TIP-DIEBACK IN YOUNG LOBLOLLY PINE PLANTATIONS

David B. South, Patrick Brown, Phillip M. Dougherty, Sonya Olykan, Brett Runion, Adya Singh, and Malcolm Skinner[1]

Abstract— Dieback of loblolly pine (*Pinus taeda* L.) has been observed in certain intensively managed plantations throughout the South. There are two distinct types of dieback; winter dieback usually appears in February and March while summer dieback appears in July (or later) and increases during the fall. Both types have very high levels of K in terminal shoots. Winter dieback progresses in a "top-down" pattern while summer dieback progresses in a "bottom-up" pattern. Winter-dieback appears to be related to freezes and growth rate as slower-growing wildlings in the plantation almost never exhibit dieback. Freeze injury (brown cambium) is sometimes observed in the stem (at breast-height) and in the terminal shoot. Often the terminal pith turns brown. One fast-growing family, 7-56 from the Coastal Plain in South Carolina, is sensitive to freezes and is prone to tip-dieback. Although winter dieback is most noticeable in plantations, it also occurs on open-grown trees that are growing in weedy, non-fertilized areas. Land managers have grown accustomed to this dieback in rapidly growing plantations that are 2 to 5 years old. On some soils, summer dieback appears to be exacerbated after fertilization with macronutrients. There is currently no consensus as to the cause of this phenomenon but we believe that growth rate, freezes, K, and B may be involved. This paper reviews some of the literature on dieback on pines and proposes some hypotheses to test.

INTRODUCTION

For more than 30 years, a disease of unknown etiology has been observed on fast-growing plantations of loblolly pine. The first reported cases were made by Doug Crutchfield at Georgetown, South Carolina (Clark 1972). Terminals of 4-year-old loblolly pine died back and subsequently, one or more lateral branches assumed dominance. It was concluded that the most likely explanation was due to freeze injury. "The trees were young. They were growing at a rapid rate due to good site conditions, hence any fall flush of growth probably would not have hardened-off in time to be protected from early frost."

Dieback ranges from Virginia to Florida and west as far as Louisiana. Many cases involved intensively managed plantations planted with family 7-56. As more cases were investigated, it became apparent that there was no consensus as to the cause of the dieback. The objective of this paper is to review the current state of knowledge and to propose alternative hypotheses to explain this phenomenon.

SYMPTOMS

There are two types of dieback: winter and summer. Winter symptoms appear after several warm days following hard freeze events. Although the freeze event may occur in mid-December or in January, symptoms in Alabama typically begin to appear in late February and March. On some trees, symptoms begin to appear in April. The date of the first appearance of winter symptoms will vary with both year and latitude. There is a "top-down" pattern of symptom progression; necrotic tissue first appears at the top of the shoot. On some trees, the pith of the terminal shoot is necrotic and affected needles are typically entirely necrotic. The terminal shoot of affected trees usually is easy to snap-off, indicating a lack of lignification. Although there are no reports of wide-spread dieback in 10-year-old plantations, open-grown trees that are 10 to 18 years old (or older) have shown signs of winter dieback. Pictures of winter dieback are found at: www.forestry.auburn.edu/south/tipdieback.html.

When new needles develop in April, they appear unaffected. By mid-summer, necrotic needles have fallen off and many stands appear to be growing normally. Upon close examination, some trees show dead terminals with a lateral bud expressing dominance. At some locations, the entire 1 m of the top is dead on a few trees and the crown develops a bushy appearance. Casual observations suggest soil type is not related to the occurrence of winter symptoms.

On some sites, dieback occurs during the summer and fall. Summer-dieback can appear in July and gradually increases over the next several months. These symptoms develop in a "bottom-up" pattern. By September, the 3rd flush may have 50 percent of the needle length affected while needles on the 5th and 6th flush are symptom free (Martin and Blakeslee

[1]Professor, School of Forestry and Wildlife Sciences, Auburn University, AL; Professor, Department of Pomology, UC Davis, Davis, CA; Scientist, Westvaco, Summerville, SC; Scientist, Forest Research, Christchurch, NZ; Plant Pathologist, National Soil Dynamics Laboratory, Auburn, AL; Scientist, Soil Scientist Forest Research, Rotorua, NZ, respectively.

