FREEZE INJURY TO SOUTHERN PINE SEEDLINGS

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Abstract—Freeze injury to roots and shoots of pines is affected by genotype and nursery practices. Local sources of shortleaf pine and Virginia pine that are grown in nurseries in USDA hardiness Zones 6 and 7a are relatively freeze tolerant. However, loblolly pine, slash pine, and longleaf pine seedlings have been injured by a number of freeze events (0 to 24 °F) in hardiness Zone 7b and 8. Some fast-growing half-sib families from the Coastal Plain are more susceptible to freeze than Piedmont sources. Temperatures that produce freeze injury symptoms are lower when pines are acclimated to cold weather than when seedlings have been deacclimated due to several nights of warm nighttime temperatures. Unusually warm temperatures in January of 2004 deacclimated pine seedlings, and this resulted in root injury from a hard freeze (18 °F). Since shoots typically do not show injury (unless they are actively flushing), root injury is often overlooked, and many freeze-injured seedlings died quickly after planting. Since freeze injury symptoms are sometimes difficult to identify, foresters typically offer various reasons (other than a freeze) for the poor seedling performance. This paper reviews some data on freeze events that have occurred over the past century.

INTRODUCTION

Although transplanted pine seedlings have been injured by a number of freezes in the past, foresters sometimes are unaware when a damaging freeze causes a reduction in outplanting survival. This is because freeze-damaged seedlings sometimes show no obvious signs of root injury (Krasowski and others 1993). Therefore, it is sometimes difficult to pinpoint the exact cause of death once seedlings have dried and turned brown. Injured roots eventually turn orange or brown. This paper presents a review of freeze injury to pine seedlings in the Southern United States.

There are four basic classes of injury that result from low temperatures: root injury, shoot injury, frost-heaving, and winter desiccation. Frost-heaving and winter desiccation will not be discussed in this review. Freeze injury to roots and shoots can be classified into three groups: pre-acclimation, acclimation, and deacclimation. Pre-acclimation injury (PAI) typically occurs during fall or early winter. PAI occurs before seedlings have been exposed to a sufficient amount of chilling temperatures (< 46.5 °F). Acclimation injury (AI) affects seedlings after they have been acclimatized by short days and low temperatures. Deacclimation injury (DI) occurs after acclimation (or partial acclimation) has occurred and after a sufficient amount of warm nighttime temperatures has stimulated a resumption of cell division. Although DI occurs mainly in early spring (during or just before shoot growth), it sometimes occurs in the winter when unusually warm temperatures have stimulated cambial activity (table 1). The following is a summary of freeze events that have occurred in the Southern United States.

1899 FREEZE

February 11 to February 13 brought 2 nights of intense cold to the entire South. Record low temperatures were recorded throughout the United States, many of which still stand today. Temperatures fell to -2 °F in Tallahassee, FL, -16 °F in Minden,

Table 1—Dates and temperatures resulting in injury to southern pines

Date	°F	Type of freeze	Type of injury
Nov 5, 1991	19	Preacclimation	Needle burn
Nov. 25, 1950	-8	Preacclimation	Root and needle burn
Dec 12, 1962	-17	Acclimation	Needle burn
Dec 17, 1955	15	Preacclimation	Needle burn
Dec 23, 1989	0	Acclimation	Needle burn
Dec 25, 1983	5	Deacclimation	Root injury
Jan 7, 2004	18	Deacclimation	Root injury
Jan 11, 1977	-15	Acclimation	Needle burn
Jan 19, 1994	7	Acclimation	Root injury
Jan 19, 1957	20	Deacclimation	Needle burn
Jan 19, 1996	16	Acclimation	Root injury
Jan 21, 1985	0	Acclimation	Needle burn
Feb 5, 1996	15	Acclimation	Root (longleaf containers)
March 9, 1932	20	Deacclimation	Frost ring
April 7, 1938	24	Deacclimation	Frost ring

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LA (both are record lows for the State), and -4 °F in Montgomery, AL. Snow may have helped protect roots from the -10 °F temperature at Biltmore in North Carolina.

