What the Future Holds for *Tree Planters' Notes*: Getting TPN Back on Schedule

The *Tree Planters' Notes* Editorial Board has started a major effort to correct the unfortunate time lag you see between the calendar date and the date on the issue! Various factors are the cause of this problem and we are working on fixing them while still improving article quality and improving our services to our readers. We've taken the more difficult path and decided against just skipping 1996 because of the bibliographic problems this would create.

In addition to research articles and all the new categories of articles we talked about in the last issue, we will be publishing what we are calling **LITTLE-KNOWN CLASSICS.** These are good papers that have been published in newsletters and regional publications and thus are not always seen by many readers and are often not in the databases. The first of these is the article by Dierauf and Garner on root collar diameter and its effects on yellow-poplar survival and growth. We are also working on a 10-year index, to be published this year.

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Comments

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Cover: Collecting pre-bagged cones of a known blister-rust-resistant sugar pine *(Pinus lambertiana* Dougl.) by spurless climbing on the Mt. Home Demonstration State Forest, California; other trees in the photograph are mature giant sequoia *(Sequoiadendron giganfeum* (Lindl.) Buchholz (climber Carl jackovich was photographed by Dean Bungart).

Adapting JIT Principles to Nursery Production

Some say that 1996 was a record year for seedling production in the southern United States— a record shortfall. Seedling demand was so great that many nurseries were sold out by April. The exact reason for the increased demand is debatable. Some people placed their orders earlier in 1996 due to a shortfall of seedlings in 1995. Others believe the increased demand is due to higher levels of timber harvests (a result of higher stumpage prices). But whatever the reasons, it is a shame that in a country with such a high demand for wood fiber, so many acres will not be planted this year. Can we avoid similar shortages in the future? If we adopt "Just-In-Time "– JIT– principles, I believe we can at least reduce the magnitude of the shortfall.

What are these JIT principles? *They include rapid response to changes in markets or technology, the elimination of waste, striving for continued improvement, and employee involvement to make it all happen. Just-in-time requires that every phase of current processes be reexamined, rationalized, and simplified in order to respond quickly to customers' needs.*

Many nurseries in the southern United States continue to use outdated ordering systems. For example, some nurseries allow only large, industrial customers to place orders for seedlings before sowing; some do not allow private landowners to order seedlings before October 1. Some are using the same paper-driven system that was developed before the days of computers. In my opinion, the old systems should be reexamined and modified. Some nurseries are already making improvements. For example, in Alabama, a new system will allow all customers to order seedlings from the state nursery months or even years in advance.

Traditionally, nursery managers and state foresters have had to make their best guess at predicting seedling demand by non-industrial landowners, who use over 48% of the seedling crop. Many customers (even some who use forestry consultants) have become accustomed to showing up at the nursery in December or January and leaving with 50 bags of seedlings. If antiquated systems are kept in place, and if demand for seedlings continues to increase at an average rate of 25 million seedlings/year (since 1950), both overestimates and shortfalls will get larger in the future. What is needed is a better system that will take some of the guesswork out of predicting seedling demand. I believe adapting JIT principles would be a great improvement over the current system. For nursery use, the acronym for this system is JBS (for "Just-Before-Sowing").

The JBS system would reward and encourage customers to order seedlings at least 1 month before sowing. Customers ordering loblolly or slash pine may have a March 1 deadline. For bareroot longleaf pines, this may be a September 1 deadline (15 months before lifting). Customers who order before these deadlines are identified as JBS customers. Like passengers in first class, they get special perks. First, they get a discount on the price of seedlings. Second, their seedlings are identified on a map and are given "reserved" status. Third, the appropriate seed source is sown for their planting area. "Regular" customers may order seedlings anytime after the deadline, but (1) they do not get a discount on price and (2) their seedlings are allocated only after the fall inventory check. When the fall inventory is short, regular customers run the risk of having their order downsized. At the time of placing the order, both regular and JBS customers pay a nonrefundable deposit (about 10%).

It will be unlikely that all nurseries will adopt this system for use in 1997. Some bean-counters may not see the advantages of this system and may oppose a change for the better. However, nurseries that use and print the new system on price lists may, over time, attract the lion's share of JBS customers. Organizations that do not adopt the JBS system may find that they are the ones who are left with the problem of predicting demand from regular customers.

The key to success of the JBS system is getting a greater number of individuals ordering seedlings before seed stratification. This year has demonstrated that many non-industrial landowners are willing to place orders early. In fact, the peak month for seedling orders was in May (December has traditionally been the peak month). If we can just move the peak date up 2 more months to March, future seedling shortages would be relatively minor in comparison. No doubt there will always be landowners who place orders after sowing because they do not know the system or do not use the advice of forestry consultants. However, if we go ahead and make the change-and inform consultants and regular customers of the advantages of ordering early-we can have a win-win situation in which both the JBS customer and the nursery benefit. Just as JIT principles have been particularly crucial to improving the efficiency of retail stores, JBS can improve the efficiency of forest tree nurseries.

[Views expressed here are my own, and I am not speaking on the behalf of others. - DBS]

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Fifth-Year Results From a Test of Longleaf Pine Seed Sources on the Francis Marion National Forest and in Central Georgia

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Longleaf pine seedlings from 8 sources ranging from eastern North Carolina to southern Mississippi were planted in tests at 3 locations on the Francis Marion National Forest in South Carolina and 1 location in central Georgia. Seedlings were started in the greenhouse in January and field-planted in May 1991. At age 5 years from seed, survival was high and few seedlings were still in the grass stage. Variation among seed sources was significant for survival in 1 location, for height in 2, and for within-plot coefficient of variation in height in 1. In combined analyses, neither survival nor CV in height varied significantly among seed sources averaged over plantations, but height did. Differences among plantation averages were significant for height and CV in height. Height growth was best and least variable in the Georgia plantation. Tree Planters' Notes 47:6-10; 1996.

Hurricane Hugo in 1989 destroyed much of the timber on the USDA Forest Service's Francis Marion National Forest (FMNF) in South Carolina. Forest managers plan to plant longleaf pine on suitable sites in the storm-damaged area. However, the local longleaf pine seed orchard was also destroyed. Until the seed orchard is re-established and producing, using seeds from other sources will be necessary. Some of these seed sources may not be genetically well-adapted to conditions on the FMNF whereas others may do better than the local source. In 1991, a study was installed on the FMNF to evaluate relative performance of 8 prospective seed sources. Data from the study will provide a basis for deciding whether to use natural methods, such as shelterwood, to reproduce stands established from nonlocal sources, and whether some sources perform well enough on the FMNF to be used even after local seeds are available.

Background

Early European settlers found most of the land in what is now the southeastern United States covered by park-like stands of old-growth longleaf pine. The range of the species extended from southeastern Virginia to eastern Texas and from south-central Florida to north-central Alabama and Georgia (figure 1). Over this range, it originally occupied about 60 million acres. Longleaf pine stands have now been reduced to about 4 million acres by land clearing for agriculture or harvesting without provision for reproduction (Croker 1987).

Longleaf pine is prized for its resistance to fire, insects, and disease; deep root system; and rapid growth through middle age. Its demanding planting requirements, however, have caused planting failures in the past that discouraged management of the species. Mature stands can be regenerated with shelterwood techniques that include prescribed burning, and directseeding has had some success (Croker 1987, Derr and Mann 1971).

Successful planting techniques have recently been developed, greatly increasing interest in managing longleaf pine (Croker 1987). These techniques include producing large seedlings, handling and storing them carefully (including refrigeration), planting at the correct depth, and controlling competition and brown-spot needle blight (caused by *Mycosphaerella dearnsii* Barr) (Brissette and others 1990, Croker 1987, Hatchell and Muse 1990, Sirmon 1990, Snow and others 1990, Wakeley 1954).

With artificial regeneration, nonlocal seed can be used, but forest managers first need to know the geographic limits within which seed can be moved safely. The Southwide Pine Seed Source Study has provided information on the broad pattern of genetic variation in longleaf pine. Significant variation in survival, growth, and resistance to brown-spot needle blight occurred among the widely spaced seed sources in the study (Henry and Wells 1967, Schmidtling and White 1990, Wells and Wakeley 1970). Results indicate that variation patterns permit wide movement of seeds with low risk of failure within certain specified climatic limits. Other studies indicate that local variation is greater than that associated with broad geographic patterns (Kraus and Sluder 1990, Snyder and Derr 1972).

A breeding program to improve the genetic quality of planting stock would increase benefits from use of artificial regeneration in managing longleaf pine. Longleaf pine areas in the national forests of the Southern Region (region 8) have been divided into breeding populations;

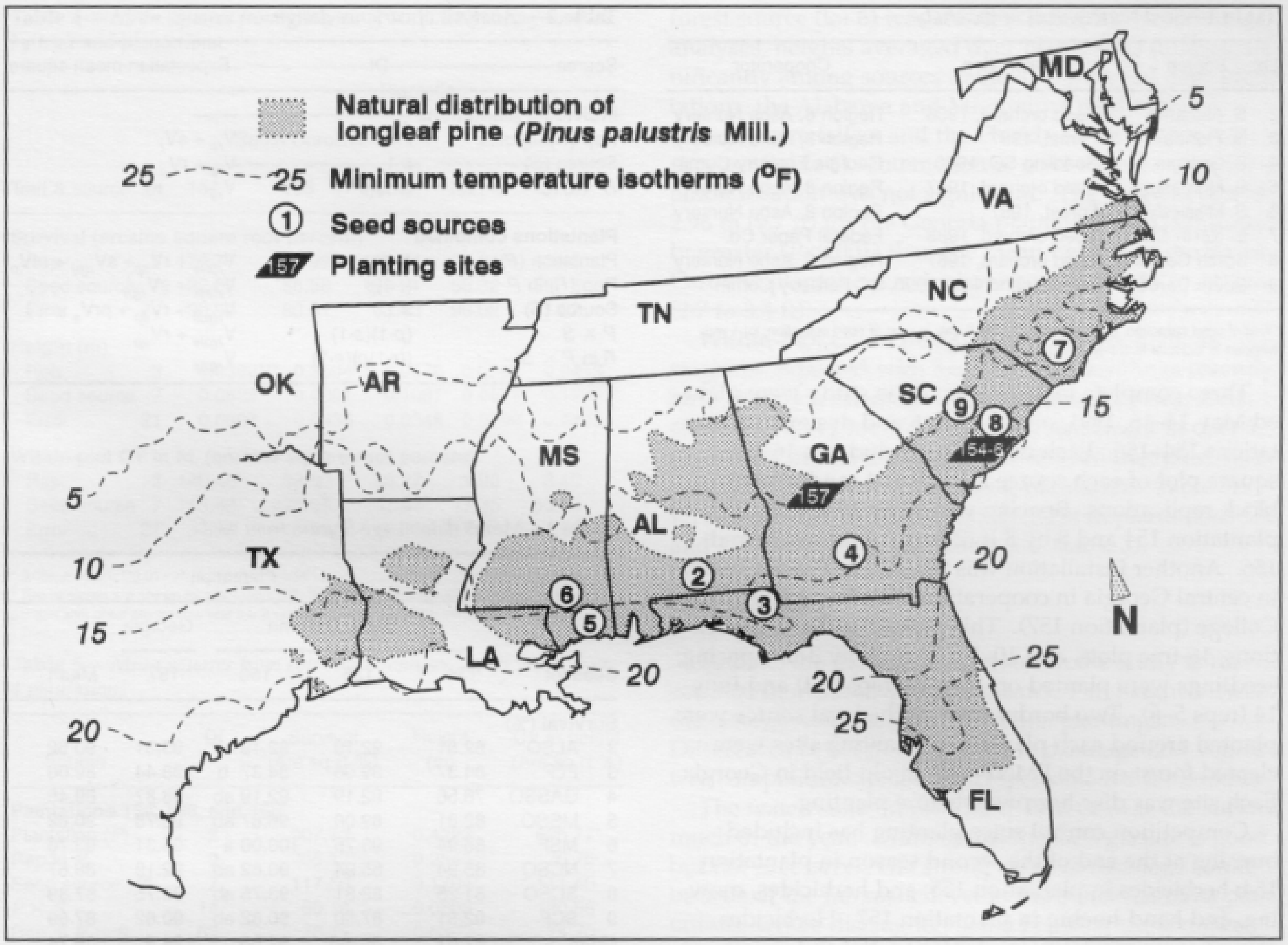

Figure 1—*Natural distribution of longleaf pine and minimum temperature isotherms in southeastern United States, seed sources, and planting sites.*

phenotypically superior trees have been selected; and clonal seed orchards and progeny tests have been established (Schmidtling and White 1990, Wells and McConnell 1984).

Tests that determine the limits within which planting stock from the region 8 seed orchards could safely be moved are needed. Only then will forest managers be able to meet possible future emergency planting needs caused by disasters such as that inflicted by Hurricane Hugo on the FMNF. This paper describes a test designed to fill this need.

