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An Assessment of Ponderosa Pine Seedlings Grown in Copper-Coated Polybags

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Ponderosa pine—Pinus ponderosa *Dougl. ex Laws.—seedlings grown in copper-treated polybags had heights, root collar diameters, and biomass values that were similar to those of seedlings grown without copper. However, untreated seedlings were characterized b1 an abundance of spiraling roots concentrated in the bottom of the polybag. These spiraled roots were matted, often very thick, usually devoid of secondary roots, sometimes kinked, and probably accounted for the 33% greater root volume, 32% greater root mass, and significantly lower shoot–root ratio than that of copper-treated seedlings. Copper-treated seedlings produced a much finer, fibrous root system that was well-distributed throughout the polybag.* Tree Planters' Notes 48(3/4):60-64; 1997.

In developing countries, nursery production of stock in polybags is a common practice. Polybags are usually filled with native soil and placed on the ground during production of the nursery crop (Mexal 1996). Often, seedlings grow roots out the bottom of polybags and into soil, making subsequent harvest more difficult for the laborer. In addition, the resulting cutting or tearing of roots to free nursery stock from soil may unsatisfactorily influence seedling viability. Further, root spiraling, or coiling, is common in polybags and often results in root girdling after outplanting (Sharma 1987; Mexal 1996). After outplanting, seedlings with coiled root systems often grow poorly and die (Sharma 1987).

Copper compounds on interior surfaces of containers have effectively reduced root coverage on exteriors of root plugs at the container wall interface, promoted fine root development, improved root development in the upper portions of containers, decreased root circling, kinking, and production of matted roots at the container bottom, and often increased the number of white, unsuberized root tips in temperate conifers (Burdett 1978; McDonald and others 1981; Saul 1968; Wenny and Woollen 1989), temperate hardwoods (Arnold 1996; Arnold and Struve 1989, 1993; Arnold and Young 1991), and subtropical hardwoods (Schuch and Pittenger 1996; Sparks 1996; Svenson and others 1995). Often, copper-induced changes in root system morphology were associated with improved mechanical stability (Burdett 1978) and increased survival (Struve 1993) of seedlings after outplanting.

We grew ponderosa *pine—Pinus ponderosa* Laws. var. *ponderosa—in* copper-coated polybags to assess resulting seedling form.

Materials and Methods

One-liter polybags were provided by Griffin Corporation (Valdosta, Georgia). Each black bag was constructed of 2-mil, high-density polyethylene coated on the interior with Spin Out® Root Growth Regulator, a coating based on copper hydroxide—$Cu(OH)_2$. Each bag had eight 0.6-cm (0.25-in) diameter drainage holes, 4 side holes about 0.6 cm (0.25 in) up from the bottom, and 4 bottom holes. The treatment consisted of using the polybags as intended, with the copper coating on the inside of the polybag. For controls, we turned the bags inside-out so that the copper coating was on the outside of the polybag. We used 20 polybags for control and 20 polybags for the treatment. In March, all polybags were filled with 1:1 peat–vermiculite medium (Pacific Soil, Hubbard, Oregon); 2 to 3 seeds were sown; and the seeds covered with a 1-cm-deep (0.4-in) layer of silica grit.

Filled polybags were randomly placed inside 1 of 2 wooden frames with 32 x 56 cm (12.5 x 22 in) inside dimensions and wire mesh bottoms-0.6-cm (0.25-in) openings—that were placed on a bench within a greenhouse used to produce an operational crop of ponderosa pine seedlings grown in Copperblock 160/90's, with volumes of 90 ml (5 in^3). The polybags had a surface area of about 64 cm^2 (10 in^2), were about 15 cm (6 in) deep, and had a growing density of about 135 bags/m^2 (12.5/ft^2). After germination was complete, we thinned out extra seedlings, leaving 1 seedling/polybag.

We "fertigated" (fertilizer in irrigation water) the seedlings about twice each week for 35 weeks using various formulations of fertilizer that provided seedlings with about 385 mg of N total (120 mg before bud initiation at week 12). Photoperiod was extended with intermittent all-night lighting using 300-watt incandescent bulbs for the first 12 weeks of the growing cycle.

In December, we removed seedlings from the polybags and gently washed the roots. Heights were measured from ground line to the tip of the terminal bud. Root collar diameter (RCD) was measured at ground line. We used Burdett's (1979) water displacement technique to determine root volume. Shoots and roots were separated, dried for 72 hours at 60 °C (140 °F), and weighed to determine seedling biomass. Height, RCD, root volume, and biomass data were analyzed with an analysis of variance.

Results and Discussion

Seedling height and RCD were unaffected by treatment (figure 1). Although dry root weight was reduced on treated seedlings, dry shoot weight was increased by the treatment, resulting in similar seedling biomass regardless of treatment (table 1). The copper treatment also decreased root volumes (table 1). Shoot–root ratios were significantly higher when seedlings grew in contact with copper (table 1). At our nursery, several studies have shown ponderosa pine height, RCD, and biomass were unaffected by copper-coated containers (Wang 1990; Wenny 1988; Wenny and Woollen 1989).

Roots of seedlings exposed to the copper coating did not penetrate bottom drainage holes. Seedlings grown without exposure to copper readily grew roots through bottom drainage holes and subsequent growth made removing control seedlings from polybags more difficult than removing treated seedlings. Roots were obvious on the surface of root plugs in control polybags, but absent when roots grew in contact with copper (figure 2). Similar results were found on temperate and subtropical hardwood species (Arnold and Struve 1993; Schuch and Pittenger 1996; Svenson and others 1995). Seedlings with copper-pruned roots generally had more uniform root distribution throughout the medium (figure 3), and lacked dense accumulation of spiraled roots in the bottom of polybags, as was the usual growth of untreated seedlings (figure 4). Spiraled roots in the bottom of untreated polybags were usually thick-2 to 6 mm diameter (1/16 to 1/4 in).

