Too much rain can slow growth of container-grown pine seedlings

David B. South and Tom E. Starkey[a]

Summary

Observations over the past three decades indicate that waterlogged conditions in bareroot nurseries can adversely affect the survival of transplanted *Pinus taeda* L. seedlings. Waterlogged seedbeds can develop when frequent rains occur over an extended period of time. Anaerobic conditions may occur when warm soils remain saturated for just a few days. At some nurseries, problems occurred when rainfall exceeded 50 mm/week for a period of three weeks or more during the autumn. In 2009, data were collected that suggests this response also occurs in container nurseries. Rainfall during the autumn exceeded 151 mm during an 11 day period and this amount likely reduced seedling quality. Seedlings transplanted into sand exhibited complete mortality. However, if given a month to recover in a greenhouse, seedlings recovered. A similar detrimental effect from the saturating rain was not observed with *Pinus palustris* Mill.

Introduction

Over the last several years, we have inspected several plantation failures that were not caused by poor planting practices. Low survival of bareroot conifer seedlings appeared to be related to reduced seedling physiology since pest-related symptoms were not detected and morphology was acceptable (root mass was adequate and shoot length was not excessive). Symptoms included blackened root surfaces, abundant development of lenticiles, no new root growth, mortality soon after spring bud-break (if any), and seedlings dying from the roots up. Root systems deteriorated quickly when seedlings were stored under refrigerated conditions for three weeks or less.

A common factor in these cases was unusually high rainfall during the month prior to lifting (South and Carey 1999). Typically, above average rainfall occurred over a three or four- week period and as a result, the soil remained "waterlogged" for an extended length of time. The resulting anaerobic soil conditions would have a negative impact on root physiology. In some cases, lenticels (Topa and McLeod 1986; Aronen and Häggman 1994; Craine and Orians 2006) were observed on stems and roots. In addition, aerenchyma can form in the roots (McKevlin et al. 1987). Under laboratory conditions, aerenchyma can develop in just 15 days (Topa and McLeod 1986). Waterlogged soils not only affects root anatomy, but low soil oxygen reduces the rate of nutrient uptake (Gadgil 1972), transport of photosynthate to the roots may be affected (Kozlowski 1984) and toxic compounds can be produced (Sanderson and Armstrong 1980).

At some locations in the USA, average rainfall for the month of October might be half that for certain regions in NZ in April (Table 1). In some regions in both countries, rainfall over a four week period in the autumn might exceed 160 mm (Newhook 1959). In some years, survival of pines after saturating rains in the autumn is much lower than expected. For example, in 1982, rainfall at one bareroot nursery in the USA averaged more than 90 mm per week (from 16 November until 10 December). Lifting began on 9 December with subsequent widespread mortality. Mortality increased when seedlings were kept in refrigerated storage for longer than a week (Oak 1983). As the lifting season progressed, seedling performance gradually improved. By mid-February, seedlings appeared to be fully recovered.

Table 1. Monthly rainfall (mm) for selected locations in the USA (southern Georgia) and NZ (Whangarei; from Newhook 1959).

Year	October - USA	April - NZ
Average	56	129
1950	--	176
1951	--	147
1952	--	59
1953	--	88
1954	--	120
1955	--	61
1956	--	219
2005	27	--
2006	43	--
2007	121	--
2008	128	--
2009	161	--

[a] *Professor and Research Fellow, Auburn University Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Alabama, USA 36849-5418; Corresponding author: southdb@auburn.edu*

Although studies have been conducted on the effects of flooding or waterlogging on roots in situ, few studies have transplanted seedlings soon after a waterlogging treatment. In one study, a 15% decrease in survival was reported after just one day of storing pine seedlings in tubs of water (Wakeley 1954).

In 2009, rainfall in the fall was excessive in several regions of the southern United States and three states set records for the month (Table 2). Several foresters from throughout the region sent bareroot seedlings to the Auburn University Southern Forest Nursery Cooperative in hope that we could identify a likely cause for low survival. In 17 cases, lenticels (just above the root-collar) and black roots were observed on seedlings. In the past, most of the information about these events have been circumstantial. However, we were fortunate enough to have one study affected by excessive rainfall. This paper provides results from that planting date study.

