From Lifting to Planting: Root Dip Treatments Affect Survival of Loblolly Pine (*Pinus taeda*)

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Abstract: Hydrogels and clay slurries are the materials most commonly applied to roots of pines in the southern United States. Most nursery managers believe such applications offer a form of "insurance" against excessive exposure during planting. The objective of this study was to examine the ability of root dip treatments to: (1) support fungal growth; and (2) protect roots from injury during exposure for 1, 2, or 4 hours. Four treatments were tested: kaolin clay, two grades of polyacrylamide hydrogels, and a cornstarch-based hydrogel. In laboratory tests, kaolin clay was the only treatment that inhibited the growth of three soilborne fungi (*Pythium* spp., *Fusarium* spp., *Rhizoctonia* spp.). When applied to roots, however, the clay slurry did not effectively prevent permanent root damage during exposure of more than 1 hour. Gel treatment provided some protection when roots were exposed to air for 2 or 4 hours. Current use of root gels is still good "insurance" against poor handling of the seedlings after they leave the nursery.

Keywords: hydrogel, clay, polyacrylamide, cornstarch, seedlings, dessication

Introduction

During the 19th century, roots were often kept moist at the nursery during counting and sorting to improve the chance of seedling survival (Hodges 1883). The practice of "puddling" has been used for more than a century; this involved dipping roots into a mixture of clay and water (the consistency of paint) either at the nursery (Goff 1897) or at the planting site (Hodges 1883; Pinchot 1907).

Several materials have been added to roots before packing seedlings. Sphagnum moss was preferred during the 19th and first half of the 20th century; as moss became harder to acquire, alternative treatments were investigated (Davey 1964; Fisher 1974). Slocum and Maki (1956, 1959) reported benefits of treating roots with clay when seedlings were exposed to an hour or two of drying. In 1960, Weyerhaeuser asked that their seedlings be treated with clay at the nursery (Bland 1964), and this practice was quickly adopted by the North Carolina Forest Service Nursery (Goldsboro). Soon after, other researchers began to report on tests using clay slurries (Dierauf and Marler 1967, 1971), and the practice spread.

During the 1980s, nursery managers began operational use of polyacrylamide gels. In some cases, use of gels increased survival compared with roots treated with a clay dip (Venator and Brissette 1983). Polyacrylamide gels are likely preferred over clay because they usually cost less, require less storage space, and are less messy (Bland 1964). A nursery that produces 25 million seedlings may only need a pallet of product, while clay might require the delivery of 23 tonnes (25 tons) (Pryor 1988). Most managers agree with Alm and Stanton (1993), who believe that polymer gels "offer a form of insurance against survival loss resulting from seedlings being exposed to drying during the planting process."

Despite this "insurance" aspect, no economic studies support the use of either gels or clays in the production of loblolly pine (*Pinus taeda* L.). Therefore, these trials were initiated to examine the effects of three root dip treatments on their ability to: (1) support fungal growth; and (2) protect roots from injury during exposure.

Materials and Methods

Study I: Fungal Growth

This study was designed to address concerns that root treatments may support the growth of soil-borne fungi. In some cases this might be detrimental to seedling survival. Treatments included: kaolin clay; two grades of polyacrylamide hydrogels (PAM gels "A" and "B"[Soil Moist®, JRM Chemicals, Cleveland, OH]); and a cornstarch-based hydrogel, CSB gel (Zeba®, Absorbent Technologies, Beaverton, OR). Samples of the kaolin clay and PAM gels were obtained from the nursery, while the CSB gel was provided by the manufacturer. A comparison of particle size for the root dip treatments is provided in figure 1. The rate of material used for each treatment is provided in table 1 and is comparable to nursery use. Companies offer different gel formulations based on particle size (Venator and Brissette 1983). Particle size can affect physical properties such as water-holding capacity and ability to go into suspension. The fungi used were pathogenic isolates of *Pythium* spp., *Fusarium* spp., and *Rhizoctonia* spp.

Water agar is a basic medium made with distilled water that supports minimal fungal growth. A 3-mm (0.12-in) plug of the fungus was placed on the center of a water-agar Petri plate (85 mm diameter [3.3-in]) that had been augmented with either clay, PAM gel "A" or "B," or CSB gel as provided in table 1. Control plates were water agar without any gel or clay amendments. Each treatment was replicated 12 times. The radial growth of each fungus was recorded daily. Differences in fungal growth on the various amended media demonstrate the ability of the gel or clay to support fungal growth relative to that of non-amended media.