1932 FREEZE

February of 1932 was warmer than any previously recorded in Mississippi. The mean monthly temperatures were almost 10 °F warmer than normal and longleaf pine (*Pinus palustris* Mill.) began diameter growth. Temperatures at Magnolia, MS, were above 80 °F on March 1 and 2, but a sudden DI freeze occurred a week later. Nighttime temperatures dropped from about 62 °F on March 3 to 20 °F on March 9 (fig. 1). This caused frost rings to form on longleaf pine (Stone 1940).

1938 FREEZE

During March at Lubbock, TX, daytime temperatures were greater than 70 °F for 22 days. On April 4 and 5, temperatures exceeded 84 °F. A sudden DI freeze occurred a few days later when temperatures fell to 24 °F on April 7 (also 23 °F on April 8). This freeze injured at least 16 different woody species (Glock 1951) including loblolly pine (*Pinus taeda* L.). This freeze event disrupted newly formed cells in the cambium and resulted in frost rings.

1950 FREEZE

There was a warm fall in Illinois where temperatures were in the 80s during October. There was a sudden PAI freeze on November 11, and the temperature dropped to 17 °F (fig. 2). A second freeze event occurred on November 25 when temperatures at the Union State Tree Nursery dropped to -8 °F (Minckler 1951). "Most of the 1-0 loblolly pine from eastern South Carolina seed sources were killed. The 1-0 loblolly stock from Maryland and Arkansas sources, on the other hand, showed a slight browning of the top needles but negligible killing. It was striking to see the beds of seedlings from the different seed sources side by side in the nursery. They presented a strong argument for recognizing the importance of seed source in forestry practices" (Minckler 1951). Loblolly pine seedlings were injured more than shortleaf pine (*Pinus echinata* Mill.).

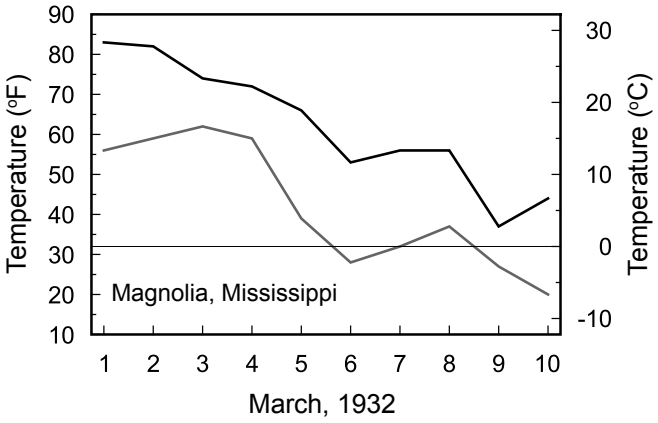

Figure 1—Maximum and minimum temperatures recorded at Magnolia, MS, for the first 2 weeks in March, 1932. The deacclimation-injury freeze on March 10 resulted in frost rings on longleaf pine (Stone 1940).

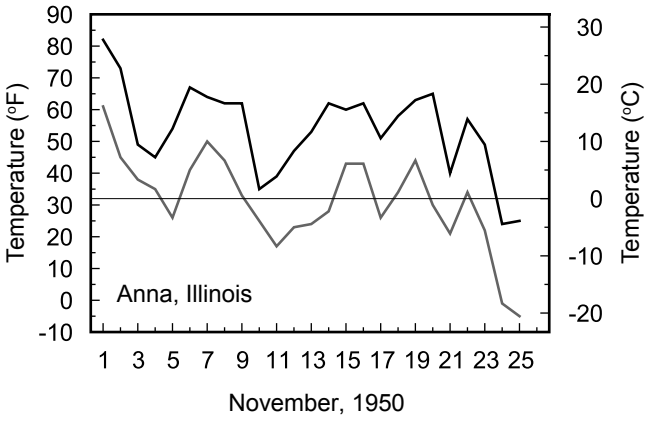

Figure 2—Maximum and minimum temperatures recorded at Anna, IL, for the first 3 weeks in November, 1950. The nursery manager at the Union State Tree Nursery indicated the -8 °F freeze in late November killed the loblolly pine seedlings (Minckler 1951).

1955 FREEZE

Temperatures at Akin, SC, reached 75 °F on December 4. Freezing temperatures occurred from December 9 to 23 and this "exceptionally cold period" was associated with high, drying winds. On December 17, the temperature at the Savannah River Project dropped to 15 °F. This PAI freeze resulted in a "dehydration burn" on newly planted slash pine and longleaf pine seedlings (Tofte and Hatcher 1956).