Table 2. October rainfall (mm) by state (National Oceanic and Atmospheric Administration). Values listed in parentheses indicate a record amount of rainfall for the past 116 years.

Region	October 2009	Average (1895-2009)
Alabama	181	72
Arkansas	(364)	89
Georgia	147	70
Louisiana	(344)	87
Mississippi	(250)	73
North Carolina	76	83
Oklahoma	179	77
South Carolina	124	76
Tennessee	170	74
Texas	144	67
Virginia	76	78

Materials and Methods

The location of the container nursery is in southern Georgia. In May 2009, seeds of *Pinus taeda* and *Pinus palustris* were sown in containers that contained a peat-verimucliate-pearlite mix. Container trays (cavity size 122 mm deep with a 38 mm diameter) were placed outside and were irrigated under a centre pivot irrigation system. Operational fertilization and irrigation regimes were followed. Periodically, seedlings were extracted from the containers and were transported to our research facility at Auburn, Alabama. Seedlings were extracted at the nursery on 19 June 15 July, and 8 August. On the 21 October, eight container trays were transported to Auburn. Within 48 hours of arriving at Auburn, 30 to 45 seedlings of each species were transplanted into specially designed bins containing sand (Figure 1). One bin was used per planting date and a total of seven bins were used (one species on one half and the other on the remaining half). All bins were under a protective roof but there were no walls to protect the seedlings from wind.

Figure 1. Pinus taeda *seedlings being transplanted into sand near the summer equinox in 2009.*

Seedlings sampled from the nursery in October were sorted into four groups. One group was planted in the sand bins while the other three groups were placed in a heated greenhouse for a period of 1, 2 or 3 months. Therefore, seedlings transported from the nursery in October were transplanted on 22 October, 23 November, 15 December, and 21 January.

Following each planting date, the bins containing the newly planted seedlings were watered sufficiently to saturate the top 30 cm of sand. From 16 June until 1 Nov, 2009, seedlings were watered three times per week, sufficient to wet the top 10 cm of sand. Seedlings were fertilized approximately every three weeks until 1 November. After that date, seedlings were watered once per week. No additional fertilizer was applied until March, 2010. Seedling mortality was recorded approximately four months after each planting date.

Results and Discussion

For *Pinus palustris*, survival four months after transplanting was greater than 89 % for all seven planting dates (Figure 2). In contrast, none of the *Pinus taeda* seedlings survived from the October transplanting date. Survival for this species was greater than 80 % when transplanted in June, July and August and greater than 95% when transplanted in November, December or January. At first, we had no idea what caused all the seedlings to die, especially since seedlings from the same group were alive when kept in the greenhouse.

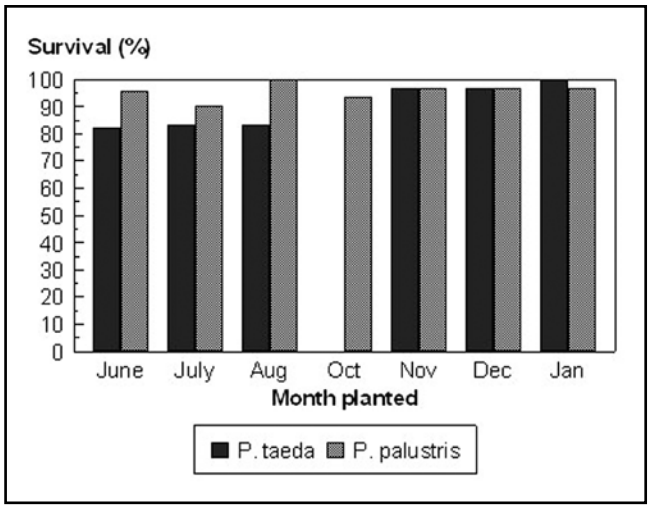

Figure 2. Survival of container-grown pine seedlings after being transplanted into sand (2009-2010). All Pinus taeda *seedlings transplanted in October died.*

After recording mortality on 21 January, 2010, lenticles were noticed on seedlings of *Pinus taeda* (Figure 3) and *Pinus palustris* that were transported in October. This gave us the clue we needed. We examined rainfall records and determined there had been an excessive amount of rainfall between 5 and 16 of October at the nursery (Figure 4). During this time there was a total of 151 mm of precipitation, equivalent to 96 mm/week. Apparently, this was enough to lower the physiology of the *Pinus taeda* seedlings. The stress experienced in the bins was enough