Study II: Seedling Survival Following Exposure

Each treatment was mixed in a separate bucket with 7.5 L (2 gal) of tap water at the rates indicated in table 1. The clay had to be stirred continuously during treatment because it doesn't dissolve. Both PAM gels went into suspension with less than 1 minute of stirring; gel "A" went into suspension faster than gel "B." The CSB gel, however, was very difficult to mix. When it was placed in the water, it immediately clumped and required considerable stirring and agitation to break up the clumps. Once this was done, it was similar in appearance to the PAM gels.

The amount of gel sprayed operationally on roots of machine-lifted loblolly pine seedlings is approximately 3.6 g (0.13 oz) per seedling. Dipping roots of 20 seedlings 5 times removed about 72 g (2.5 oz) of gel solution, or about 3.6 g (0.13 oz) of gel per seedling. All root gel or clay treatments were hand-dipped five times before exposure.

Seedlings were treated with one of four root treatments (table 1), while the roots of control seedlings were dipped into water. The seedlings (20 per experimental unit) were laid on an expanded metal bench in the greenhouse for 0, 1, 2, or 4

Table 1. Rate of material used expressed as total mass of material per liter (L) of water (1L = 0.26 gal).

	Clay	PAM gel "A"	PAM gel "B"	CSB gel
Mass (g)	300	2.2	3.3	1.8
Mass (oz)	10.582	0.077	0.116	0.063

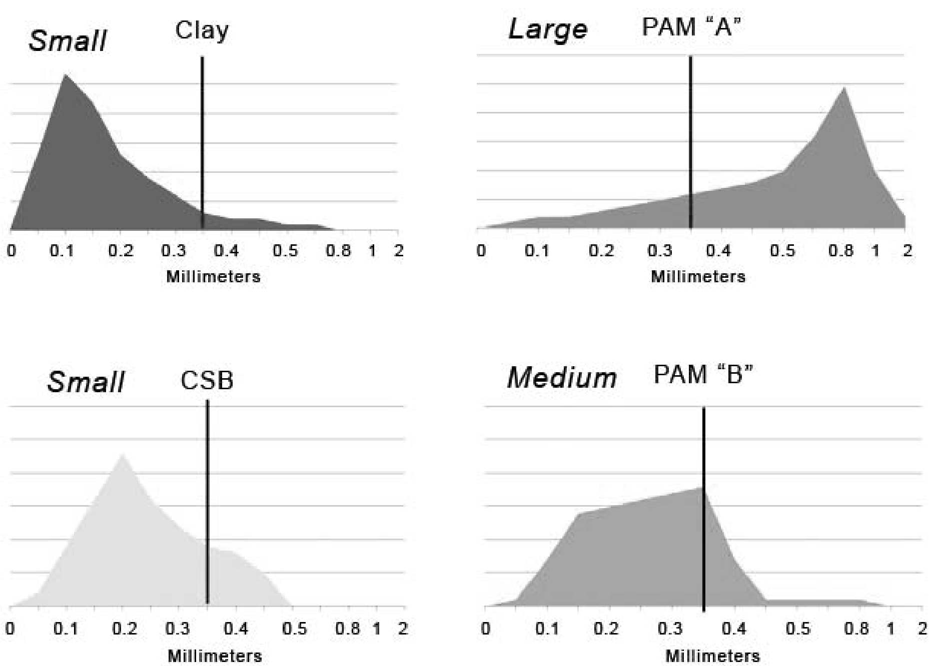

Figure 1. Comparison of particle size of root dip treatments. The Y-axis in each graph is a measure of relative proportion. The vertical black line at 0.35 mm is for comparative purposes.

hours. Greenhouse temperatures during exposure ranged from 28 to 37 °C (82 to 99 °F); relative humidity ranged from 16% to 38%. The average solar radiation measured within the greenhouse was 22,700 lumen/m^2 (2,100 lux).