1957 FREEZE

During the winter, there was a 7-week warm period at Gainesville, FL. Warm nighttime temperatures initiated new growth on slash pines (*Pinus elliottii* Engelm.) (Weber 1957). Temperatures at Gainesville dropped to 24 °F in some places (fig. 3) and 20 °F in others. This DI freeze resulted in dead needles and brown terminal shoots.

1962 FREEZE

Record low temperatures occurred in Morgan County, TN and loblolly pine needles were injured (Thor 1967). Temperatures reached -17 °F on December 12-13, 1962, and January 24-25,

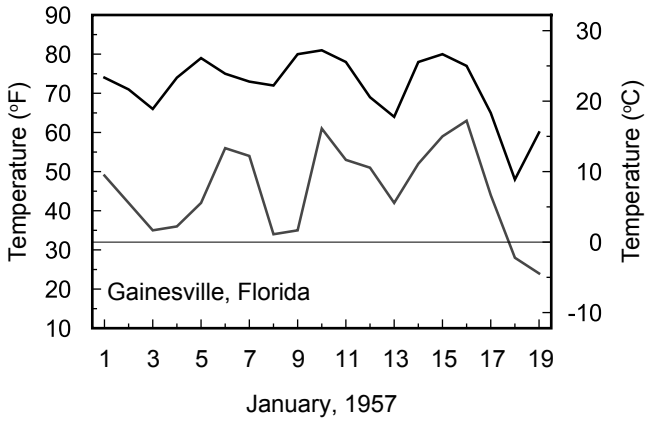

Figure 3—Maximum and minimum temperatures recorded at Gainesville, FL, for the first 3 weeks in January, 1957. The deacclimation-injury freeze injured new shoot growth on slash pine (Weber 1957).

1963, at the nearby town of Crossville, TN. AI freeze damage likely reduced loblolly pine growth if the seed originated from the Piedmont of north Georgia or the Coastal Plain of North Carolina. Sources with moderate foliar injury (> 35 percent of the trees having more than 24 percent brown needles) were from the South Carolina Coastal Plain and the Piedmont of North Georgia.

1977 FREEZE

January was a cold month, and temperatures at Red Bay, AL, dropped to -1 °F. Temperatures in Calloway County, KY, were as low as -15 °F on January 11 (Kolb and others 1985). One-year-old loblolly pine seedlings (in a progeny test) exhibited injury to foliage. There were strong genetic differences in susceptibility to the freeze. Families from the Mid-South Region were more tolerant than families from the Piedmont of North and South Carolina.

1983 FREEZE

Record low temperatures occurred throughout the South on December 25. This freeze killed many orange trees [*Citrus sinensis* (L.) Osbeck], and the damage was estimated at one billion dollars. The artic high pressure system spread quickly south (along with associated high winds), and the ground froze at a number of forest tree nurseries. Damage was confined mainly to nurseries in hardiness Zone 8 (table 2). Freeze injury to pine roots was not reported in Zone 6 or 7 (i.e., Kentucky, Tennessee, Arkansas, Oklahoma). Daytime temperatures at Auburn, AL, were above 50 °F for several weeks prior to the freeze (fig. 4). This PAI freeze resulted in injury to roots (fig. 5), and several papers documented this event (Carlson 1985, Lantz 1985, Rowan 1985).

1985 FREEZE

Nighttime temperatures during the first part of January were below freezing at many nurseries (fig. 6). An AI freeze on January 21-22 set state records in Virginia (-30 °F), North Carolina (-34 °F), and South Carolina (-19 °F). Although temperatures were generally lower than those recorded on Christmas 1983, there was not an unusually warm period preceding the freeze. Although the AI freeze killed many orange trees, minimal injury was noted on pines seedlings in nurseries. However, injury did occur if loblolly pine families were planted too far north. Pine families from hardiness Zones 8B and 9A were injured more than families from Zone 7 (Hodge and Weir 1993). In general, fast-growing families were more injured by the freeze than slower growing families.