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Table 1— Seedbed density, mean root-collar diameter (RCD) and visual freeze damage estimates (percent of seedlings) for 60 seedlings from five seedlots at a nursery in Alabama in February 1996. A –9° C freeze occurred on January 19 and a –13° C freeze occurred on February 5

Family	Density	RCD	Damage
	#/m2	mm	%
7-56	237	5.3	97
12-42	215	5.6	27
1-82	237	5.4	15
1.5 orchard mix	215	5.0	22
2.0 orchard mix	226	4.7	13

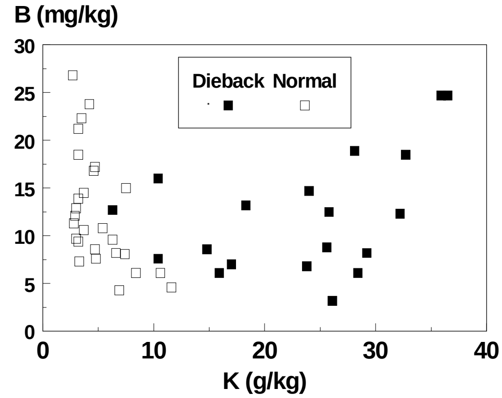

Figure 1— Concentrations of B and K in the foliage of the terminal shoots from normal (open squares) and symptomatic (closed squares) loblolly pines exhibiting winter dieback in Alabama. Each point represents one tree.

1998). By mid-November, the 5th and 6th flush will have affected needles. Necrosis appears on needle tips first and then progresses down the fasicle. On each needle, there is a sharp transition from necrotic tissue to living tissue and the distance from the tip to the transition line is the same on all three needles. On some trees, the terminal buds die and dry out. On a few trees, the terminal growth is deformed and the lateral branches form a "nest-like" appearance (Martin and Blakeslee 1998).

For both winter and summer symptoms, the probability of occurrence in intensively-managed plantations is highest 2 to 5 years after planting and then appears to decline with age. Some shoots with dieback have many 4- and 5-needle fasicles. As trees get older and larger, competition increases and the incidence of dieback decreases.

The symptoms have a genotypic component since fast-growing families are more susceptible than others. In particular, family 7-56 often shows winter dieback symptoms and on certain sites, has exhibited summer dieback symptoms. Wildlings in the same plantation almost never show dieback symptoms. Slash pine (*Pinus elliottii*) does not appear to be affected in intensively managed stands.

SIX HYPOTHESES

Tip-dieback in intensively managed plantations can likely be explained by one of the following hypotheses: 1) freeze injury; 2) K imbalance; 3) B deficiency; 4) some other abiotic agent; 5) a biotic agent. Since there are two types of dieback, it is possible dieback is; 6) caused by two independent factors.

The Freeze Injury Hypothesis

Winter dieback symptoms might be simply explained by freezing temperatures as suggested by Clark (1972) 30 years ago. Low temperatures that cause injury to pines will vary with the amount of warm weather that precedes the freeze (Mexal and others 1979). For example, a –4° C freeze at a nursery can injure loblolly pine needles in November (South and others 1993). In late December or early January, it may require a –7° C freeze. However, if loblolly seedlings are from a northern seed source and are well acclimated (with no succulent tissue), a –16° C freeze in late-December might cause little visual injury to seedlings in a bare-root nursery. The degree of freeze injury will depend on how many cells in the cambium are actively dividing at the time of the freeze. Winter dieback of Corsican pine (Pinus nigra var. calabrica) is more likely to occur when a February freeze of –7° C follows a mild period than when a –14° C freeze follows a cold January (Read 1967).

Some loblolly families can be injured at –5° C (Hodge and Weir 1993) and family 7-56 is susceptible to freeze injury (table 1). Certain individuals within this family are more freeze sensitive than others. On January 26, 1999, the temperature at Auburn, AL dropped to –7° C and symptoms were noticed in two intensively managed 7-56 plantations at the end of February. Further investigations revealed freeze injury symptoms (brown tissue) under the bark at breast height.

One year later, on December 21, 2000, temperatures at Auburn, AL dropped to –10° C and dieback symptoms were noticed on several open-grown trees (ages > 10 years) two months later on February 24, 2001. Three trees were located on the campus of Auburn University. Intensively managed plantations (7-56) also showed symptoms.

At Waycross, GA, temperatures dropped to –7° C (December 21, 1996) and summer dieback symptoms were noticed on an intensively managed plantation (7-56) seven months later in July (Martin and Blakeslee 1998). This plantation was planted in December, 1995 and, therefore, the trees were about 2.5 years old from seed when symptoms appeared. Concentrations of macro and micronutrients in the terminal were higher in the affected needles than in unaffected needles. Symptoms were observed on trees ranging in height from 0.5 to 3.6 m.

The Potassium Imbalance Hypothesis

High K in foliage from affected shoots is a unifying trait for both winter and summer dieback. When plotted together, it is apparent that dieback is more related to high K levels (>10 g/kg) than with low B (figure 1). In some cases, the foliar K levels are 4 to 10 times higher than normal, therefore some wonder if there is an error in analysis. Terminal shoots of 7-56 seedlings contain high levels of K while lower branches are normal (table 2). Terminal shoots and branches of wildlings also have normal levels of K even though treated with the same herbicides and fertilizers as adjacent planted trees. The lack of high K in wildlings indicates a genetic basis; likely related to growth rate.