After exposure, seedlings were planted in the Southern Forest Nursery Cooperative's seedling testing facility. This facility consists of six pits (23 m [75 ft] by 23 m [75 ft] by 1 m [3 ft]) containing 100% sand. Twenty treatments (5 root by 4 exposure treatments) were replicated 12 times in a randomized complete block design with five seedlings per experimental unit. The sand in the pits was irrigated for 4 hours before planting. In order to obtain a separation among treatments, irrigation was withheld after transplanting. Rainfall for the test period from 7 February to 7 May 2007 totaled 15.9 cm (6.3 in): 5.0 (2 in), 7.1 (2.8 in), 3.8 (1.5 in), and 0.0 cm (0 in) for February, March, April, and May, respectively. At the end of the study period (7 May 2007), seedling survival was recorded.

Study III: Root Growth Potential

Root growth potential (RGP) is a measure of the ability of the seedling to initiate and elongate roots when placed in an environment favorable for root growth. The gel and clay treatments for this study were the same as above (table 1). After root treatments had been applied, the seedlings were exposed for 1, 2, or 4 hours. Greenhouse environmental conditions were similar to those in the previous study.

The trial used two seedlings per experimental unit, with 18 replications (a total of 36 seedlings per treatment-exposure); 15 experimental units were contained in one aquarium (5 treatments by 3 exposure times). Seedling roots were suspended in aerated water, and the water level in each aquarium was adjusted daily. After 4 weeks, the numbers of new white root tips greater than 0.5 cm (0.2 in) on each seedling were counted.

Data from each study were analyzed by analysis of variance (ANOVA) for a randomized complete block design. When the F-test for treatment was significant ($\alpha = 0.05$), treatment means were separated using Duncan's New Multiple Range Test. SPSS® software (SPSS Incorporated, Chicago, IL) was used for all data analysis.

Results

Study I: Fungal Growth

Particle size varied considerably among the gel treatments. PAM gel "A" had a greater percentage of large particles; the CSB gel had a greater percentage of fine material (fig. 1). The water-agar control was the baseline for each fungus tested. Therefore, any growth less than that observed in control plates indicated an inhibitory effect on the fungus (table 2), whereas more growth than in the controls indicated that the fungus was able to use the amendment as a food source. *Rhizoctonia* spp. grew the fastest, with one or more treatments reaching the edge of the petri plate before day 6.

In all cases, clay inhibited fungal growth. All of the gel treatments inhibited growth of *Pythium* spp., but the clay treatment had the greatest effect. More plate-to-plate variation occurred with the *Pythium* spp. than the other fungi. The growth of *Fusarium* spp. on the CSB gel was greater than for the control plates; clay was the only inhibitory treatment. Growth of *Rhizotonia* spp. was increased by all gels.

Study II: Seedling Survival Following Exposure

Treatments significantly affected seedling survival, but no differences were detected among treatments with 0 or 1 hour of exposure (table 3). The root gels increased survival after 2 or 4 hours of exposure. Clay or water dips, however, did not protect the roots exposed to these longer times of desiccation. This is very evident at 4 hours of exposure, where the gel treatments increased survival by 40% or more.

Study III: Root Growth Potential

The RGP study showed similar trends as the survival study. In the water-only treatment, 1 hour of exposure reduced RGP by half, compared with the clay or CSB gel. In both the 2- and 4-hour desiccation treatments, RGP was reduced to fewer than four roots in both the clay and water treatments (table 4). Even when placed in water, the desiccated roots were not able to recover and produce new root

Table 2. Fungal growth (mm) on amended or unamended water agar medium.

Amendment	Pythium (day 6)	Fusarium (day 6)	Rhizoctonia (day 4)
Clay	10d[1]	51c	58c
PAM gel "A"	26c	60b	75a
PAM gel "B"	31c	60b	74a
CSB gel	42b	63a	76a
Control	69a	61b	70b
$lsd_{(0.05)}$	6.5	1.6	2.8

[1]Means in columns followed by the same letter are not significantly different ($\alpha = 0.05$; Duncan's New Multiple Range Test).

Table 3. Loblolly pine survival (percentage) after 3 months, as affected by root dip treatment and length of exposure.

	Length of exposure (hours)			
Dip treatment	**0**	**1**	**2**	**4**
PAM gel "B"	94.5a[1]	86.8a	87.0b	60.0b
PAM gel "A"	82.6a	88.9a	93.5b	56.1b
CSB gel	79.2a	76.2a	85.9b	52.8b
Clay	91.2a	87.9a	52.9a	12.1a
Water	97.8a	85.7a	77.2ab	12.1a
$lsd_{(0.05)}$	23.8	13.5	30.3	15.0

[1]Means in columns followed by the same letter are not significantly different (α = 0.05; Duncan's New Multiple Range Test).