Table 2—Nursery location, December 25, 1983 temperature, USDA hardiness Zone, and associated root injury to pine seedlings

Nursery	State	°F	USDA zone	Nursery manager's comments
Kentucky Dam	KY	-14	6	No root injury; severe needle burn on N. AL source
Pinson	TN	-9	6	No injury to loblolly pine
Chatsworth	GA	-3	7	No injury to loblolly pine
White City	AL	-2	7	Loblolly 3-37% injury
Little Rock	AR	-1	7	No injury to loblolly, shortleaf or virginia pine
Edwards	NC	2	7	No injury to loblolly pine
Goldsboro	NC	2	7	Longleaf 4-8%; no injury to loblolly and slash
Camden	AL	2	8	Longleaf 50%; no injury to loblolly pine
Prov. Forge	VA	3	7	No injury to loblolly pine
Opelika	AL	3	8	Loblolly 5 to 65%; slash 10-15%; longleaf 40-45%
Winona	MS	3	7	No injury to loblolly pine
Eutaw	AL	5	7	Loblolly 3-70% (depending upon family)
Newton	TX	6	8	No injury to loblolly pine
Selma	AL	6	8	Loblolly <2% injury; slash <1%
Buena Vista	GA	6	8	Loblolly 12-18%; slash 18%; sand 1%
Swansea	SC	6	8	No injury to loblolly or Virginia pine
Hodge	LA	6	8	No injury to loblolly; some frozen bags discarded
Autaugaville	AL	6	8	Loblolly 10 to 65 %; slash 49%; longleaf 61-88%
Atmore	AL	7	8	Longleaf 49-72%; loblolly 28 to 88%; slash 53-70%
Ashe	MS	7	8	Longleaf 9-15%; loblolly 5%
Cedar Springs	GA	7	8	Loblolly 1-2%; slash 2%; longleaf < 10%
Statesboro	GA	8	8	No injury to loblolly or slash pine
Jasper	TX	8	8	No injury to loblolly-minor needle burn
Munson	FL	8	8	Loblolly <4%; slash 2-17%; longleaf 6-63%
Glennville	GA	9	8	No injury to loblolly, longleaf and slash
Brewton	AL	10	8	Loblolly 10%; slash 21%; longleaf 50%
Washington	NC	10	8	No injury to loblolly pine
Lee	FL	11	8	Undercut longleaf 50%; loblolly <5%
Ravenel	SC	11	8	No injury to loblolly pine
Chiefland	FL	12	8	South Florida slash pine > 50%

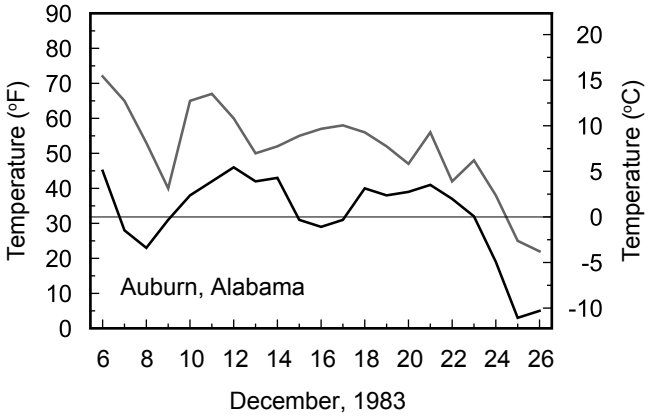

Figure 4—Maximum and minimum temperatures recorded at Auburn, AL, for the 3 weeks during December, 1983. The deacclimation-injury freeze injured pine seedling roots throughout hardiness Zone 8.

Figure 5—Root injury to a bareroot longleaf pine seedling from the Christmas 1983 freeze. The taproot shows injury symptoms several inches below the groundline.

1989 FREEZE

Bareroot longleaf pine were planted in Autauga County, AL, on December 13 and December 20. A hard freeze occurred on December 23; temperatures reached 0 °F and did not rise above freezing until December 27. It is estimated the freeze reduced survival by more than 50 percent (South and Loewenstein 1994).