Methods

Longleaf pine seeds from 8 geographic sources (4 from clonal seed orchards, 3 from forest collections, and 1 from a seedling seed orchard) were included in this study (table 1). The sources, located in 6 states, were distributed within or near a zone with average minimum temperatures of 10 to 15 °F (-12.2 to -9.5 °C). This zone includes the Francis Marion National Forest (figure 1). Seeds from cooperators were obtained in 1990 (table 1). Seeds collected before 1990 were stored at subfreezing temperatures.

Seeds were planted in the greenhouse in January 1991, in 10-in^3 (164-cm^3) plastic tubes filled with a medium of peat, perlite, and vermiculite to which a slow-release fertilizer had been added. When the seedlings became crowded, tubes were rearranged to occupy alternate spaces within the racks. In April, seedlings were moved from the greenhouse to a shadehouse, then a week later to full sun. A benomyl (Benlate®) drench was used periodically to control fungal infection.

Table 1—*Seed sources used in the study*

Lot	Source	Description	Cooperator
2	S. Alabama	Seed orchard, 1988*	Region 8, Ashe Nursery
3	N. Florida	Forest, 1987	Region 8, Ashe Nursery
4	S. Georgia	Seedling SO, 1990	Georgia Forestry Comm.
5	S. Mississippi	Seed orchard, 1987	Region 8, Ashe Nursery
6	S. Mississippi	Forest, 1987	Region 8, Ashe Nursery
7	E. North Car.	Seed orchard, 1988	Federal Paper Co.
8	South Carolina	Seed orchard, 1987	Region 8, Ashe Nursery
9	South Carolina	Forest (sandhills), 1990	SC Forestry Comm.

*Year of seed collection. Lot 1 differed from lot 2 only in year of seed collection; lot 1 was dropped to facilitate field layout. SO= seed orchard.

Table 2— *Analysis of variance design*

Source	Df	Expectation mean square
Individual plantations		
Rep (*R*)	*r*-1	$V_{rs} + sV_{r}$
Source (*S*)	*s*-1	$V_{rs} + rV_{s}$
R × *S*	(r-1)(s-1)	V_{rs}
Plantations combined		
Plantation (*P*)	*p*-1	$V_{r(p)s} + rV_{sp} + sV_{r(p)} + rsV_{p}$
Rep (*R*) in *P*	(*r*-1)*p*	$V_{r(p)s} + sV_{r(p)}$
Source (*S*)	*s*-1	$V_{r(p)s} + rV_{sp} + prV_{s}$
P × *S*	(*p*-1)(*s*-1)	$V_{r(p)s} + rV_{sp}$
R in *P* × *S*	((*r*-1)*p*)(*s*-1)	$V_{r(p)s}$

Three complete installations of the study were planted May 14-16, 1991, on the FMNF and designated plantations 154-156. Each plantation included a 16-tree square plot of each source in each of 4 randomized-block replications. Spacing was 10 by 10 ft (3 by 3 m) in plantation 154 and 8 by 8 ft (2.4 by 2.4 m) in 155 and 156. Another installation was planted in Peach County in central Georgia in cooperation with Fort Valley State College (plantation 157). This plantation has 6 replications, 16-tree plots, and 10- by 10-ft (3- by 3-m) spacing; seedlings were planted on May 24 (reps 1-4) and June 14 (reps 5-6). Two border rows of the local source were planted around each plantation. Planting sites were cleared forest on the FMNF and an old field in Georgia. Each site was disc-harrowed before planting.

Competition control since planting has included burning at the end of the second season in plantation 154; herbicides in plantation 155; and herbicides, mowing, and hand-hoeing in plantation 157. Herbicides caused some mortality in plantation 157 and excess water caused some in plantation 155 during the first growing season. The vacant spots were replanted with tubelings from the same sources. The tubelings had been transferred to larger containers and kept to replace dead trees.

The study was assessed at the end of the 1995 growing season, the end of the seedlings' fifth year from seed. Survival was recorded and heights measured to the nearest centimeter. Data were analyzed for survival, plot mean height, and within-plot coefficient of variation (CV) in height. Percentage data (survival and CV) were transformed to the arcsines of their square roots for analysis. Data were analyzed by plantation and with plantations combined (table 2).

Results

Survival was high and varied significantly among seed sources in only 1 plantation (tables 3 and 4). Plantation mean survival ranged from 83% in plantation 154 to 94% in plantation 157. Table 5 shows that sur-

Table 3—*Means data at age 5 years from seed*

	Plantation				
	South Carolina			Georgia	
Seed lot	154	155	156	157*	Mean
Survival (%)					
2 ALSO	82.81	92.19	92.19 ab	95.31	90 62
3 FLF	84.37	89.06	84.37 b	98.44	89.06
4 GASSO	76.56	92.19	92.19 ab	96.87	89.45
5 MSSO	82.81	89.06	96.87 ab	93.75	90.62
6 MSF	85.94	93.75	100.00 a	95.31	93.76
7 NCSO	85.94	85.94	90.62 ab	92.19	88.67
8 SCSO	81.25	82.81	93.75 ab	93.75	87.89
9 SCF	82.81	87.50	90.62 ab	90.62	87.89
Mean	82.81	89. 06	92.58	94.53	89.74
Height (m)					
2 ALSO	0.89	0.92	1.18 ab	3.22	1.55 ab
3 FLF	0.57	0.70	0.78 b	2.83	1.22 c
4 GASSO	0.86	0.75	0.94 ab	2.80	1.34 bc
5 MSSO	1.06	1.15	1.01 ab	3.08	1.57 a
6 MSF	0.68	0.79	1.17 ab	2.76	1.35 abc
7 NCSO	0.83	0.94	0.88 ab	2.97	1.41 abc
8 SCSO	0.80	0.95	1.26 a	2.93	1.49 ab
9 SCF	0.79	0.95	1.09 ab	3.05	1.47 ab
Mean	0.81 c	0.89 c	1.04 b	2.96 a	1.42
Within-plot CV (%)					
2 ALSO	45.86 ab	63.91	60.40	23.32	48.37
3 FLF	41.58 ab	61.04	56.63	28.03	46.82
4 GASSO	40.05 b	80.25	67.96	23.48	52.92
5 MSSO	66.66 a	55.61	56.01	21.63	49.98
6 MSF	43.84 ab	73.04	49.81	27.01	48.42
7 NCSO	56.01 ab	59.25	61.33	21.61	49.55
8 SCSO	45.60 ab	55.68	48.43	29.94	44.91
9 SCF	42.11 ab	50.26	51.69	22.86	41.73
Mean	47.72 b	62.54 a	56.52 a	24.74 c	48.71

In columns or lines with letters, means not followed by a common letter differ at the $P< 0.05$ level according to Bonferroni's method (Miller 1981).

* Plantation 157 means include only reps 1–4.

Table 4— *Mean squares from analyses of variance of 5th-year data, by trait and plantationa*

		Plantation				
		South Carolina			Georgia[†]	
Trait & source	Df	154	155	156	157(4)	157(6)
Survival (arcsine square root percent)						
Rep	3	176.77	307.99*	130.74	32.84	43.46
Seed source	7	22.09	56.58	199.21*	65.32	36.13
Error	21	90.50	80.51	63.43	98.02	91.32
Height (m)						
Rep	3	0.3362***	0.3594***	0.0678	0.0246	0.0413
Seed source	7	0.0823	0.0801	0.1087*	0.0977*	0.1707**
Error	21	0.0397	0.0435	0.0348	0.0392	0.0495
Within-plot CV in ht. (arcsine square root percent)						
Rep	3	140.46*	38.50	33.27	1.90	6.40
Seed source	7	115.48*	175.98	61.67	17.35	35.63
Error	21	34.93	140.80	48.38	17.01	17.59

* 0.05> P >0.01; **0.01> P >0.001; *** P<0.001.

[†] Two analyses are shown for plantation 157, for 4 and 6 reps; the 4-rep analysis is for comparison with ohter plantations and the 6-rep analysis for complete information.

Table 5— *Mean squares from combined analyses, age 5 years, 3 or 4 plantations*

Source	Df	Survival (Arc sq rt %)	Height (m)	CV in height (Arc sq rt %)
Plantations 154, 155, and 156				
Plantation (*P*)	2	907.73	0.4223	695.77*
Rep in *P*	9	205.17*	0.2545***	70.75
Seed source (*S*)	7	117.50	0.1704*	111.40
P × *S*	14	80.18	0.0503	120.86
Rep in *P* × *S*	63	78.15	0.0393	74.70
Plantations 154, 155, 156, and 157[†]				
Plantation (*P*)	3	1166.74	33.6066***	3290.74***
Rep in *P*	12	453.77	0.1970***	53.54
Seed source (*S*)	7	96.20	0.22.62**	69.00
P × *S*	21	82.33	0.0475	100.49
Rep in *P* × *S*	84	83.12	0.0393	60.28

* 0.05> P >0.01; ** 0.01>P >0.001; *** P<0.001.

[†]Only reps 1-4 from plantation 157 were used in these analyses.

vival rates among plantations did not differ significantly, with or without the Georgia plantation. No plantation-by-seed-source interaction in survival was evident.

According to standard analysis of variance (table 4), mean heights varied significantly among sources (P<0.05) in plantations 156 and 157. However, Bonferroni's somewhat conservative method of multiple comparisons among means (table 3) showed significance among mean heights only in plantation 156. In 156, the SC seed orchard source (lot 8) was tallest and the Florida source (lot 3) was shortest. In 157, the Alabama source (lot 2) was tallest and the Mississippi forest source (lot 6) was shortest (table 3). In combined analyses, heights averaged over plantations differed significantly among sources (table 5). Averaged over plantations, the Alabama and Mississippi seed orchard sources were tallest and the Florida forest source was shortest (table 3). Interaction of seed source with plantation location was not significant. The mean height of 2.96 m (9.7 ft) for the Georgia plantation was significantly greater (P<0.001) than the mean heights in the South Carolina plantations, which ranged from 0.81 to 1.04 m (2.7 to 3.4 ft).

Within-plot CV in height was generally high, as might be expected with longleaf pine seedlings recently emerged from the grass stage. Variation among seed sources in this trait, however, was significant in only 1 plantation (tables 3 and 4). In combined analyses, variation was significant only among plantations (table 5). Within-plot CV in height was greatest in plantations 155 and 156 and least in plantation 157 (table 3).

Discussion

To date, the most striking result in the study is the contrast in mean height and mean CV in height between the Georgia and the South Carolina plantings. Differences between the 2 areas in drainage and vegetative competition are largely responsible for the contrast.

The water table on the FMNF is at or near the surface much of the year. Drainage on the Georgia site is good but not excessive. The strong effect of drainage could be seen at the microsite level in the South Carolina plantations, where discing left some planting spots noticeably lower than others. After rains, seedlings in low spots stayed under water longer, had higher mortality, and grew less than those in better drained spots.

Vegetative competition built up slowly in the South Carolina plantations and has not been well controlled. Competition on the Georgia site was almost immediate and would have been severe without intensive control measures. Because vegetation was controlled and drainage was good on the Georgia site, a majority of the seedlings began height growth during the second growing season, and many were more than 4 m (13 to 15 ft) tall by the end of the fifth season.

The brown-spot needle blight disease has been no problem in this study. A few seedlings were noticeably infected during the second year in the Georgia plantation, but little infection was evident at the end of the third, fourth, and fifth seasons.

The plantings are well established, and the next assessment will occur at age 10 years. By that age, the effects of the grass stage and early competition on height variation should be relatively small, and managers should be able to base decisions on reliable variation patterns. The study has already shown that sources of longleaf pine from a wide east-west and relatively narrow north-south band of similar climate will perform similarly on the FMNF. The performance of the west Florida source may reflect local variation in the genetic quality of the stand from which the seed was collected rather than a deviation from a broad pattern of variation associated with climate. The high survival rate of seedlings used in this study is due in part to the use of container planting stock. High survival with bareroot stock can be difficult to achieve. In a study comparing performance of bareroot and container planting stock, with the best combination of treatments, survival was 66% for bareroot and 97% for container seedlings (Boyer 1988).

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Susceptibility to Brown-Spot Needle Blight and Fusiform Rust in Selected Longleaf Pine and Hybrids

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Fusiform rust (Cronartium quercuum *(Berk.) Miyabe ex Shirai f. sp.* fusiforme (Hedgc. & Hunt) Burdsall & Snow) *collected on loblolly pine* (Pinus taeda *L.*) *was used to inoculate progeny from 15 longleaf pine* (P. palustris *Mill.*) *controlled crosses, 7 longleaf* x *slash pine* (P. elliottii *Engelm.*) *hybrids, 5 longleaf* x *Sonderegger (natural longleaf* x *loblolly hybrid) hybrids, 3 longleaf* x *loblolly hybrids, and wind pollinated progeny from each of the parent trees. Field plantings also were established to compare fusiform rust in green house inoculations with field incidence of fusiform rust as well as brown-spot needle blight* (Mycosphaerella dearnessii *Barry. There was no relationship between fusiform rust infection in the greenhouse and brown-spot needle blight after 3 years in the field in the longleaf crosses and the hybrids. There was also no relationship between nursery height and brown-spot needle blight in the longleaf crosses, but there was a negative relationship in the hybrids. The results indicate that resistance to brown-spot can be incorporated into longleaf breeding programs without changing susceptibility to fusiform rust.* Tree Planters' Notes 47:11-15; 1996.

