able to avoid water stress through increased water uptake. Mycorrhizal hyphae may provide a water pathway with less resistance than that encountered in the soil. This pathway of less resistance may become important as soils dry (Newman, 1974).

Ectomycorrhizal inoculation of container-grown seedlings can be achieved by several methods. Soil duff or humus collected from established pine plantations is the most widely used inoculum, especially in developing countries. Inoculum is mixed into the growing medium at an inoculum:medium rate of 1:10 (v/v). Sporophores or spores of various fungi have been used as inoculum as well. Sporophores are dried and chopped before mixing into the growing medium. Spores of *Pisolithus tinctorius*, mixed with a moistened carrier such as vermiculite, have been used successfully (Marx et al., 1982). Vegetative inoculum of ectomycorrhizal fungi is generally most successful, but most expensive (Marx and Kenney, 1982).

Plant response to inoculation is a function of short roots available for infection. McDonald et al. (1984a) attempted to increase the number of short roots of containerized *P. ponderosa* and *P. contorta* by using a chemical root pruner ($CuCO_3$). Cupric carbonate increased the number of short roots for *P. contorta* and percent mycorrhizal infection for both species. Cupric carbonate plus inoculation increased short root number on *P. ponderosa*. Conversely, inoculation alone increased the number of short roots on *P. contorta*, but not *P. ponderosa*. Root/shoot ratios for inoculated and root-pruned *P. ponderosa* ranged from 0.36—0.47, and from 0.54—0.64 for *P. contorta*. Mycorrhizal inoculation or $CuCO_3$ lowered R/S ratios for both species when compared to control seedlings (Fig. 4).

Field performance of these seedlings was not evaluated, but plant vigor

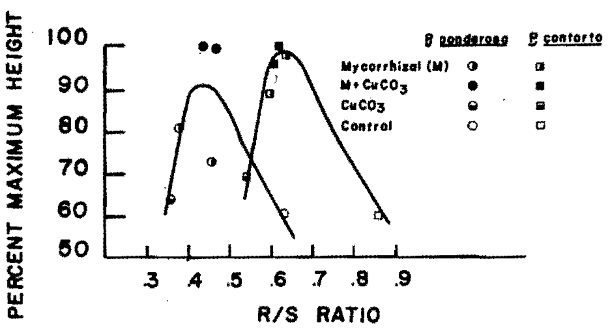

Fig. 4. Effect of root/shoot ratio on seedling height expressed as a percent of maximum (McDonald et al., 1984a).

was noted. Logically, increased vigor attributed to mycorrhizal infection should translate into increased survival in the field (McDonald et al., 1984a).

ROOT/SHOOT RATIO

The balance between roots and shoots (R/S ratio) is assumed to be important to the successful establishment of conifer transplants (Lopushinsky and Beebe, 1976; Nambiar, 1980) especially for semiarid and arid land plantings (South et al., 1985). However, not all researchers agree with this hypothesis (Sutton, 1980). Lopushinsky and Beebe (1976) and Hermann (1964) have shown that visual root quality is a stronger predictor of performance than quantitative measurements. In work with *Pseudotsuga menziesii* and *P. ponderosa* seedlings, Lopushinsky and Beebe (1976) found survival of seedlings with large root systems was increased approximately 24 and 10%, respectively, when compared to that of seedlings with small root systems. Similarly, shoot growth of seedlings with large root systems was 2—4 times greater than for seedlings with small root systems.

Containerized seedlings should suffer minimal root disturbance at transplanting, even with the existence of an imbalance between shoot and roots. It has been reported that containerized seedlings with lower R/S ratios performed better than those with larger ratios (McGilvray and Barnett, 1981). Additionally, they reported that growth of containerized loblolly pine seedlings was negatively correlated with R/S at time of outplanting. However, Mexal and Dougherty (1983) reported the opposite relationship for bareroot loblolly pine seedlings (Fig. 5). McGilvray and Barnett (1981) stated that performance probably was related to initial height, more than R/S ratio. That is, large seedlings had low R/S ratios and greater growth. In view of the data presented by Mexal and Dougherty (1983), this is probably the case. Wakeley (1969) noted that growth potential increases with increasing seedling size.