Figure 3. An example of lenticels on the stem of a Pinus taeda *seedling.*

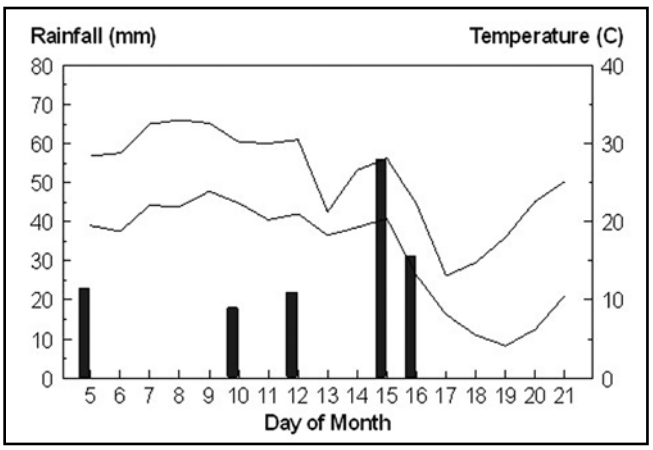

Figure 4. Rainfall events (bars) and maximum and minimum temperatures for October, 2009 (station location 8 km from the container nursery in southern Georgia).

to kill seedlings but those kept in the greenhouse survived (i.e. they received more irrigation and were not exposed to winds).

Prior to this trial, we had could only speculate on how long it would take before *Pinus taeda* seedlings might recover from exposure to anaerobic conditions. It was just by coincidence that (1) this study utilized the same seedling stock (ie. lifted at the same time from the nursery) for the last four transplanting dates, and (2) the seedlings were protected from additional saturating rainfall events. It appears that if protected from additional rain in a greenhouse, seedlings may recover sufficiently in four weeks to be in suitable condition for transplanting. Tests with cuttings of *Pinus contorta* also indicate that pines can recover from 3 weeks of anaerobic conditions (Sanderson and Armstrong 1980). Results from our trial suggest that *Pinus palustris* may be more tolerant of anaerobic conditions than *Pinus taeda*, but further research is required to test this hypothesis.

In addition to the excessive rain, warm temperatures can contribute to lowering oxygen levels in either potting media or soil. It is well known that injury from flooding is greater when soil temperatures are high (Kozlowski 1986). Warm water contains less oxygen and soil microbes are more active (microbial respiration is at a higher rate). Therefore, excessive rains in a warm autumn would be more harmful than the same pattern of rainfall during a cold winter.

Problems associated with excessive rainfall in the autumn are not new. Pine seedling mortality from heavy rainfall in the autumn may go back as far as 1924 (Newhook 1954). Wakeley (1954) stated "In a year of extraordinary weather conditions, severe late fall or early winter drought might reduce survival; or excessive fall rain might reduce it by lowering the physiological quality of the nursery stock." Gilmour (1960) noted that excessive mortality of *Pinus radiata* in shelter belts occurred after periods of abnormally high rainfall.

When nursery managers record above average rainfall in the autumn, they may want to check their seedlings for signs of root injury before shipping seedlings to the field. Lenticels on the stem and taproot (Figure 4) are signs that seedlings have been exposed to anaerobic conditions. When lenticels and black roots are detected, it may be advisable to delay lifting seedlings (to allow the roots time to recover). Managers should first consider lifting from areas of the nursery where roots have mycorrhizae and are not black. Anaerobic soil conditions can kill both white root tips and mycorrhizal roots (Gadgil 1972; Stenström 1991).

Conclusions

Prior to this study, our assumptions regarding how long it would take for *Pinus taeda* to recover from anaerobic conditions in the nursery were based solely on observations from plantation failures. It now appears that in some cases (i.e. a warm environment), it may take only a month for container-grown seedlings to recover from an anaerobic event. Further research is needed to determine if there is a simple test (such as electrolyte leakage) that could be used to evaluate the relative health of roots before shipping seedlings to the field.

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