The area of longleaf pine in the southern United States has declined from 12.2 to 3.8 million acres (4.94 to 1.54 million hectares) over the past 30 years (Kelly and Bechtold 1990). In many ways, longleaf is the most valued of the southern pines (Croker 1990), and there is now renewed interest in restoring longleaf pine to its historical commercial and ecological prominence.

One of the primary reasons that the acreage of longleaf pine has declined has been the lack of successful reforestation. Natural regeneration is sporadic, and planting is difficult. The species has a "grass" stage lasting one to several years during which height growth is delayed. Early survival and growth are often severely affected by brown-spot needle blight (Wakeley 1970). Breeding programs have been underway for more than 35 years to improve brown-spot resistance and height growth of longleaf pine (Bey and Snyder 1978).

Fusiform rust is generally considered not to be a problem in longleaf pine management (Hepting 1971) but it is the most damaging disease of slash pine as well as loblolly pine in the southeastern United States (Powers and others 1981). Fusiform rust susceptibility is heritable in longleaf pine (Snyder and Namkoong 1978) and occasionally causes substantial losses (Kraus and Sluder 1990). Wakeley (1968) has suggested that plant breeders, selecting for early height growth and brown-spot resistance, may also select for susceptibility to fusiform rust because the genes for early height growth and brown-spot resistance may occur in longleaf pine as a result of hybridization and introgression with loblolly or slash pines.

Restoration of the longleaf pine ecosystem will necessarily require a great deal of planting (or perhaps direct seeding) of longleaf pine. Choosing the proper seed source will be essential to ensure long-term success of restoration plantings. It is necessary to understand the implications of breeding programs not only on disease susceptibility but also on retaining those traits that make longleaf such a desirable species. The present study was initiated to examine the relationship between height growth, fusiform rust infection, and brown-spot needle blight in longleaf pine and its hybrids.

Materials arid Methods

Ten longleaf pines were selected from a brown-spot breeding program representing a range from moderate to good resistance to brown-spot needle blight (Snyder and Derr 7972). These trees were crossed with 6 other pines: a longleaf pine that was susceptible and a longleaf that was resistant to brown-spot; 2 slash pines and 1 loblolly pine that were resistant to fusiform rust; and a Sonderegger pine (natural longleaf (loblolly hybrid, Chapman 1922) that was susceptible to fusiform rust (table 1). Wind-pollinated seed were also collected from each parent tree. Sufficient seed were available from 46 families for use in the study.

The study consisted of 2 tests. The first was done in the greenhouse for fusiform rust inoculations, and the other was done in the field to evaluate brown-spot infection and fusiform rust. For both tests, seed were

Table 1—*Mating design and family identification numbers for interspecific and intraspecific longleaf pine hybrids*

	Longleaf pine females											
	Resistant to brown-spot					Moderately resistant to brown spot						
Males	Abe	27-168	5-77	14-346	15-366	16-300	11-467	3-356	22-214	10-434	8-144	Wind
Longleaf Abe Br-spot-resistant		43	2	5	8	11	15	20	26	40		32
Longleaf 12-13 Br-spot-susceptible	49	44	39				38			41	47	37
Slash pine 8-7 Rust-resistant			1		33	10	13	17	22			28
Slash pine 9-2 Rust-resistant									23			29
Loblolly B-144-L Rust-resistant							36	18	24			30
Sonderreger 2-7 Rust-susceptible				4	7		14	19	25			31
Wind-pollinated	32	45	3	6	9	12	16	21	27	42	48	

germinated on vermiculite at 20 °C in a growth chamber. After germination the seedlings were transferred to 2.8- x 21.6-cm plastic tubes containing a 1:1 mix of vermiculite and peat moss. They were then maintained in a greenhouse under a 16-hour day length.

In the greenhouse test, 3 replications each of 10 seedlings from each of the 46 families were inoculated with a composite culture of fusiform rust. The rust culture had been derived from 5 galls collected from loblolly pines in Harrison County, Mississippi. The seedlings were inoculated when they were 10 weeks old with a forced air system (Snow and Kais 1972). After inoculation, seedlings were grown in a greenhouse and maintained for 3 months. They were then planted in a nursery bed and maintained for 9 months. The seedlings were then lifted and measured for height, diameter, and presence of galls. Each seedling was cut in half to verify gall readings.

A field planting was established on the Johnson Tract of the Palustris Experimental Forest near Alexandria, Louisiana. Sufficient seedlings were available to plant 39 of the 46 families in 10-tree row plots in a randomized complete block design of 5 replications. The planting site was prepared by scalping 30-cm-wide strips 3 m apart for each row using a fire plow. Seedlings were planted 2 m apart within the rows using a wheel-driven tree planter.

All seedlings were measured yearly for 5 years and again at age 7 for brown-spot infection (percentage needles affected), height, ground-line diameter, and fusiform rust galls. SAS (1985) GLM procedure and Duncan's multiple range test were used to test for significance among family means. Linear regression was also used to explore relationships among the variables.

Results and Discussion

Fusiform rust. Fusiform rust infection varied greatly among the 47 families inoculated in the greenhouse (figure 1; table 2). Longleaf pine is generally considered to be resistant to fusiform rust, but this is not evident in the inoculation test. Infection in the longleaf families actually averaged higher (46.7%) than the other species and hybrids (43.7%), although it should be pointed out that the slash and loblolly pines used in this test were

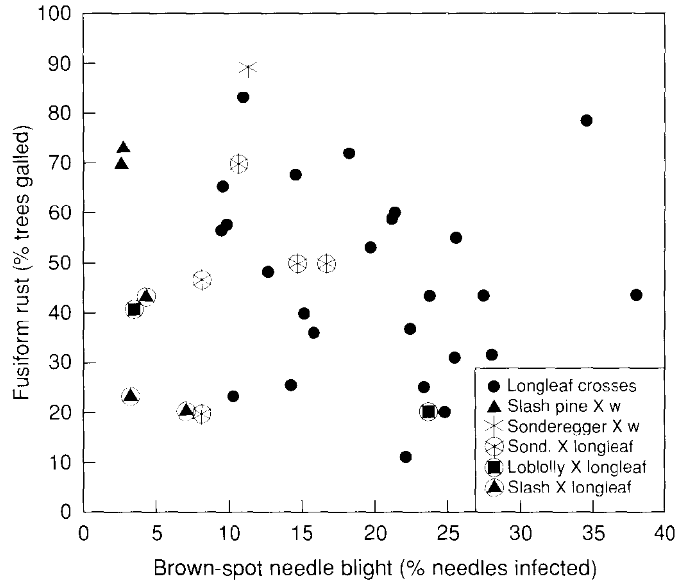

Figure 1—*Scatter plot of fusiform rust infection (greenhouse inoculation) versus brown-spot infection after 3 years in the field for slash, loblolly and longleaf pine crosses and hybrids. Based on individual cross means.*

all considered resistant to fusiform rust; only the Sonderegger pines were considered susceptible to the disease in the field.

Fusiform rust infection ranged from a low of 10.9%, to a high of 83% for the longleaf crosses. The other species and hybrids averaged slightly higher, ranging from 12.5 to 89.3% (table 2; figure 1). The highest infection did occur in the windpollinated Sonderegger seedlings, which were supposed to be susceptible, but infection was nearly as high in the wind-pollinated seedlings of the putatively resistant slash pines (70 and 73%).

Table 2— *Brown-spot needle blight infection, fusiform rust infection, and height growth after 7 years in the field on interspecific and intraspecific crosses of longleaf pine*

Cross type	ID	Brown-spot (%)	Rust greenhouse (%)	Rust field (%)	Height 7-yr (m)
Long × long	47	37.9	43.3	0	1.78
	11	25.5	55.0	0	2.29
	40	14.4	67.7	6.6	2.45
	42	34.5	78.5	0	2.55
	37	28.0	31.5	0	2.69
	48	22.3	36.7	0	2.79
	5	9.3	56.7	0	2.81
	6	12.5	48.3	0	2.90
	32	15.0	40.0	0	2.94
	20	21.1	58.8	0	2.96
	39	18.2	72.1	0	3.10
	2	9.4	65.5	0	3.13
	41	27.4	43.3	6.6	3.17
	3	21.3	60.0	0	3.27
	38	23.3	25.0	0	3.34
	9	23.7	43.3	3.3	3.40
	8	10.1	23.3	0	3.41
	49	9.6	57.8	0	3.46
	45	24.7	20.0	0	3.49
	12	22.1	10.9	0	3.51
	16	14.1	25.4	0	3.61
	27	25.4	31.0	0	3.67
	21	15.7	36.0	0	3.80
	44	19.6	53.1	0	4.28
	43	10.8	83.3	0	4.31
Long × lob	18	23.7	20.1	0	3.55
Long × Sond	7	16.6	50.0	0	3.77
Long × Sond	19	7.9	46.7	6.7	4.53
Long × Sond	25	14.6	50.0	0	4.58
Long × Sond	14	7.9	20.0	0	4.60
Long × Sond	4	10.5	70.0	0	4.98
Sond × wind	31	11.2	89.3	59.0	4.63
Long × slash	13	3.03	23.3	0	4.98
Slash × wind	28	2.4	70.0	0	5.19
Long × slash	17	6.9	20.4	5.0	5.22
Lob × wind	30	3.3	41.0	13.1	5.44
Slash × wind	29	2.6	73.3	29.7	5.77
Long × slash	23	4.1	43.3	4.9	5.81

Long = longleaf pine, lob = loblolly pine, and Sond = Sonderegger pine. See table 1 for family identification numbers.

Overall, fusiform rust infection in the field was low, averaging less than 1% in the longleaf crosses and only 9% in the hybrids (table 2). This result was not unexpected, because all parent trees except for one were considered resistant to fusiform rust. Infection in the one family that was considered highly susceptible, the Sonderegger × wind family, was 59%, indicating that inoculum was present. This family serves as the only fusiform-rust-susceptible control in this experiment.

The resistance of longleaf to fusiform rust is more evident in the field data than in the greenhouse inoculation test (table 2). Galls developed on only 3 of 25 longleaf families. Frequency of galls in the 3 infected families ranged from 3 to 7 %.

In the other species and hybrids, the Sonderegger × wind seedlings (which had the highest infection rates in greenhouse inoculation test) also had the highest infection rates in the field planting, with 59% developing galls (table 2). The second highest number of galls occurred on slash 9-2 × wind, and the third highest number was on the loblolly × wind (table 2). Many of the longleaf hybrids were not galled.

Brown-spot disease and height growth. Brown spot blight varied from 9 to 38% needles infected in the longleaf crosses and from 2 to 24% in the hybrids (table 2; figure 1). The relative ranking of the longleaf crosses paralleled expectations (figure 2). The resistant male crossed with the resistant females produced the most resistant progeny with less than 10% infection. Infection was higher, nearly 20%, in the progeny when the resistant male was crossed with a "moderately" resistant female. The highest infection rate (30 %) was in the progeny produced when the susceptible male was crossed with the moderately resistant female.

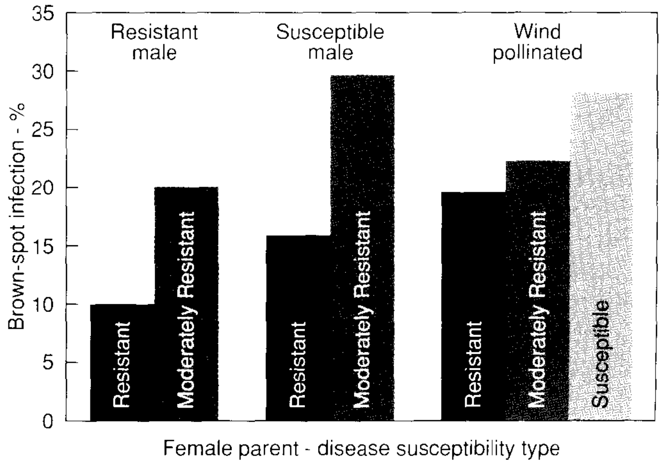

Figure 2—*Brown-spot needle blight infection in controlled-cross longleaf pine families from parents of known susceptibility.*

Brown-spot infection was not related to height growth in the nursery in the longleaf crosses but was negatively correlated with height when the hybrids are included in the regression (figure 3). None of the progeny from the longleaf crosses had started height growth in the nursery at lifting; they averaged between 3 and 12 cm in height, although subsequent brown-spot infection in the field ranged from 9 to 38%. The general lack of height growth in the first year in the nursery is a good indication that the longleaf used in this experiment are relatively pure genetically, because hybrids with other species show height growth in the nursery.