The reduction in root mass of treated seedlings in our study may have been attributable to an absence of roots at the interface between polybag and medium, as was concluded by Furuta and others (1972) for *Eucalyptus viminalis* Labill., and/or by the reduction of thick spiraled roots at the bottom of polybags. However, a change in biomass induced by Spin Out, especially of root mass, may be species specific, as *Pinus montezumae* Lamb. and *Pinus pseudostrobus* Lindl. both showed significant increases in root weight, stem weight, and

Figure 1— *Ponderosa pine seedlings growing in polybags with Spin Out copper coating in contact with the root system (left), or with copper coating facing away from roots (right).*

Table 1—*Means (± standard errors) for morphological characteristics of ponderosa pine seedlings grown in polybags with Spin Out copper coating inside the bag (available to roots; copper) or outside the bag (unavailable to roots; control)*

Treatment	Height (cm)	RCD (mm)	Root volume (ml)	Dry weight (g)		Biomass (g)	Shoot–root ratio
				Shoot	Root		
Control	21.1 ± 0.7	5.77 ± 0.30	31.4 ± 2.9	6.2 ± 0.4	6.6 ± 0.6	12.8 ± 1.0	0.94 ± 0.06
Copper	22.2 ± 0.8	6.38 ± 0.21	23.5 ± 2.8	7.5 ± 0.6	5.0 ± 0.5	12.5 ± 1.0	1.50 ± 0.11
P value	0.38	0.14	0.05	0.05	0.07	0.90	0.00

Note: RCD = root collar diameter; n = 20 seedlings/treatment; *P* values from an analysis of variance for each seedling characteristic are provided.

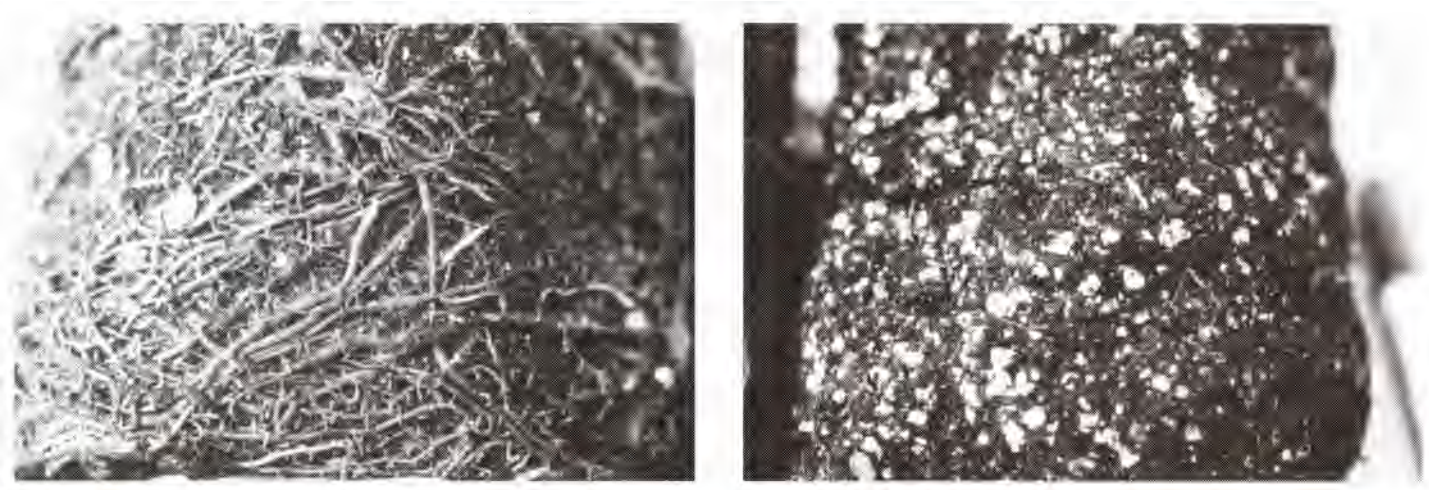

Figure 2—*Ponderosa* pine roots growing on the surface of the root plug in control polybags (left) were absent on root plugs grown in Spin Out—treated polybags (right).

Figure 3—*Ponderosa* pine roots were uniformly distributed, fibrous, and lacked any spiraling when grown in contact with Spin Out (left). Control roots were poorly distributed and generally concentrated at the bottom of the polybag (right).

Figure *4-Ponderosa pine roots spiraling in the bottom of a control polybag.*

height when grown in copper-coated polybags (R. Phillips, see Crawford (1997)). Our observations that copper compounds applied to interior walls of containers promoted a more fibrous root system and more uniform root distribution and that an absence of copper promoted an accumulation of roots at container bottoms have also been reported by others (Arnold and Struve 1989; Schuch and Pittenger 1996).

We observed kinking (particularly in bottom folds), circling, and matting of roots of ponderosa pine at the base of untreated polybags (figure 4). Such root deformities were absent when those seedlings were exposed to copper, as was the case for coarse-rooted temperate hardwood species (Arnold and Struve 1993).

Conclusion

Ponderosa pine seedlings grew well in copper-coated polybags. Our assessment indicates that copper-coated polybags offer an opportunity to improve seedling viability. Root systems of seedlings grown in Spin Out-treated polybags were more fibrous and better distributed throughout the polybag; lacked kinking, spiraling, and other root deformities; and failed to grow out of the drainage holes in the bag.

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