1991 FREEZE

Very warm temperatures occurred in October and a PAI freeze occurred during the first week of November. Daytime temperatures a few weeks before the freeze were above 80 °F, and nighttime temperatures were above 50 °F (fig. 7). Within 60 hours, the temperature dropped approximately 40 °F. Minimum temperatures recorded at a north Alabama nursery were 19 °F, and at this location more than 95 percent of the seedlings exhibited some necrotic needles. Pine needles that were not elongating were not injured (South and others 1993). This PAI freeze apparently did not injure roots.

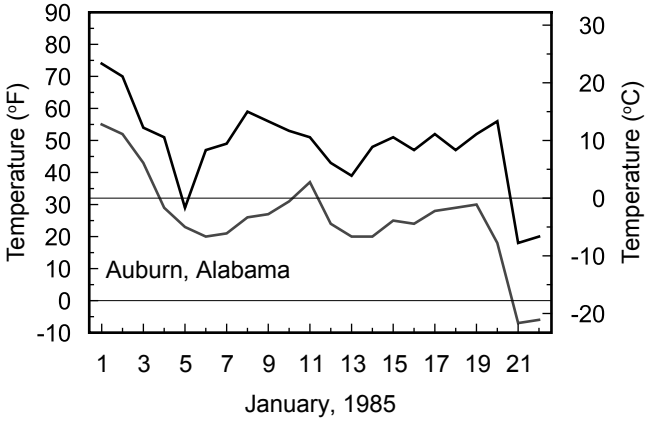

Figure 6—Maximum and minimum temperatures recorded at Auburn, AL, for the 3 weeks during January, 1985. This freeze injured few pines (of local origin) since nighttime temperatures before the event were generally below freezing.

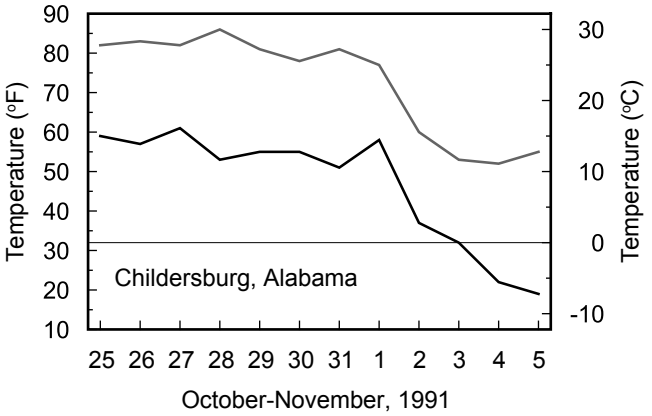

Figure 7—Maximum and minimum temperatures recorded at Childersburg, AL, for 2 weeks in October-November, 1991. This deacclimation-injury freeze affected a number of pine seedling roots planted prior to the freeze event.

1994 FREEZE

Pine seedlings in Alabama and Mississippi were affected by an AI freeze that occurred on January 19 through January 20. At Camp Hill, AL, temperatures dropped 44 °F over a 36 hour period (low temperature = 7 °F). Subsequently, seedlings from several organizations exhibited low root growth, slow bud-break, and many seedlings were brown in March and April. A survey of planting chances in Alabama indicated survival of seedlings planted before the freeze ranged from 64 to 73 percent. If seedlings were planted after the freeze, survival ranged from 77 to 90 percent. This suggests that seedlings suffered freeze injury in the field (as opposed to in the nursery). First-year height growth of seedlings affected by the freeze was less than expected.

1996 FREEZE

Pine seedlings in Alabama were affected by a freeze that occurred on January 19. Temperatures dropped 52 °F in about a day (low temperature = 16 °F). A few days later, temperatures fell again to a low of 5 °F (February 9). Seedlings from one nursery were examined, and 97 percent of the samples from family 7-56 showed symptoms of freeze injury (South and others 2002). In December, a 16 °F freeze killed 400,000 container-grown longleaf pine seedlings at the Ashe Nursery in Mississippi (Tinus and others 2002).

2000 FREEZE

In many locations across the South, air temperatures dropped to below 20 °F on December 21. Nationally, it was the seventh coldest December on record. Frozen container-grown longleaf pine seedlings from three nurseries were allowed to thaw, and these seedlings were outplanted in sand at Auburn, AL, in January. By March 6, 100 percent of the seedlings survived from a nursery where air temperatures dipped to 21 °F. At another nursery, survival was 98 percent after air temperatures dropped to 14 °F. At the third nursery, survival averaged 87 percent after air temperatures dropped to 7 °F. These data are encouraging since the container plugs had frozen solid at each nursery. Apparently, the extra-cold weather in late November and early December caused the longleaf pine seedlings to acclimate more than in previous years where frozen containers died after outplanting (Tinus and others 2002).