Seedlings of the Sonderegger × longleaf cross, which is a longleaf X loblolly natural hybrid backcrossed to longleaf and is therefore approximately 75% pure longleaf, were all taller than pure longleaf seedlings in the nursery (ranging from 14 to 24 cm in height) and were relatively resistant to brown-spot infection. The tallest trees in the nursery were the pure slash pine, followed by the F_1 hybrids.

Height growth of the longleaf crosses after 7 years in the field varied from 1.78 to 4.31 m (table 2). The hybrids and other species were taller, varying from 3.55 to 5.81 m. Although the tallest trees in the nursery were the slash pine (figure 3), after 7 years the tallest trees were a longleaf by slash hybrid (table 2).

Brown-spot infection in the field was not related to previous height growth in the nursery but did appear to affect growth after 7 years in the field. Although brown-spot infection was not severe, there was a negative correlation between infection and height at age 7 ($r = -0.435$).

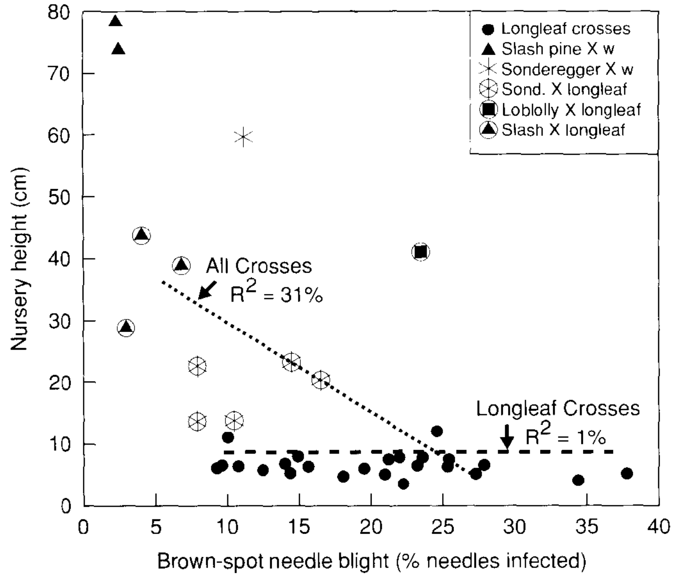

Figure 3—*Scatter plot of height growth after 9 months in the nursery versus subsequent brown-spot infection after 3 years in the field for slash, loblolly, and longleaf pine crosses and hybrids.*

Conclusions and Recommendations

The results indicate that resistance in a general sense to brown-spot can be incorporated into longleaf breeding programs without changing resistance to fusiform rust. Although a hybrid origin for brown-spot resistance in longleaf pine cannot be ruled out, it appears that this trait can be incorporated into improved longleaf pine with little danger of losing "typical" longleaf traits.

Performance of the hybrids in this study indicates that fast growth as well as resistance to disease can be incorporated into a breeding program for longleaf pine. Longleaf would be a good candidate for hybrid back cross breeding using some of the newer molecular methods (Nance and others 1991).

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The Effects of Seedling Quality and Forest Site Weather on Field Survival of Ponderosa Pine

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In this study, we report field survival results of *an analysis of the USDA Forest Service Reforestation Improvement Program. The field survival of 3 test plantings of ponderosa pine* (Pinus ponderosa *Lazes. var.* ponderosa) *were modeled with regression analysis using a modified logit transformation. The initial predictor variables tested included nursery seedling morphological traits such as height, diameter, and stem and root weights; several performance attributes such as root growth potential, cold hardiness, and root exposure stress tests; arid days since planting of the seedlings. Forest site weather variables measured during the first growing season reduced confounding between seedling duality tests and field survival measurements Root growth potential was consistently important as a performance attribute in explaining survival of three field tests of ponderosa pine. The root exposure stress test was a useful measure for predicting survival of seedlings planted on warm sites, and the mean initial height of seedlings was an important predictor for survival on warm and very dry sites.* Tree Planters' Notes 47(1):16-23; 1996.

The importance of seedling survival monitoring became widely recognized with the creation of the National Forest Management Act in 1976, which mandates that the USDA Forest Service submit an annual report to Congress on the plantation survival of seedlings. During the early 1980's when the Forest Service was experiencing failures rates of 18% for the 270,000 acres planted annually, the Reforestation Improvement Program (RIP) was created in an effort to stem the high cost of plantation mortality (USDA Forest Service 1985). The RIP relies upon the extensive use of monitoring and seedling testing in the nursery to improve the quality of bareroot seedlings, and a systematic recording of forest site weather conditions and survival in the field to make reforestation more predictable and successful (Owston and others 1990). The RIP objectives were focused on increasing knowledge of seedling biology by nursery personnel and enhancing the consistent production of high-quality stock, resulting in lower reforestation costs by avoiding the occasional need for replanting.

The program was directed at identifying whether planting success or failure was a result of seedling quality or other postshipment factors (Rietveld and others 1987). The RIP did not constitute a controlled research experiment. Despite the lack of a rigorous statistical design of RIP, the program was begun in 1986 with the intention that it would eventually provide sufficient information for correlation and regression analysis between planting stock quality variables with field performance variables. A significant difference between the RIP effort and most seedling survival studies, was that the RIP contained both nursery and field weather stations that monitored surface and other ambient meteorological attributes of the beds or planting sites. This paper discusses how seedling quality tests and measures of forest site weather conditions can be used to determine if nursery or post-planting conditions have been the major factor in poor seedling survival.

The ease with which most seedling morphological parameters can be measured makes them the most popular method for measuring seedling quality (Thompson 1986). The morphological measurements reported in this program include: height, stem diameter, bud length, shoot weight, and root weight. Thompson (1986) notes that as the planting site becomes more arid, the optimum seedling height for survival probably decreases. Larsen and others (1986), Tuttle and others (1987), Wilder-Ayers and Tolliver (1987), and Mexal and South (1991) reported a negative correlation between seedling survival and seedling height. Mexal and Landis (1990) state that shorter stockier seedlings are preferred for arid sites and taller seedlings are superior for sites where vegetative competition or animal damage is severe. Shiver and others (1990) however, reported a strong positive relationship between loblolly pine (*Pinus taeda* L.) survival and initial seedling height on sites where the survival was less than or equal to 75% and essentially no relationship on sites where the survival exceeded 75%.

Seedling root collar diameter is generally accepted as better than height as a positively correlated morphological measure of field survival and growth (Thompson 1986, Mexal and Landis 1990). Root weight is often correlated with seedling diameter; but height, diameter, and stem weight have been found to be better predictors of field survival.

Thompson (1986) speculated that bud length could potentially be a useful indicator of field height between seed lots rather than within a lot. A longer bud length is indicative of a more vigorous seedling as it becomes dormant. Mexal and Landis (1990) disagree and state that cultural practices late in the growing season can impact bud size with no appreciable effect on seedling height.

Root growth potential (RGP) represents the ability to regenerate new roots and is closely linked to the seedling's ability to avoid water stress after planting (Duryea and McClain 1984). High RGP is often correlated with high field survival (Feret and Kreh 1985, Barden and others 1987). The best results occur if measurement is taken immediately before planting (Ritchie 1984). Mexal and South (1991) state that if either survival or RGP is uniformly high, there will likely be poor correlation between RGP and survival. Ritchie and Tanaka (1990) have provided a matrix diagram that partially justifies why on 25% of occasions there is a poor correlation between RGP and field survival. Their figure depicts the interaction of RGP with the uncontrolled factors of site and weather conditions in the field. They state that the performance of poor stock on harsh sites or good stock on good sites is predictable, whereas the performance of good stock on harsh sites or poor stock on mild sites is less so.

Ritchie (1985) proposed that RGP was a good predictor of seedling survival and growth because of RGP's correlation with cold hardiness and stress resistance. Studies reported by Burr (1990) support Ritchie's hypothesis; however, she recommended that cold hardiness be monitored at the time of lifting and that RGP be measured immediately before planting. Cold hardiness is the ability of a seedling to survive or resist injury from exposure to freezing temperatures. It is frequently expressed as the minimum temperature at which 50% of the seedlings are killed, which is expressed as lethal temperature 50 (LT_{50}) (Glerurn 1985).

Root-exposure or vigor testing attempts to simulate the normal stresses encountered during planting and first year establishment by exposing the seedling to artificial stress (McCreary and Duryea 1985). Such testing has been used to predict potential rather than actual field survival, because site conditions and yearly weather patterns can confound the ability to predict field performance of lots of varying quality.

Materials and Methods

We analyzed the data of the 4 USDA Forest Service bareroot nurseries that were responsible for the production of ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa).* Each nursery tested at least 2 seed sources. Standard Forest Service practices for matching seed source to outplanted forest sites, together with nursery production methods and cultural regimes were followed (Duryea and Landis 1984). Two forest sites were selected for outplanting the test seedlings from each nursery.

Consistent with a RIP objective of training operational personnel in monitoring, the nursery staff conducted frequent tests of seedling performance attributes and morphological measurements. Nursery staff or ranger district personnel measured field performance and maintained the forest weather stations. The added and new responsibilities in scientific testing, measuring, monitoring, and reporting were accomplished with mixed success. Several of the key nursery tests such as RGP, cold hardiness, or root exposure test (heat stress test) were not consistently repeated over the 3 outplanting years. Exchanges of seedlots, conflicting survival records, dearth of regular scheduled measurements, and the downtime of forest site weather stations made the analysis of the RIP problematic. As a result, only the results of 2 of the 4 pine nurseries are reported here: 1+0 stock of the Placerville Nursery, Camino, California, and 2+0 stock of the Bend Nursery, Bend, Oregon.

Stock quality tests. For the purpose of maintaining consistency among test years and nurseries, we used the RGP, root exposure, and cold hardiness test results that were collected at the time of shipping. These tests were initiated on average 30 days and 23 days before outplanting of the Placerville and Bend nursery stocks, respectively. The RGP tests were conducted by suspending 15 seedlings in mist chambers at 27 °C and 100% relative humidity and counting the mean number of new roots (Burr and others 1987, Rietveld and Tinus 1987). The seedlings were left in the mist chambers for 26 days at the Placerville nursery and 15 days at the Bend nursery before the count was made. The root exposure test (heat stress test) consisted of taking 30 seedlings, removing all moisture-holding media from the roots, blotting dry the roots, and exposing them to 30 minutes of forced air at 30 °C. The seedlings were then potted and grown in a greenhouse for 60 days with temperatures between 15 to 27 °C and relative humidities between 40 to 80%, at which time the percentage mortality was recorded (McCreary and Duryea 1985). The root exposure test data were only partially complete for the Bend nursery.

Cold hardiness was determined by placing 2 pots with 5 seedlings each in a freezer and cooling them until a target temperature was reached, removing the pot, and after 14 days of growing the seedlings in the greenhouse with conditions identical to the root exposure test, slicing the stem to compute the percentage dead area. The target temperatures were -5, -10, -15, -20, and -25 °C. The LT_{50} was computed by interpolating between target temperatures to find a value that represented 50% mortality (Burr and others 1990). The cold hardiness test data were only partially complete for the Bend nursery. Plant moisture stress tests were conducted at the time of lifting. Lifting occurred on average 79 days before outplanting at the Placerville nursery and 24 days before outplanting at the Bend nursery. Plant moisture stress was determined by the pressure chamber technique with a sample of 10 seedlings and measured to the nearest 0.1 bar. Plant moisture test data were only partially complete for the Placerville nursery.

The morphological measurements of the test seedlots were conducted just before packaging. Seedling height was measured to the tip of the visible stem to the nearest centimeter, and diameter was measured with calipers to the nearest 0.1 mm. Dry weight was measured by removing soil and severing the seedling into 2 parts at the cotyledon scar. Dry shoot and root weights were recorded to the nearest 0.01 g. Bud length was measured to the nearest millimeter.

Planting site conditions. A planting site for each seed lot was selected that had at least a 10-acre opening with a relatively uniform in slope and aspect. Over a span of approximately 3 years, one-third of the planting area was randomly selected for planting each year. Site preparation for each planting sub-area was completed in the year before spring planting using the best local practices for the site. An automated weather station was located at the center of each planting site. Information recorded at the weather station included air temperature, wind speed and direction, relative humidity, precipitation, and solar radiation. In addition, soil moisture was monitored with gypsum blocks at the field site.

The 2 ponderosa pine seedlots grown at the Placerville nursery were outplanted during a span of 3 years (1988-90) at 2 locations on the Pacific Ranger District of the Eldorado National Forest and Weaverville Ranger District of the Shasta– Trinity National Forest, both in California. Both were considered typical good planting sites (table 1). Each year, about 400 seedlings/ seedlot were outplanted at a spacing of 3 by 3 m. Only 1 seedlot was planted at each location. The planting tools (auger, hoedad, and shovel) varied from year to year, as did the contract planting crews. The seedlots planted in 1988 were monitored for 4.4 years for field survival, whereas those planted in 1990 were monitored for 2.4 years. A total of 51 observations was available for modeling survival at the Eldorado location, while 41 observations were available at Shasta– Trinity location.