At one site, newly planted 7-56 seedlings were fertilized in March, 1996 with 56, 12 and 23 kg/ha of N,P,K, respectively, and summer dieback symptoms appeared in July of 1997. High concentrations of K were observed in September, 1997 with the mean of symptomatic shoots approaching 24 g/kg (Tim Martin, pers. Comm.). One sample had a value of about 48 g/kg K which is likely a record for loblolly pine. All elements were above commonly accepted "critical" levels. Although K toxicity is not known to occur in pine trees, fertilization with K can sometimes increase dieback symptoms (Kurkela 1983). At Bainbridge, GA, summer dieback symptoms were much lower after K was removed from fertigation (Tom Cooksey, pers. comm). Several scientists question the belief that high K levels in pine shoots do not cause nutrient imbalances. In fact, some believe that high K:Mg ratios can affect fast-growing pines (Beets and Jokela 1994). At one location, the K:Mg ratio in winter dieback shoots was 25 (table 2). Since high K values in foliage is obtained from a range of soil types (and sometimes from non-fertilized trees), we hypothesize that freeze injury in the cambial zone results in high K values in the shoot.

The Boron Deficiency Hypothesis

Some observers have noted a similarity to dieback symptoms caused by a deficiency in B. Damage to buds and tip dieback are typical symptoms of B deficiency. The pith is often completely brown and dieback symptoms may resemble that caused by pathogens (Stone 1990). Boron related dieback on pines in New Zealand typically occurs in midsummer after droughts but unusual cases of winter dieback can also occur (Will 1985).

Table 2— Nutrient content (g/kg) of selected elements in the foliage of the terminal shoots and lateral branch (height approximately 2 m) of loblolly pines in an intensively managed plantation (April 5, 2000). Dieback was observed only on the shoots of 7-56. Each mean represents a sample of three trees (means within a row having common letters are not significantly different α = 0.05)

Nutrient	7-56 Shoot	7-56 Branch	Wildling Shoot	Wildling Branch
N	21.0a	20.0a	21.0a	20.0a
P	2.3a	0.8b	1.2b	0.8b
K	35.0a	3.7b	3.6b	3.6b
Mg	1.4a	1.1a	1.5a	1.0a
Ca	2.0a	2.4b	3.6a	2.8ab
B	0.022a	0.013b	0.020ab	0.016ab

Fertilization with B reduced summer dieback of loblolly pine in China (Zhu 1988, Zhou and others 1997) and reduced winter dieback symptoms in Africa (Vail and others 1961, Procter 1967). However, fertilizing the soil with B failed to ameliorate the problem in South Carolina (Clark 1974) and Alabama (personal comm. Scott Cameron). In some cases, shoots with winter dieback symptoms have B levels as high as 22 ppm (table 2). In other cases, shoots with no dieback symptoms have B levels as low as 5 ppm (figure 1).

Symptoms of B deficiency are usually characteristic, "although diagnosis may be confounded by variable foliar concentrations, erratic occurrence and possible climatic damages" (Stone 1990). In fact, "near the minimum end of the range, concentrations of apparently healthy trees may be less than those in visibly deficient trees" (Stone 1990). It should be noted that a "grossly unequal distribution" of B can exist in pine needles with high levels in the tips and low levels at the base (Stone 1990). In addition, improper sampling procedures could contaminate the foliage and could result in an upward bias.

Boron is important for lignification of tissue and non-lignified tissue is more sensitive to freezes than lignified tissue. Therefore, marginally B deficient pines can be damaged by a freeze (Kolari 1983). However, it is not clear if trees with B deficiency are actually more susceptible to the freeze or if the freeze simply caused the expression of the B deficient injury (Stone 1990). Boron may also be related to infection rate of certain diseases. Data from a greenhouse study with Eucalyptus indicated that seedlings were more susceptible to *Lasiodiplodia theobromae* when B concentrations in the leaves were below 30-35 ppm (Silveira and others 1996).

Prior to development of dieback symptoms, many of the intensively managed plantations were fertilized with N and P. Fertilization of macronutrients can sometimes induce dieback on low-B soils (Kolari 1983, Brockley 1990, Stone 1990). "Because B deficiency symptoms can develop rapidly following an interruption in B uptake, and because top dieback can have such an adverse effect on stem quality and value, it is recommended that B be added to N fertilizer when undertaking aerial fertilization projects in lodgepole pine forests when average foliar B concentrations are <15 ppm" (Brockly 1990). In the southern U.S., one company now uses a fertilizer mix that includes B along with N and P. This fertilizer combination was developed for use in intensively managed loblolly pine plantations to avoid problems with B deficiency.