2004 FREEZE

Unseasonably warm temperatures occurred during the first week of January. At some locations, nighttime temperatures were above 60 °F 2 days before the DI freeze (fig. 8). In some locations, temperatures (5 feet above the ground) dropped from 74 °F on January 5 to 18 °F on January 7. Temperatures of 17 °F were recorded at Florence, SC, and were 21 °F at Shreveport, LA, Meridian, MS, and Ft. Valley, GA. Although it did not get as cold, the absolute drop in temperature was even greater than that associated with the infamous Christmas 1983 freeze. Winds associated with the 2004 freeze were about 10 to 15 miles per hour. Seedling roots were injured while shoots initially appeared uninjured. As a result, millions of pine seedlings with injured roots were outplanted. Areas with poor seedling survival ranged from Smith County, TX, through Louisiana, Mississippi, Alabama, Georgia, and into southeastern South Carolina (Jasper County). Temperatures in Florida were not as cold, but at least one longleaf pine planting chance in the panhandle may have been affected by temperatures below 26 °F. Freeze pockets can be 10 °F colder than temperatures recorded at official weather stations. It has been estimated that financial losses from this freeze event exceeds one million dollars. Many foresters wondered why so many seedlings were dead by May.

Roots and shoots injured by the freeze showed no immediate signs of injury. Although symptoms can show up if seedlings are exposed to warm temperatures for about 24 to 48 hours, in many cases seedlings kept cool show no obvious outward signs of freeze injury.

Injured cambial and parenchyma cells were detected just above the groundline and down several inches below the root-collar (fig. 9). In some cases, the pith of the stem turned brown to black (Cameron and Lowerts, in press). Many out-planted seedlings exhibited a lack of new root growth. For the southern pines, new root growth is dependent upon current photosynthesis (not stored carbohydrates). As a result, when transport of carbohydrates to the roots is inhibited, new root growth is reduced. Therefore, reduced root growth is a symptom of freeze injury (Carlson 1985).

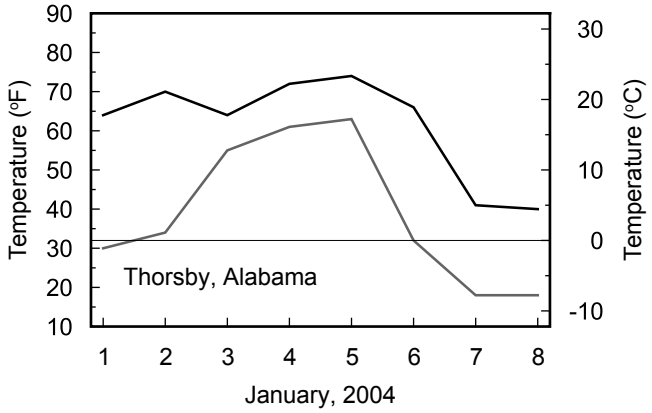

Figure 8—Maximum and minimum temperatures recorded at Thorsby, AL, for the first week in January, 2004. This deacclimation-injury freeze affected roots and reduced survival throughout hardiness Zone 8 (from East Texas to southeast South Carolina).

Figure 9—Root injury to loblolly pine seedlings from a 16 °F freeze on January 7, 2004. Air temperatures were above 70 °F just a few days prior to the freeze. These seedlings were lifted on 17 February and were stored until planting. Seedling stored had red-brown bark that slips with ease, and the cambium is a spongy and gray-brown in color. Seedling mortality occurred quickly after planting. The freeze injured roots extend several inches below the groundline. Color photo at www.sfws.auburn.edu/sfnmc/museum/frozen.html.

Areas with injured pine seedlings were in hardiness Zones 8 and 7b, and injured seedlings were mostly from Coastal Plain sources. Although temperatures on January 7 were actually lower in hardiness Zone 7, Piedmont sources in this Zone escaped injury. For example, Jackson, TN, recorded a temperature of 9 °F, but injury to pine seedlings was not reported. Likewise, no reports of injury were forthcoming from central Arkansas where temperatures dropped to 12 °F.