The 2 ponderosa pine seedlots grown at the Bend nursery were outplanted during a span of 4 years (1988-91) at 2 locations on the Sisters Ranger District of the Deschutes National Forest, Oregon. All the seedlings outplanted in 1988 failed, so that we began the experiment again in 1989. The seedlots planted in 1989 were monitored for 4.4 years for field survival, and those planted in 1991 were monitored for 2.4 years. A forest weather station at 1 location did not function during the 1991 growing season, and after consultation with local ranger district staff, we decided to pool the seedlot and weather station information. A total of 24 observations were available for modeling survival of the pooled locations. Other attributes, such as elevation, aspect, percentage slope, habitat type, and soil type for each of the planting sites are presented in table 1.

Table 1- *Physical attributes and habitat type of forcst planting sites*

	Location		
	Pacific RD, Eldorado NF, CA	Weaverville RD, Shasta– Trinty NF, CA	Sisters RD, Deschutes NF, OR
Elevation (ft)	5,000	3600	3300, 5000
Aspect	North	Southwest	West, flat
Slope (%)	15	35	30, 0
Habitat type	Mixed conifer	Mixed conifer	Mixed conifer
Soil type	Deep granitic loam	Forbes loam	Pacific pumy

RD = ranger district. NF = national forest, and ZIP code abbreviations for states.

The daily climatic variables that we utilized in our study were average surface temperature and average percentage relative humidity. The variables of surface temperature and wet and dry air temperature at a height of 1.5 m were scanned every 5 minutes by weather sensors and stored in an automatic data logging system. Every 60 minutes, an average surface temperature and relative humidity were calculated and recorded. We used daily values of surface temperature and relative humidity or the average of the 24-hourly values.

Results

The monitoring of forest site weather was a critical element in this study, because the Reforestation Improvement Program was not a controlled experiment, and there were only small measured morphological and physiological differences within seedlots during the 3 years of outplanting. The differences in seedling quality from year to year reflected the normal yearly variation that occurs in the weather and timing of bareroot nursery operations of large nurseries (Burdett and Simpson 1984, Landis 1984). The inclusion of forest-site-weather-related variables in the statistical analysis was essential for reducing the unexplained variation and confounding between seedling quality and meteorological conditions on seedling survival.

Temperature extremes have considerably more influence on seedling survival than weekly or monthly averages (McCreary and Duryea 1985). We analyzed daily surface temperature and relative humidity readings for each seedlot during the first growing season (day of outplanting until September 15) because it is the most critical year in explaining survival performance. Table 2 presents, by location and year, the key weather attributes that were demonstrated by statistical analysis to influence seedling survival.

Table 2— *Forest site weather data: number of days in growing season with temperature or relative humidity extremes*

		Days from planting until September 15		
Location	Year	Ave. surface temp. ≥ 21 °C	Ave. surface temp. ≥ 30 °C	Ave. rel. humidity < 30%
Eldorado	1988	60	0	29
NF, CA	1989	3	0	9
	1990	0	0	28
Shasta–Trinity	1988	98	33	77
NF, CA	1989	95	4	44
	1990	78	26	36
Deschutes	1989	16	0	8
NF, OR	1990	78	7	100
	1991	82	56	155

NF = national forest.

We selected the linear transformation of the logistic curve, or logit, for modeling survival. Barden and others (1987) modeled survival as a function of RGP, and found that the logit provided the best fitting linear model. Following a technique of Wonnacott and Wonnacott (1981), the modified dependent variable of the logit is

$$\ln\left[\frac{\frac{(S+1/2)}{n}}{1-\frac{(S-1/2)}{n}}\right]$$

where
S = number of surviving seedlings per plot
n = total number of seedlings planted per plot
ln = natural logarithm

The modified logit remains defined when $S = n$, and permitted us to use more field observations than if we had used the logit definition of $\ln[P/(1-P)]$, where $P = S/n$. Our estimated model for seedling survival for ponderosa pine on the Eldorado National Forest

$$\ln\left[\frac{\frac{(S+1/2)}{n}}{1-\frac{(S-1/2)}{n}}\right] =$$

$$3.031 - 0.0043A + 0.000002A^2 + 0.158RGP - 0.0112TG_{21}$$

where

A = age in days since planting
RGP = root growth potential
TG_{21} = number of days in the first growing season (from planting day until September 15) where the average daily surface temperature exceeded 21 °C

All coefficients were significant at the a=0.05 level, the number of observations n=51, and the R^2=0.86. In the presence of A, RGP, and TG_{21} all other variables for this planting site including the morphological variables of height, diameter, weight, Dickson quality index*, and performance attributes such as cold hardiness and root exposure failed to enter the model with significant coefficients. We did not use the weighted least squares technique, suggested by Neter and others (1985). We were largely interested in constructing an explanatory model, and the weighting technique drastically reduced the significance of the estimated coefficients. The model may be expressed in

$$P = \frac{S}{n} = \frac{1}{1+e^{-x}} + \frac{1-e^{-x}}{(1+e^{-x})\,2n} \qquad (1)$$

where

$$X = 3.031 - 0.0043A + 0.000002A^2 + 0.158RGP - 0.0112TG_{21}$$

If age (A) is set to 365, and TG_{21} (the number of days in the first growing season where the average daily surface temperature exceeds 21 °C) is set to 30, this equation predicts that survival after 1 year decreases from 94% to 90% if *RGP* decreases from 9 to 5. The observed range of *RGP* at the Placerville nursery for the Eldorado outplanting was 5 to 9 new roots/ seedling /seedlot of 15 seedlings. The functional relationship between survival and age, *RGP*, and TG_{21} for the Eldorado National Forest is displayed in figure 1.

Our model for seedling survival for ponderosa pine on the Shasta-Trinity National Forest may be expressed

*Dickson quality index = $\dfrac{\text{Total seedling dry wt (g)}}{\dfrac{\text{Height (cm)}}{\text{Diameter (cm)}} + \dfrac{\text{Shoot wt (g)}}{\text{Root wt (g)}}}$

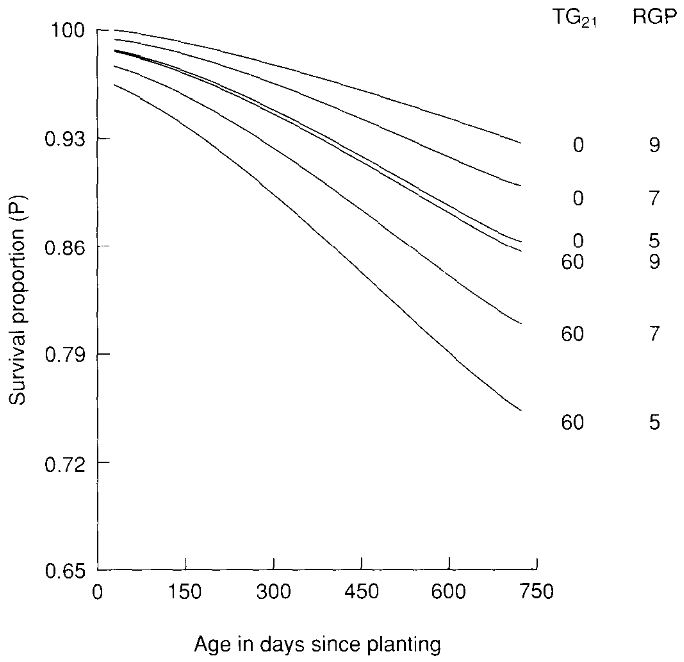

Figure 1— *Predicted survival proportion on the Eldorado National Forest.* TG_{21} *= the number of days in the first growing season when the average daily surface temperature exceeds 21 °C, and RGP = root growth potential.*

in terms of the survival proportion (*P*) by inserting the following value for X into equation (1):

$$X = - 1.944 - 0.0035A + 0.000002A^2 + 0.824RGP - 0.02181$$

where

A = age in days since planting
RGP = root growth potential
I = interaction between the number of days in the first growing season (from planting day until September 15) where the average daily surface temperature exceeded 30 °C and the percentage mortality from the root exposure stress) test.

All coefficients, except for the intercept, were significant at the "=0.05 level, the number of observations n=41, and the R^2=0.85. The threshold surface temperature of 30 °C was chosen because it corresponds to the temperature used in the root exposure (heat stress) test. In the presence of *A*, *RGP*, and *I*, all other variables including the morphological variables of height, diameter, weight, Dickson quality index, the cold hardiness performance attribute and plant moisture stress failed to enter the model with significant coefficients. If age set to 365, and *I* (the product of the number of days in the first growing season where the average daily surface temperature exceeds 30 °C and percentage mortality of the root exposure test) is set to 20, this equation predicts that survival after 1 year decreases from 91% to 75% if *RGP* decreases from 7 to 5.5. The observed range of RGP at the Placerville nursery for the Shasta– Trinity outplanting was 5.5 to 7 new roots /seedling/seedlot of 15 seedlings. The observed range of percent mortality of the root exposure test at the Placerville nursery for the Shasta– Trinity outplanting was 0 to 3.5%. The functional relationship between survival and age, *RGP*, and *I* for the Shasta– Trinity National Forest is displayed in figure 2.

Our model for seedling survival for ponderosa pine on the Deschutes National Forest may be expressed in terms of the survival proportion (P) by inserting the following value for X into equation (1):

$$X = 6.883 - 0.0009A + 96.406/A - 498.706/A^2 + 2.850\, RGP/RHL_{30} - 0.3316HT$$

where

A = age in days since planting
RGP = root growth potential
RHL_{30} = number of days in the first growing season (from planting day until September 15) where the average relative humidity was below 30%
HT = average height to the tip of the stem in centimeters

All coefficients were significant at the "=0.05 level, the number of observations *n*=24, and the R^2=0.90. In the presence of *A, RGP*, RHL_{30}, and *HT*, all other variables including the morphological variables of diameter, weight, Dickson quality index, and performance attributes such as cold hardiness and root exposure stress failed to enter the model with significant coefficients. The model predicts only small changes in survival as a function of RGP, largely because the average observed range of RGP at the Bend Nursery was 0.8 to 3.5 new roots/ seedling/seedlot of 15 seedlings. If age (A) is set to 365, RGP is set to 2.1, and RHL30 (the number of days in the first growing season where the average relative humidity is below 30%) is set to 120, this equation predicts that survival after 1 year decreases from 81% to 53% if HT increases from 16.4 cm to 20.3. The functional relationship between survival and age, RGP, RHL30, and seedling height for the Deschutes National Forest is displayed in figure 3.

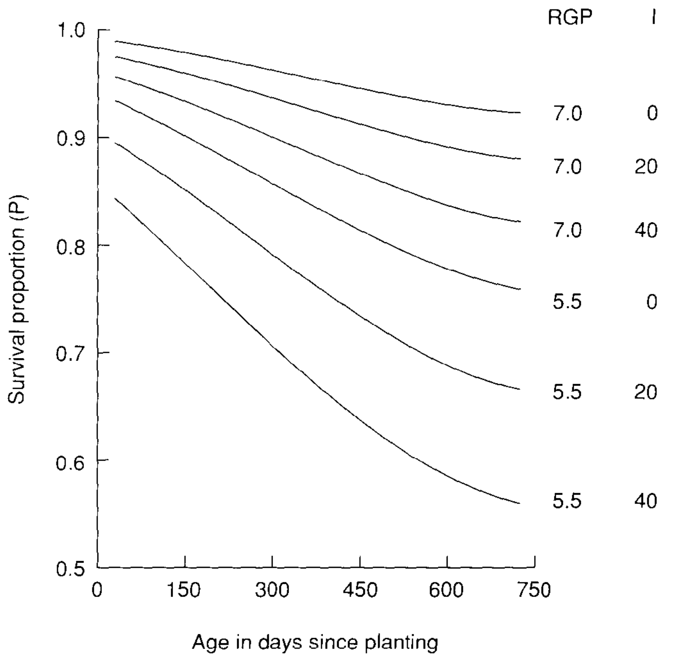

Figure 2— *Predicted survival proportion on the Shasta–Trinity National Forest. RGP = root growth potential and I = the product of the number of days in the first growing season when the average daily surface temperature exceeds 30 °C and the percentage mortality from the root exposure test.*