Except for the high K levels in shoots, there appear to be many similarities between growth disturbances reported from Finland (Kolari 1983) and the dieback reported on loblolly pine in the U.S. The once-confusing dieback symptoms in Finland "Now appear largely, though not exclusively, due to B deficiency" (Stone 1990). Some wonder if the high levels of K in loblolly pine foliage could interfere with normal B metabolism.

The Abiotic Hypothesis

In addition to freezes and imbalances of B and K, other abiotic causes for dieback have been proposed. Some believe loblolly pine may be growing faster now than in the past due to elevated levels of carbon dioxide (Valentine and others 1999). Faster stem growth might be having an effect on the production of short-roots (Dean 2001) that might affect uptake of certain nutrients. Some allege that natural electrical point discharges from the shoot tip can interrupt the hardening process and increase freeze damage (Aurela and Punkkinen 1983). Others wonder if air pollution might cause dieback.

The Biotic Hypothesis

Lasiodiplodia theobromae is a ubiquitous facultative wound pathogen that has been associated with cankers and dieback of several trees including *Cupressus sempervirens* (Bruck and others 1990), *Eucalyptus citriodora* (Silveira and others 1996), *Liquidambar styraciflua* (Garren 1956), *Platanus occidentalis* (Lewis and van Arsdel 1976, Cooper and others 1977) and *Albizia falcataria* (Sharma and Sankaran 1988). This fungus has been found on slash pine seed in orchards (Fraedrich and Miller 1995) and on seedlings in loblolly pine and slash pine nurseries (Rowan 1982). Roy Hedden isolated this fungus from winter-dieback trees in South Carolina and Georgia and his student determined that inoculations cause dieback of 2-year-old loblolly pine seedlings (Jolley 2001).

Secondary fungi associated with dieback of loblolly in China include *Sphaeropsis sapinea* (Su and others 1991), however, loblolly pine is generally more resistant to this vectored fungus than other pines (Bega and others 1978, Swart and others 1988). Secondary insects are occasionally associated with winter dieback symptoms include Scolytid twig borers (*Pityophthorus pulicarius*) (Clark 1972).

The Two-factor Hypothesis

Due to the difference in symptom development for summer and winter dieback ("top-down" vs. "bottom-up"), it would not be surprising if two independent vectors were involved. It is possible that winter dieback is a function of freeze injury as suggested by Clark (1972). The combinations of rapid shoot growth followed by warm falls would likely increase the susceptibility of certain genotypes to injury from a –5^{o}C freeze. Freeze injury would likely increase the rate of infection from *Lasiodiplodia theobromae* while adjacent genotypes without freeze injury would not be infected.

In contrast, summer dieback symptoms appear to be less common and may be restricted to certain soil groups. Summer dieback might be due to an imbalance of nutrients resulting from either fertilization with only macronutrients, an imbalance between K and B, or perhaps an inadequate production of short feeder roots.

RECOMMENDATIONS

Only a few experiments have been conducted to test hypotheses related to dieback on loblolly pine. Trials should be conducted to determine if the high foliar K levels are a direct result of freeze injury. This might be accomplished by growing 7-56 in large containers in a heated greenhouse in Virginia and moving selected individuals outside just prior to a –10^{o} C (or colder) freeze. The foliage levels could be monitored to determine if the freeze affected nutrient levels in the shoot and sap.

Trials should be conducted to determine if K toxicity occurs on loblolly pine. Tree injectors could be used to apply potassium carbonate or potassium sulfate to 3-year-old seedlings. Rates applied should increase K levels in the foliage to 30 g/kg or greater. In addition, periodic nutrient analysis of a progeny test should be conducted to determine if 7-56 normally has high K levels in the terminal shoot.

Although a few B fertilizer trials have failed to produce beneficial effects, we have no information regarding the timing or amounts of B applied. We propose that prophylactic trials be conducted in young 7-56 plantations with the new N,P,B fertilizer (along with traditional N,P fertilizer). These trials should be conducted on the same soil groups where summer-dieback symptoms have occurred in the past. Greenhouse trials should be conducted to determine if K or B levels in loblolly pine shoots affect susceptibility to *Lasiodiplodia theobromae*.

In some conifers, dieback does not seem to cause a significant problem with wood quality (Bodner 1988). However, there is some concern that even small crooks can affect both the stumpage and lumber value. With loblolly pine, compression wood associated with dead terminals might reduce pulp yields by 1.5 to 2.5 percent (Hedden 1998). Plantations with severe winter dieback should be documented and later evaluated at harvest to determine the effects on wood quality.

SUMMARY

Evidence is yet not fully convincing for any of the above hypotheses. Each hypothesis has supporters. The next step is for scientists to conduct trials to determine the true causes of winter and summer dieback.

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