Considering the above-mentioned factors, R/S ratios of containerized

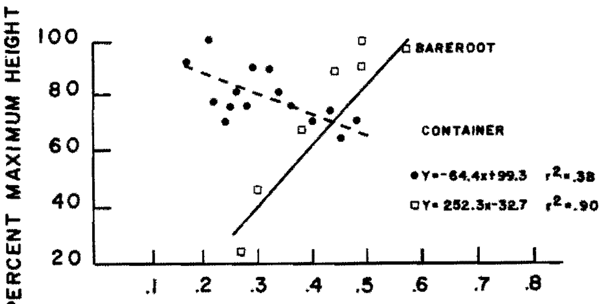

Fig. 5. Effect of root/shoot ratio on height growth of *P. taeda* expressed as a percent of maximum (McGilvray and Barnett, 1981; Mexal and Dougherty, 1983).

seedlings should not be ignored. Cultural practices should encourage rapid, yet balanced, plant development. Factors that influence R/S ratio include seedling age (Ledig et al., 1970), growing density (Harms and Langdon, 1977), media (Matthews, 1972), fertility (Hocking, 1972), mycorrhiza (Fortin, 1972), rooting volume (Endean and Carlson, 1975) and chemical root pruning (Burdett, 1978; Sutton, 1980; McDonald et al., 1984b). Most nurserymen try to increase R/S ratio. In some cases, however, a higher ratio may indicate poor shoot growth caused by environmental stress. This undesirably high ratio can occur with high temperature stress (J.T. Fisher and J. Chan, unpubl. results) and cultural practices (Tinus and McDonald, 1979).

A model for optimum R/S ratio can be constructed from various data sources (Fig. 6). Root/shoot ratios within the range of 0.45 to 0.65 should result in optimum survival and growth (Mexal and Dougherty, 1983). Ratios below 0.40 would result in increased transplant shock, while ratios above 0.65 may indicate a physiological imbalance that could carry over to field planting. Typically, transplants with small shoots compete poorly with surrounding vegetation after outplanting. It appears many pines fit into the optimal range described above. However, R/S ratio is a function of species, and varies accordingly (Fig. 4). This does not negate the validity of the model. However, it requires some baseline information before applying the model.

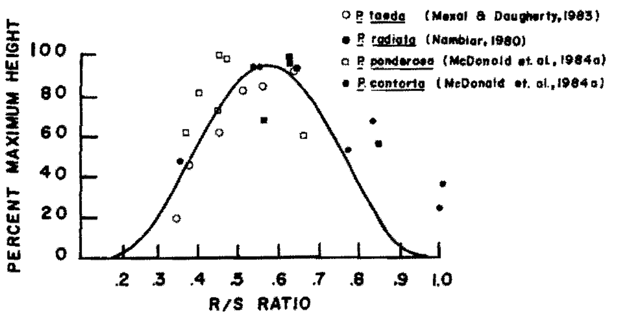

Fig. 6. Proposed optimum root/shoot ratio for conifer seedlings.

SUMMARY

Root/shoot ratio is a more accurate indicator of seedling quality than height alone. As such, it should be included as a parameter to predict seedling field performance. Cultural practices can modify root morphology, and thus R/S of container-grown conifer seedlings. Root/shoot ratio can be modified by rooting volume and chemical root pruners ($CuCO_3$). Incorporation of mycorrhizal inoculum into growing media, in conjunction with a chemical root pruner, may increase the number of short roots while lowering R/S ratio.

Many researchers have ignored the importance of R/S ratio as a criterion

for evaluation of seedling (transplant) field performance. Root/shoot ratios may be species-specific, and the optimal range may vary. Root/shoot ratios between 0.45—0.65 appear to produce seedlings that achieve balanced root and shoot growth, providing maximal potential for field survival.

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