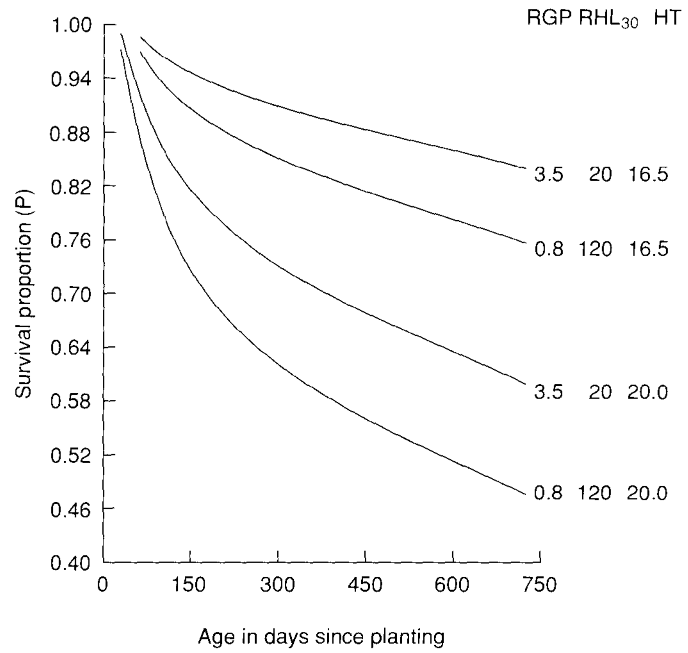

Figure 3— *Predicted survival proportion on the Deschutes National Forest. RGP = root growth potential, RHL_{30} = the number of days in the first growing season where the average relative humidity is below 30%, and HT = the average height to the tip of the stem in centimeters.*

Discussion

Ritchie (1984) states that the final test of a forest tree seedling is its performance after outplanting. It is widely acknowledged, however, that it is often difficult to assess the effect of seedling quality on field survival, given changes in yearly weather patterns. The RIP and the installation of forest site weather stations at the field sites overcomes this limitation. Given the lack of a designed experiment and the very small differences of morphological and performance attributes within seedlots from year to year of operational nurseries, the inclusion of weather variables in a survival model is imperative. Not only do weather variables reduce the confounding in the analysis data, but certain extremes, such as number of days where the average surface temperature exceeds 30 °C, or the number of days when the relative humidity is less than 30%, assist in indicating which performance test is useful in explaining field survival.

The results of the RIP are consistent with previous studies and reaffirm that several morphological and performance tests have site specific importance. The RIP analysis indicates the root exposure (heat stress) test can be important for monitoring seedling quality on warm forest sites. For those forest sites that are warm and very dry, results indicate the average height of seedlings can be a critical morphological attribute. Although average daily surface temperature is a key weather attribute for monitoring on warm sites, relative humidity appears to be a critical meteorological variable for warm and very dry sites. In all 3 test sites, the root growth potential test was effective in predicting field survival of seedlings. The results also suggest that the cost and time involved in the routine testing of all morphological and performance tests may be unnecessary. Considerable savings in data collection and evaluation of the tests can be achieved by customizing site specific testing procedures.

When confronted with a plethora of morphological measurements, performance tests, meteorological variables, in addition to seedling age, it seems quite natural to first screen the variables in a survival model using a statistical stepwise regression technique. This approach can lead to some misleading results, if a forest site weather variable is not included in the model immediately following the inclusion of the independent variable of age or transformations of age. In the case of the Eldorado and Shasta– Trinity test sites, stepwise regression analysis included bud length as a predictor variable in either the first or first 3 steps, to the exclusion of any forest site weather variable or performance test attribute. The stepwise models predicted however, that field survival decreased as bud length (measured at the time of nursery lifting) increased. By ignoring the stepwise results, and including a forest site weather variable in the survival model, we were able to obtain a logical survival model with goodness of fit statistics that equaled or exceeded the results provided by the stepwise regression analysis. The results of this study may be considered as the first step in providing better accountability toward identifying whether planting failure is a result of seedling quality or uncontrolable weather factors.

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Growth of Hardwoods and Conifers After 47 Years on Coal Mine Soils in Southern Illinois

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Survival, height, and DBH are reported for 18 tree species planted chiefly in 1947 by the USDA Forest Service on lands surface-mined for coal in southern Illinois. Species with the best overall performance among 16 species planted in plots by row were black walnut (Juglans nigra *L.) planted as seedlings or seed, sweetgum* (Liquidambar styraciflua *L.), and tuliptree (yellow-poplar)* (Liriodendron tulipifera *L.). Conifers performed poorly except on extremely acidic sites. Tuliptree, silver maple* (Acer saccharinum *L.), and white and red oak* (Quercus alba *L. and* Q. rubra *L.) planted in single-species stands grew well.* Tree Planters' Notes 47(1):24-29; 1996.

Systematic study of tree growth on lands in the Midwest that were surface-mined for coal was begun by the USDA Forest Service in the years following World War II. The Forest Service's Central States Experiment Station, under the leadership of Dr. Arthur G. Chapman, first carried out an inventory of mined lands. Several series of plots were then established, usually with both hardwoods and conifers, from Ohio to Oklahoma on mined lands with differing topography, soils, and presence of overstory trees. The plots have well-documented planting plans that include soil conditions and other factors affecting tree performance (tables 1 and 2).

Eight hardwood and 8 conifer species were planted on plots in Illinois in 1947. Early tree survival and height growth were followed closely. Results after 10 to 12 years were reported for Illinois by Boyce and Neebe (1959) and by Limstrom (1960) for the entire Midwest in an able summary of the factors affecting successful reclamation with trees on mined land. Fifteen-year data were reported for 2 sets of plots in southern Illinois by Ashby and Baker (1968).

In 1976, the Forest Service funded re-measurements of remaining tree plantings on mined lands in the Midwest. Forest canopies of planted and volunteer trees had developed with examples of good to excellent growth by regionally adapted tree species in Kansas, Missouri, Indiana, and Illinois (Ashby and others 1980) and in Ohio (Larson and Vimmerstedt 1983). Volunteer trees were numerous (Ashby and others 1981); typically on the southern Illinois sites, hackberry/sugarberry and black cherry were characteristic of mesic sites. Coarse fragments in the spoil had weathered, A1 horizons darkened by organic matter were present, and extremely acidic soils had become less acidic on plots both included and not included in this paper (Davidson and others 1988). Pieces of siltstone had been penetrated by fine roots and often could be broken by hand.

In Illinois, diameter at breast height (DBH) was measured on all trees, and heights of commercially important species were measured for 5 to 10 representative trees/plot (Ashby and Kolar 1997). Some plots had been lost to landfills, housing developments, or re-mining by 1976, and still more by 1993. Several coal-company single-species block plantings with known planting dates were also measured in 1976. Before World War II, a coal company association in Illinois, under an agreement with the Illinois Division of Forestry, voluntarily planted an acre of trees for each acre mined.

In 1993, the 10 remaining Forest Service plots in southern Illinois along with 4 coal company block plantings were re-measured. Measurements were not postponed to age 50 because additional plots were threatened by a highway relocation following mine closure. The chief objective was to determine species performance in the several plantings.

Materials and Methods

Physical and chemical properties of each site, along with the abbreviations used in the text to identify each site, are listed in table 1. The rooting medium on all sites was a mixture of soil fines and coarse fragments from the overburden overlying the coal prior to mining. Overburden cast into spoil banks was the kind of rooting medium typical of mined sites prior to the passage of state laws and a 1977 federal law. The post-mining soils at 3 sites— RA, PEBL, and PESP— are mapped in recent county soil surveys as the Lenzburg Series, "well drained and moderately well drained, moderately slowly permeable soils on the sides and crests of spoil banks and on graded slopes in surface-mined areas in the uplands. These soils formed in fineearth material that is mainly a mixture of calcareous loamy till and weathered siltstone. Rock fragments of siltstone and limestone are common" (Miles 1988). The post-mining soils at sites— SAEA and SADP— are mapped as Orthents in an older soil survey.

Table 1—*Physical and chemical properties of USDA Forest Service experimental tree-planting sites in southern Illinois; methods used for pH, P, and K determination from NC Regional Publication (1975).*

Descriptive properties	County and site				
	Saline Co.		Randolph Co.	Perry Co.	
	SAEA	SADP	RA	PESP	PEBL
Overstory	None	None	None	Pine*	Locust*
Spoil banks	High	Dragline pullback	High	Moderate	Moderate
Soil pH					
1947	3.4	6.1	7.6	7.5	7.3
1976†	4.7	6.1	7.2	7.6	7.5
Soil phosphorus‡ (ppm)					
1976	3	4	11	4	7
Soil potassium§ (ppm)					
1976	89	108	172	168	178

Source: SAEA = Saline County, extremely acidic soil (Sahara Mine No. 6); SADP = Saline County, partially leveled with dragline pullback (Sahara Mine No. 6); RA = Randolph County (Streamline Mine); PESP = Perry County with 10-year-old shortleaf pine overstory (Fidelity Mine); PEBL = Perry County with 10-year-old black locust overstory (Fidelity Mine).

* Planted in 1938 at 2.1 × 2.1 m (7 × 7 foot) spacing or 2,200 trees/ha (889 trees/ac).

† Beckman Zeromatic SS-3 pH meter and a 2:1 distilled water to soil mixture.

‡Olsen sodium bicarbonate soil extract and ascorbic acid spectrophotometer method.

§Bray-1 acidified ammonium fluoride soil extract and atomic absorption spectrophotometer method.

Table 2—*Common and scientific names of species in the text*

Common name	Scientific name
Silver maple	*Acer saccharinum* L.
Hackberry/sugarberry	*Celtis occidentalis* L./*C. laevigata* Willd.
Flowering dogwood	*Cornus florida* L.
Autumn olive	*Elaeagnus umbellata* Thunb.
Ash, white	*Fraxinus americana* L.
Black walnut	*Juglans nigra* L.
Redcedar, eastern	*Juniperus virginiana* L.
Sweetgum	*Liquidambar styraciflua* L.
Tuliptree or yellow-poplar	*Liriodendron tulipifera* L.
Japanese honeysuckle	*Lonicera japonica* Thunb.
Osage-orange	*Maclura pomifera* (Raf.) Schneid.
Locust borer	*Megacyllene robiniae* (Forst.)
Pine, jack	*Pinus banksiana* Lamb.
shortleaf	*P. echinata* Mill.
red	*P. resinosa* Ait.
pitch	*P. rigida* Mill.
loblolly	*P. taeda* L.
eastern white	*P. strobus* L.
Virginia	*P. virginiana* Mill.
Cottonwood, eastern	*Populus deltoides* Bartr. ex Marsh.
Black cherry	*Prunus serotina* Ehrh.
Oak, white	*Quercus alba* L.
Northern red	*Q. rubra* L.
Shumard	*Q. shumardii* Buckl.
Black locust	*Robinia pseudoacacia* L.

Sites RA, PEBL, and PESP had typical pre-law spoil banks and were slightly alkaline (table 1). Site SADP minesoils were slightly acidic and relatively level after dragline pullback in tandem mining with a power shovel. Site SAEA had extremely acidic spoil banks with relatively low extractable K. Levels of extractable P were low on all sites (table 1). The sites when planted had varied kinds and amounts of volunteer herbaceous cover, and occasional cottonwood (see table 2 for scientific and common names) or other volunteer pioneer trees.

The statistical design of the 1947 Forest Service plantings at each site in Illinois was 17 completely randomized rows in each of 2 adjacent blocks (plots). Each randomly assigned row had 50 trees of a single species. Tree rows ran up and down slope at right angles to the ridge-and-valley topography commonly present. All trees were planted as bareroot nursery stock with a planting bar (dibble) on a 2.1-m (7-ft) spacing within a row and between rows. Seedlings were not planted in the occasional low-lying areas or died from later flooding/siltation. No ground cover was planted on any of the sites nor were management treatments given.

Sites RA, SAEA, and SADP were planted in spring 1947 to 16 species— 8 hardwoods and 8 conifers. A second randomized row per plot of black walnut was planted as seed, 2 nuts to a planting spot for a total of 17 rows. The same 8 hardwoods (9 randomized rows of 50 trees each) and no pines were underplanted in 2 stands of 10-year-old trees planted in 1938. Site PEBL had a stand of black locust and PESP of shortleaf pine. Both overstory stands largely broke up between about 1955 and 1965 (Ashby and others 1966).

In 1993, we measured the DBH of all planted trees in the remaining Forest Service plots. Heights were measured with a Haga altimeter for all trees in a row if 10 or fewer survived. Sites with more than 10 trees/row had a minimum of 20 tree heights measured /species.

Heights were taken on 71 % of all trees. Height and DBH data were described using several statistical measures and analyzed using an ABSTAT program for ANOVA on an IBM PC. Statistically significant differences in mean heights and DBH's were evaluated at the " = 0.05 level between major hardwood species and between the several sites.

Four single-species block plantings with 2.1-m (7-ft) spacing near sites SADP and SAEA on Sahara Mine No. 6 in Saline County also were measured. Tuliptree had been underplanted in a decadent 16-year-old black locust stand by the Forest Service in 1954. Somewhat older plantations of silver maple, white oak, or red/Shumard oak had been planted by the coal company association. The rows of the plantings paralleled the ridges with 4 rows each of approximately 15 trees in the tuliptree and of 30 trees in the white oak. The silver maple and red/Shumard oak plantings were larger. All of the tuliptree and 65 or more trees of the other species were measured. Standard deviations of the means and coefficients of variation were computed.