HARDINESS ZONE AND SEED SOURCE

Four-month old container-grown seedlings can be injured by freezes in hardiness Zone 7a (Mexal and others 1979). However, if a bare-root nursery is located in hardiness Zone 6 or 7a, there appears to be little chance of a freeze injuring pine roots from local seed sources. Injury can occur if southern seed sources from Zone 8 are sown in Zones 6 or 7a nurseries. In contrast, nurseries located in Zone 8 have experienced root injury even when the genetic source is local. For example, in 1983 temperatures dropped to <5 °F at both Pinson, TN, and Opelika, AL, but freeze injury occurred only at the Opelika Nursery (table 2). Nurseries in Zones 6 and 7a do experience frost heaving and winter desiccation (Dierauf and Olinger 1977), but these injuries are different from the injury that results in broken cell membranes (Krasowski and others 1993). Freeze injury to pines is rare in Zones 9 or 10, but they do occasionally occur (Olmsted and others 1993, Weber 1957).

GENETICS AND FREEZE INJURY

Freeze injury is under strong genetic control (Allen 1961, Duncan and others 1996, Hodge and Weir 1993, Kolb and others 1985, Minckler 1951, Thor 1967). Coastal Plain sources are more susceptible to a freeze than are most Piedmont sources. Some fast-growing Coastal Plain families (e.g., 7-56) are less tolerant of freezes than other sources (South and others 2002). In general, shortleaf pine is more freeze tolerant than loblolly pine. Slash pine and longleaf pine are less freeze tolerant than loblolly pine. Longleaf pine is less tolerant of freeze than others species (Hodges 1961), and acclimation is not greatly increased by exposure to cold temperatures (Parker 1961, 1965). As one might expect, cold tolerance of eastern white pine (*Pinus strobus* L.) is greater than that for longleaf pine, and this difference might be due to a lack of sugar buildup in longleaf pine needles (Parker 1959).

ACCLIMATION AND FREEZE INJURING TEMPERATURES

It is apparent that acclimation plays a greater role in freeze injury than does the freeze temperature, per se. In general, preacclimated and deacclimated seedlings are injured at higher temperatures than acclimated seedlings. For example, acclimated loblolly pines in New Jersey apparently tolerated a -25 °F February 1934 freeze, but 2 years earlier new growth of deacclimated seedlings was killed by a light freeze (30 °F in June) (Wood 1936). Therefore, if the nighttime temperatures prior to a hard freeze have been low (e.g., fig. 6), seedlings are less likely to be injured than if nighttime temperatures before a freeze were high (e.g., fig. 4).

FREEZE INJURY IS NOT RELATED TO THE PRESENCE OF A TERMINAL BUD

This null hypothesis has not been rejected by scientific studies. Freeze injury to newly formed needles on loblolly pine was not related to the presence or absence of a terminal bud (Duncan and others 1996, South and others 1993). Many seedlings injured in the 1983 freeze had terminal buds. Slash pines with terminal buds were injured by a 20 °F freeze (Weber 1957). Although a large seedling is more likely to have a terminal bud than a small seedling (Williams and others 1988), it has not been demonstrated that a seedling with a terminal bud is more resistant to a freeze than a similar-sized seedling without a terminal bud. The myth that a terminal bud is required before a seedling acclimates to cold temperatures may have started with observations in the spring. Injury to a late spring frost is likely to occur when seedlings have broken bud and are growing.

CONCLUSIONS

Freeze injury to southern pines has occurred for millennia, and freezes likely maintain the northern boundary for these species. Injury to local seed sources is more likely to occur when seedlings are outplanted in hardiness Zone 8 than in Zones 6 or 7a. Coastal Plain sources that have deacclimated due to several days of warm nighttime temperatures are susceptible to injury from temperatures in the range of 16 to 20 °F (measured 5 feet above ground level). Southern pine seedlings exposed to warm nighttime temperatures can be injured by temperatures of 18 °F (December to January) or 20 °F (March or November). PAI or DI freeze events like that of Christmas 1983 and January 7, 2004, are likely to injure pines in Zone 8 again.

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