Table 4. Average number of white root tips at 4 weeks in RGP testing, as affected by root dip treatment and length of exposure.

	Length of exposure (hours)		
Treatment	**1**	**2**	**4**
PAM gel "B"	32.1ab[1]	29.3b	19.9a
PAM gel "A"	41.3a	16.8c	22.6a
CBS gel	45.3a	39.3a	14.9a
Clay	43.1a	1.2d	0.0b
Water	22.0b	3.4d	0.0b
$lsd_{(0.05)}$	12.4	8.3	7.9

[1]Means in columns followed by the same letter are not significantly different (α = 0.05; Duncan's New Multiple Range Test).

tips. The gels provided some protection during the extended desiccation periods.

Discussion

When seedlings are handled carefully, not exposed to drying conditions, and not stored, outplanting survival can be greater than 80% (Venator and Brissette 1983). Under ideal conditions, roots would never be exposed for 2 to 4 hours of desiccation and would always be planted in moist soil. However, nursery managers typically have no control of seedling care after stock is shipped from the nursery. Every nursery manager has a file full of examples of seedlings transported incorrectly, stored in the sun at the planting site, and handled incorrectly by the planting crew.

Many studies have exposed roots after treatment with clay or gels (Slocum and Maki 1956; Williston 1967; Miller and Reines 1974; Dierauf and Gardner 1975; Alm and Stanton 1993). In this study, we decided to subject treated seedlings to various times of desiccation and then transplant them into moist sand to allow seedlings to become established.

Results from the survival and RGP studies agreed, but the RGP test detected treatment differences after just 1 hour of desiccation. Ritchie (1985) proposes that root growth potential is a good indicator of the ability of seedlings to become establish when outplanted, assuming adequate moisture and nutrients. Our data agree with those of others who found that gels provided an increase in survival (Echols and others 1990; Alm and Stanton 1993). Although clay was not effective in preventing permanent root damage to the seedlings in our study, clay did improve seedling survival in a previous study (Slocum and Maki 1959).

A concern during the 1980s was that fermentation of wood fiber mulches or starch gels would result in deterioration of seedlings stored in the shade (Barnard and others 1981). People thought that the wood fibers (or starch) were providing a substrate for pathogenic microbes. Therefore, some nursery managers have expressed a concern that root gels, especially the starch-based gels, could support the growth of soil-borne fungi. In order for disease to develop, three factors must occur. First, the environment must be conducive to disease development (generally optimal moisture and temperature). Second, the host must be susceptible. In some cases, the host may be too old to be susceptible. Third, you must have a virulent pathogen.

Of the four root dips tested, kaolin clay was the only treatment that did not support, and in fact inhibited, the growth of the three soil-borne fungi tested. The other root dips tested stimulated fungal growth, especially of *Fusarium* spp. and *Rhizoctonia* spp. Because these are common nursery fungi, they could utilize the polyacrylamide hydrogels or the cornstarch-based hydrogel as a food source. Thus, the gels might have negative ramifications during seedling storage, especially the CSB gel in the presence of *Fusarium* spp.

Management Implications and Conclusions

When freshly lifted seedlings were exposed for 1 hour, some protection (as measured by RGP) was provided by the kaolin clay and the PAM gel root dip treatments. When seedlings were exposed for 2 hours or more, only the gel root dip treatments increased seedling survival and RGP. Thus, continued use of gel root dip treatments by nursery managers as "insurance" against poor handling after seedlings leave the nursery is worth the cost of the materials. Kaolin clay inhibited all three soil-borne fungi, whereas gel-based root dips increased growth of *Rhizoctonia* spp. In all cases, treating loblolly pine roots with root gels kept short roots alive so they could elongate when placed into a favorable environment. The current view by nursery managers that root gels provide "insurance" against poor handling after leaving the nursery is valid.

Results from these studies are applicable only when seedlings are transplanted within a few days of treatment. Additional research is required to determine if gels affect fungal growth during long-term, cool storage (for example, 1 to 2 °C [34 to 36 °F]) of seedlings.

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