Results

Percentage survival varied greatly among planting sites, among species within a site, and for a species from site to site (table 3). Except for tuliptree and Osage-orange on the PESP site, survival was less than 50% (1,100 trees/ha or 444 trees/ac). Only black walnut planted as seedlings and as seed were found on both plots of all sites 47 years after planting. Smaller, volunteer walnuts were also found. Species with low survival were often found only on one plot of a site. Some species measured in 1976 were not found in 1993 (table 3).

Survival of the pines and of sweetgum, silver maple, and ash was greatest on the extremely acidic SAEA site. Only shortleaf and Virginia pine survived on all 3 sites where planted. Survival was greater for hardwoods underplanted in the pine (PESP) than in the locust (PEBL) stand, except for silver maple with no trees in PESP Percentage survival on SAEA and SADP is underestimated because parts of some rows of plots on those sites had been bulldozed during road construction.

Among the major hardwoods (not including Osage-orange) mean tree heights after 47 years ranged from 13 m (43 ft) for white ash to 28 m (93 ft) for tuliptree and sweetgum (table 4). Tuliptree and black walnut from seed had greater height at all ages where underplanted in the black locust (PEBL) than in the shortleaf pine (PESP) stand (figure 1). Height growth of the conifers and some hardwoods was greatest on the extremely acidic site SAEA. Heights of pines ranged from 21 m (70 ft) for eastern white to 27 m (90 ft) for loblolly.

The lowest DBH among the major hardwoods was 16 cm (6 in) for sweetgum underplanted in shortleaf pine (PESP). The greatest DBH was 36 cm (14 in) for black walnut, tuliptree, and loblolly pine (table 4).

Table 3—*Percentage survival after 47 years of 100 trees/species each planted by the USDA Forest Service in 1947 on 5 sites in 3 counties of southern Illinois (no pines were planted experimentally in Perry County)*

	Saline Co.		Randolph Co.	Perry Co.	
Species	SAEA	SADP	RA	PESP	PEBL
All trees	16	12	8	29	12
Silver maple	21	6	0	0*	10
White ash	4	0*	0*	0*	0*
Black walnut (seedling)	7	21	31	36	26
Black walnut (seed)	15	29	27	20	8
Sweetgum	44	29	11	38	0*
Tuliptree	9	5	0	55	15†
Osage-orange	21	32	32	56	21
Redcedar, eastern	3	14‡	1		
Pine, shortleaf	8	5	3		
Pine, pitch	5	0*	0*		
Pine, loblolly	30	9	0*		
Pine, eastern white	23	0	0		
Pine, Virginia	16	3	1		

* Present in 1976 (30 years old). Jack and red pine also survived until age 30 and not to age 47. Planted cottonwood and black locust could not be distinguished from volunteers among scattered trees present in the plots.

† Extensive bark damage noted at age 15 years, with later mortality.

‡ A row on the border and next to osage-orange had relatively high survival in 1 plot.

Table 4—*Mean height and diameter at breast height (DBH) with standard errors by site 47 years after planting*

	Saline Co.		Randolph Co.	Perry Co.	
Species	SAEA	SADP	RA	PESP	PEBL
Mean height (m)					
All species (71% of trees)	21±1	23±1	20±1	17±6	23±1
Silver maple	19±2	22±1	—	—	22±2
White ash	13±4	—	—	—	—
Black walnut	20±3	27±2	24±1	20±1	27±1
Black walnut seed	17±2	24±2	27±1	19±1	25±3
Sweetgum	28±1	26±1	18±1	14±1	—
Tuliptree	28±1	27±5	—	22±1	26±1
Osage-orange	9±1	15±1	14±1	10±1	14±2
Redcedar, eastern	17±2	10±1	12±0		
Pine, shortleaf	23±2	20±2	13±1		
Pine, pitch	22±2	—	—		
Pine, loblolly	27±1	24±1	—		
Pine, eastern white	21±1	—	—		
Pine, Virginia	23±1	23±0	10±1		
Diameter at breast height (cm)					
All species (100% of trees)	28±1	26±1	29±1	17±1	27±1
Silver maple	25±2	23±1	—	—	27±3
White ash	17±2	—	—	—	—
Black walnut	22±4	28±2	36±2	21±1	32±2
Black walnut seed	20±2	26±2	34±2	18±2	25±3
Sweetgum	33±1	30±2	25±2	16±1	—
Tuliptree	33±2	36±7	—	21±1	34±3
Osage-orange	10±1	20±2	20±2	9±1	15±2
Redcedar, eastern	23±3	14±1	22±0		
Pine, shortleaf	24±2	28±3	27±2		
Pine, pitch	30±3	—	—		
Pine, loblolly	36±1	41±2	—		
Pine, eastern white	29±3	—	—		
Pine, Virginia	32±2	29±5	21±0		

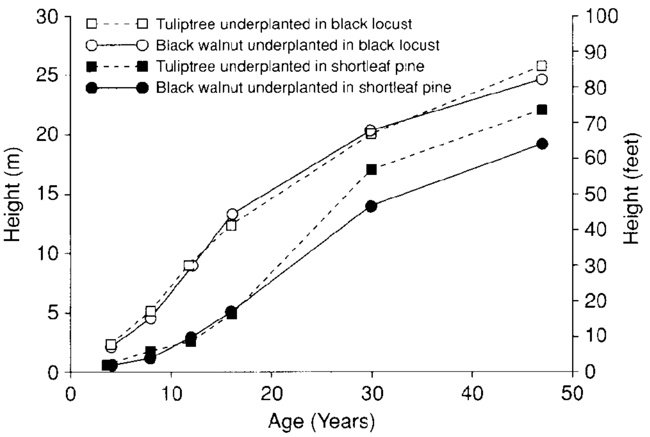

Figure 1—*Tree heights at 6 ages of tuliptree and of black walnut from seed underplanted in 10-year-old stands of black locust (PEBL) or shortleaf pine (PESP).*

Differences of height or DBH were not statistically significant between the tallest hardwood species or for walnut seedlings versus seed (table 5). Walnut and tuliptree comparisons related to overstory (PEBL vs. PESP) were significantly different. No sweetgum survived on the PEBL overstory site to be compared. Comparisons between sites based on all trees were significantly different for height and for DBH if one site was PESP, and for 2 other comparisons of height.

Trees in the block plantings generally looked to be in excellent condition. Mean heights ranged from 25 to 33 m (81 to 109 ft) (table 6). The DBH's tended to be about 1 % of the height. Coefficients of variation were higher for DBH than for height. In the red/Shumard oak plantation, northern red oaks were typically smaller than Shumard oaks. Exact numbers of each were not determined because identification was painstakingly slow and not always certain.

Table 5—*Statistical probability of equally large differences due to chance in a comparison of mean height and diameter at breast height (DBH) for species, species and overstory, and all trees by site.*

	Probability	
	Height	DBH
Species		
All sweetgum* vs. all walnut*	0.52	0.74
All tuliptree* vs. all walnut	0.11	0.35
Sweetgum vs. tuliptree	0.07	0.58
Black walnut seedling vs. seed	0.24	0.06
Species by overstory		
Walnut under locust vs. under pine	0.00	0.00
Tuliptree under locust vs. under pine	0.04	0.00
All trees by site		
RA versus PEBL	0.07	0.16
RA versus PESP	0.00	0.00
RA versus SAEA	0.47	0.20
RA versus SADP	0.01	0.30
PEBL versus PESP	0.00	0.00
SAEA versus SADP	0.04	0.94

* The coefficients of variation for mean height and DBH, respectively, were 28 and 39% for black walnut, 31 and 39% for sweetgum, and 24 and 47% for tuliptree.

Discussion

Species performance varied from site to site in a manner analogous to differences in forest types on nonmined sites (Burns and Honkala 1990). For example pines persisted and grew best on the extremely acidic site SAEA. Another site lost to a county landfill after 1976 had the best growth of pitch, red, and white pine on an extremely acidic soil, pH 4.3 in 1947 and 4.8 in 1976.

Roughly 15 to 20% dead or missing tuliptrees were observed in the Saline Co. block planting in the period from 1976 to 1993, evidently from natural self-thinning. Volunteer black cherry, white oak (from the adjacent planting), flowering dogwood, and other trees, as well as the exotic shrub invaders Japanese honeysuckle and autumn olive, and also woodland herbs were noted in 1993. Dead silver maples or white oaks were not recorded in 1976 or 1993, or dead red/Shumard oaks in 1976. By 1993 beaver damage was recorded on 46% of the living red/Shumard trees measured and 6 trees near a pond were dead. Essentially no volunteer trees were invading the stand of red/Shumard oak, with a few observed in the white oak and silver maple stands.

Pre-mining soils on the present study sites mapped in local county soil reports commonly had subsoils that restricted movement of air and water and growth of roots. Their suitability for growing black walnut was evaluated by Voss and Howerton (1980) using criteria of drainage, soil depth, texture, percentage of coarse fragments, pH of subsoil, and slope. Almost all were shown as unsuited or of questionable suitability. Only limited areas, such as along stream terraces, have suitable soils. Federal and state laws and regulations in the Midwest now require replacement of typical pre-mining soils after mining.

In contrast to performance on typical pre-mining soils, heights of black walnut at age 47 on Forest Service sites PEBL, RA, and SADP were greater than the highest reported site index (SI) age 50 for Central States plantations (Carmean and others 1989). The dragline pullback SADP relatively level site with good growth of several species was much less compacted than present-day sites replaced and graded with pan scrapers and bulldozers.

Two 45-year-old Forest Service sites with stony spoils in east-central Ohio had 42% white ash survival in 1992, 21 % white pine, and 16% tuliptree (Zeleznik and others 1993). The tuliptree heights were lower than those on the Illinois sites with no significant height differences among these three species.

Findings from tree plantings on post-mining soils help identify factors— pH, bulk density, and coarse fragments— that can reveal new understanding of tree growth. Contrary to conventional wisdom, for example, a site with extremely acidic soil gave superior growth of several hardwood and conifer species. Fresh minerals from weathering of the overburden spoil likely offset the kind of mineral nutrition problems associated with extreme acidity on other soils

Table 6—*Soil pH in 1976 and age, number measured, mean heights, and diameters at breast height (DBH) with standard errors and coefficients of variation (CoV) of single-species block plantings in Saline County*

Species	pH 1976	Age (yrs)	No.	Height (m)	CoV (%)	DBH (cm)	CoV (%)
Oak, white	5.8	55	65	26±3	13	23±1	42
Oak, red/Shumard	7.2	55	65	33±3	8	35±1	37
Maple, silver*	6.7	51	100	25±4	19	26±1	24
Tuliptree†	5.7	40	49	30±3	11	30±1	22

* The mean number of stems was 1.75±1, range 1 to 5, and CoV 50%.

† Planted in a decadent black locust stand.

Conclusions

Mine soils or spoils planted before the passage of federal and state laws were highly suited for growth of forest trees. There are thousands of acres of similar pre-law mined land in the lower Midwest. With proper species selection and management, these mined lands in southern Illinois would be a valuable resource for production of silver maple, black walnut, sweetgum, tuliptree, and white and red /Shumard oaks. Areas with extremely acidic soils are limited and had excellent growth of sweetgum and tuliptree, and of loblolly pine. Other pines also survived and grew best on acidic soils. Osage-orange performed very well as a companion species.

Results with the several types of management in the present study have important implications. Black walnut grew well as seedlings or seed in mixed row plantings. Several other species planted in blocks survived and grew exceptionally well. A shortleaf pine overstory (PESP) gave overall good survival and poor growth of underplanted hardwoods, while a black locust overstory (PEEL) gave the reverse. A site relatively leveled (SADP) by dragline pullback had overall good growth of the surviving species. With minimal grading to avoid compaction, mined lands can be productive sites for tree growth with easier access for management and cosmetic features attractive to the public.

Better soils from mining to replace the presently widespread natural soils with limiting conditions for plant growth including fragipans, claypans, and subsoil compaction would bring long-term benefits to areas similar to our study areas.

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Effect of Initial Root Collar Diameter On Survival and Growth of Yellow-Poplar Seedlings Over 17 Years

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A nursery study was installed to test the effects of seedbed density and top-pruning on field performance of bareroot yellow poplar (Liriodendron tulipifera *L.) seedlings. Seedlings were grown at a density of either 9.5 or 16.3 seedlings/ft^2 (102 or 175/m^2) and half were top-pruned in August to a height of about 10 inches (25 em). Outplanted seedlings were measured for heights at ages 2, 9, and 17 years. Survival and growth were positively related to initial root collar diameter. Neither top-pruning nor seedbed density had a lasting effect on growth.* Tree Planters' Notes 47(1):30-33; 1996.

This study was installed at the Virginia Department of Forestry's Augusta Nursery, in the Shenandoah Valley, in the summer of 1971. We wanted to look at the effect of the following 3 treatments on the size and performance of yellow-poplar *(Liriodendron tulipifera* L.), also know as tuliptree, seedlings:

1. Bed densities of 10 and 20 seedlings/ft^2 (107 and 215 / m^2)
2. Top-pruning once during the growing season vs. no top-pruning
3. Root-pruning once during the growing season vs. no root-pruning

The 3 treatments were applied in all combinations, resulting in a 2 × 2 × 2 factorial, yielding 8 treatment combinations. These 8 treatments were replicated 5 times, in 5 adjacent seed beds, for a total of 40 plots. The individual plots were 5 feet (1.5 m) long.

We thinned the plots to the target density of 10 and 20 seedlings /ft^2 (107 and 215/m^2) on July 19 and 20. Seedlings were still very small, none of them over 6 in (15.2 cm) tall. Stocking was erratic and sparse, in places, on all plots. We had hoped to leave either 10 or 20 seedlings on each square foot of each 5-foot-long plot, but many individual square feet had fewer than 20 seedlings. Actual densities left after thinning averaged 9.5 and 16.3 seedlings /ft^2 (102 and 175/m^2). We toppruned to about a 10-inch (25 cm) height on August 23. Many seedlings were not tall enough to be pruned.

We did the root-pruning on September 17, attempting to keep the under-cutter at about a 10-inch (25 cm) depth. Soils at the Augusta Nursery are very heavy and contain a lot of small rounded rocks, and the root-pruning did not go well at all. We ended up dragging a lot of seedlings, and decided to drop this part of the study, which reduced the 8 treatment combinations to just 4 (those that included just seedbed density and top-pruning).

Lifting and Grading

We lifted the seedlings on March 21, 1972. We discarded 1 of the 5 seedbed replications because of excessive variation related to soil differences. From the remaining 16 plots (4 replications × 4 treatment combinations), we lifted a 40-seedling sample across the center of each plot.

We separated the seedlings from each sample by root collar diameter into 1/16-in (1.6-mm) size-classes. Seedlings less than 5/32 in (3.9 mm) were discarded, and the remaining trees were counted by root collar diameter class. We grouped them into 2 size classes for planting in the field: the small size class included the 3/16-in (4.8-mm) and 4/16-in (6.4-mm) seedlings and the large size class included 5/16-in (7.9 mm) and larger seedlings.

Planting in the Field

We planted the seedlings on the Lesesne State Forest, which is in Nelson County, east of and at the foot of Three Ridges Mountain, one of the tall mountains that form the crest of the Blue Ridge in central Virginia. The soil is deep and rocky, developed in colluvium from the mountain above, which is largely composed of granodiorite. These soils are typically good hardwood sites.

Before planting, the area supported a stand dominated by black locust *(Robinia pseudoacacia* L.) and ailanthus *(Ailanthus altissima* (Mill.) Swingle), with some dogwoods *(Corpus florida* L.) and scattered apple trees *(Malus* spp.*),* and a moderate ground cover of honeysuckle *(Lonicera japonica* Thunb.). We harvested the stand during the winter of 1970-71, using the locust for posts. We piled the brush and burned the piles in the spring of 1971. Stumps sprouted vigorously and the honeysuckle grew rapidly. In the late summer of 1971 we sprayed the area with 2,4-dichlorophenoxy acetic acid and then in the early fall, after the honeysuckle had cured, we burned the area. Even with this intensive site preparation, hardwood sprouts again became a serious problem, especially the locust and ailanthus. Consequently, in the spring of 1974, after the poplar seedlings had been through 2 growing seasons, all competing hardwoods were basal-sprayed.

The seedlings were planted on March 28, 1972, using a spacing of 6.6 × 6.6 ft (2 m× 2 m). Even though the seedlings were grouped into small- and large-diameter classes, we noted on a map the diameter of each individual seedlings; in other words, within the small-diameter class, we knew which seedlings were 3/16 in (4.7 mm) and which were 4/16 in (6.3 mm). As seedlings were planted, the top length of each seedling was measured and recorded.

The field planting, therefore, included 8 treatments, the 4 original seedbed treatments each with 2 size classes. These 8 treatments were replicated 3 times in randomized blocks, with a 20-seedling row of each treatment in each block.

Measurements

Seedling heights were measured at ages 1 and 2. At age 9 we measured the diameter at breast height (DBH) of each surviving tree. At age 17 we measured the DBH of each surviving tree and the total height of 60% of the surviving trees. Before we took our measurements at age 17, the trees had suffered considerable top breakage from at least 1 severe ice storm. The trees on which we measured heights were, for the most part, trees that had sustained the least breakage. Many of the badly broken trees became suppressed by more fortunate neighbors. The 3 replications were installed side by side with the 20-seedling rows running approximately north and south

Seedbed Results

Seedlings grown at 10/ft2 (102/m^2) were slightly taller (7%) and slightly larger in diameter (13%) than seedlings grown at 20/ft^2= (175/m^2=) (table 1). Top-pruning reduced top height substantially; top-pruned seedlings were 33% shorter. Top-pruning also had a slight effect on diameter; top-pruned seedlings were 8% smaller.

Survival

The seedbed treatments— low and high bed densities and top— pruning-had no significant effect on survival (table 2). Root collar diameter, on the other hand, had an important effect on survival that increased with age (table 3). After age 2, the slower height growth of smaller diameter seedlings resulted in more of them dying of suppression.

Table 1—*Average root collar diameter (in 16ths of an inch) and shoot height when seedlings were lifted, by seedbed treatment*

Treatment	Height* ft	Height* m	Diameter† (# of 16ths in.)
Low density, top-pruned	1.02	0.31	4.11
Low density, not pruned	1.53	0.47	4.79
High density, top-pruned	0.97	0.29	3.90
High density, not pruned	1.42	0.43	3.96

Low-density seedlings were raised 10/ft^2 (107/m^2); high-density seedlings were raised at 20/ft^2 (215/m^2).

* Based on 120 seedlings for each treatment, measured as they were planted.

† Based on 160 seedlings for each treatment, 40 from each of 4 seedbed plots.

Table 2—*Average survival at ages 1, 2, 9, and 17 years by seedbed treatment*

Treatment	% survival 1 yr	2 yrs	9 yrs	17 yrs
Low density, top-pruned	96	92	82	74
Low density, not pruned	92	92	84	68
High density, top-pruned	93	92	84	68
High density, not pruned	94	93	82	71

Low-density seedlings were raised 10/ft^2 (107/m^2); high-density seedlings were raised at 20/ft^2 215/m^2).

Table 3—*Average survival at ages 1, 2, 9, and 17 years by initial root collar diameter (RCD)*

RCD in.	RCD mm	No. planted	% survival 1 yr	2 yrs	9 yrs	17 yrs
3/16	4.8	120	82	81	62	45
4/16	6.3	120	96	94	87	73
5/16	7.9	119	98	98	89	82
6/16	9.5	59	100	98	93	81
7/16	11.1	29	100	100	97	86
8/16	12.7	8	100	100	100	88
9/16	14.3	2	100	100	100	100
Totals		457				

Note: An analysis of variance was performed on survival at age 2 by grouping the 6/16 to 9/16th-inch seedlings. This provided 120, 120, 119, and 98 planted seedlings in the 3/16-, 4/16-, 5/16-, and 6/16-in and larger diameter classes. Survival percentages were first transformed to arc sine percentages. The overall F for initial diameter was statistically significant (probability of a larger F=0.014). Using Duncan's new multiple range test, the only significant differences (at both the 0.05 and 0.01 levels) were that both 5/16-in and 6/16-in and larger seedlings survived better than 3/16-in seedlings.

Height Growth

At age 2, the initial reduction in top length caused by top-height had disappeared; in fact, top-pruned seedlings were actually taller at age 2 (table 4). The small initial height advantage, when lifted, of seedlings grown at the lower density, had not increased, and on a percentage basis had decreased from 7 to 3%.

Heights at age 2 were strongly related to initial root collar diameter. An analysis of variance was performed, and the overall difference between large and small seedlings— 3.96 ft (1.21 m) compared to 2.91 ft (0.89 m)— was significant (probability of a larger F = 0.000009). Average heights at age 2, by initial 1/16-inch(1.6-mm) diameter classes, are presented in table 5. Average heights at age 17 are presented in table 6 by initial root collar diameter.

Table 4—*Average height by treatment at age 2*

Treatment	Height ft	Height m
Low density, top-pruned	3.56	1.08
Low density, not pruned	3.42	1.04
High density, top-pruned	3.42	1.04
High density, not pruned	3.35	1.02
Low density, top-pruned, small	3.12	0.95
Low density, top-pruned, large	4.00	1.22
Low density, not pruned, small	2.87	0.87
Low density, not pruned, large	3.96	1.21
High density, top-pruned, small	2.96	0.90
High density, top-pruned, large	3.88	1.18
High density, not pruned, small	2.70	0.82
High density, not pruned, large	4.00	1.22

Note: Low-density seedlings were raised 10/ft^2 (107/m^2); high-density seedlings were raised at 20/ft^2 (215/m^2).

Table 5—*Average height at age 2 by initial root collar diameter (RCD)*

RCD in.	RCD mm	# of Trees Planted	# of Trees Measured	Average height ft	Average height m
3/16	4.8	120	97	2.5	0.76
4/16	6.3	120	113	3.3	1.01
5/16	7.9	119	116	3.7	1.13
6/16	9.5	59	58	4.3	1.31
7/16	11.7	29	29	4.4	1.34
8/16 & 9/16	12.7 & 14.3	10	10	4.5	1.37
		457	423		

Diameter Growth

Average diameters at ages 9 and 17, by initial root collar diameter class, are presented in table 7. Diameter at base height (dbh) increased with increasing initial root collar diameter, reaching a maximum for 6/16-in (9.5-mm) and 7/16-in (11.1-mm) seedlings, and then fell off for 8/16-in (12.7-mm) and 9/16-in (14.3-mm) seedlings. We have no idea why DBH decreased for the largest seedlings, but the sample size was only 10 and 9 seedlings (at ages 9 and 17), so the difference may be a random effect. An average stand table at age 17, combining all initial root collar diameter classes, is presented in table 8.

Conclusions

Seedling size has a profound impact on both survival and growth of bareroot yellow-poplar seedlings. Although top-pruned seedlings were initially about 6 in (15 cm) shorter, growth during the first 2 years after outplanting was increased enough so there were no height differences between treatments at age 2.

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Table 6—*Average heights at 17 years, for all trees and just dominant and codominant (D&CD) trees, by initial root collar diameter (RCD)*

			All trees measured for height				D&CD trees measured			
Initial RCD					Height				Height	
in	mm	No. surviving	No.	%*	ft	m	No.	%*	ft	m
3/16	4.8	54	35	65	52.0	15.8	18	33	62.2	19.0
4/16	6.3	88	53	60	56.5	17.2	28	32	61.1	18.6
5/16	7.9	98	55	56	55.8	17.0	25	26	62.5	19.1
6/16	9.5	48	34	71	56.5	17.2	21	44	62.5	19.1
7–9/16	11.1–14.3	34	16	41	58.7	17.9	11	32	62.3	19.0
Averages				60	55.7	17.0		32	62.0	18.9
Totals		322	193				103			

* Number measured as a percentage of number surviving.

Table 7—*Average diameter at breast height (DBH) by initial root collar diameter (RCD) at 9 and 17 years*

		9 yrs			17 yrs		
Initial RC			DBH			DBH	
in	mm	No.	in	cm	No.	in	cm
3/16	4.8	74	2.44	6.20	54	5.13	13.03
4/16	6.3	104	3.26	8.28	88	5.98	15.19
5/16	7.9	106	3.50	8.89	98	5.78	14.68
6/16	9.5	55	3.98	10.11	48	7.04	17.88
7/16	11.1	28	3.90	9.91	25	6.80	16.51
8 & 9/16	12.7 & 14.3	10	3.34	8.48	9	5.78	14.68
Averages			3.32	8.43		5.99	15.21
Totals		377			322		

Table 8—*Average density of trees at age 17 by diameter class (diameter at breast height, DBH)*

DBH			
in	cm	Trees/ac	Trees/ha
1/16	2.5	25	62
2/16	5.1	38	94
3/16	7.6	58	143
4/16	10.2	88	217
5/16	12.7	71	175
6/16	15.2	73	180
7/16	17.8	135	333
8/16	20.3	73	180
9/16	22.9	56	138
10/16	25.4	38	94
11/16	27.9	10	25
12/16	30.5	6	15
Totals		671	1,657

Top-Pruning Bareroot Hardwoods: A Review of the Literature

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Top-pruning hardwoods before lifting reduces the costs involved with lifting, packing, storing, shipping and planting. This practice also decreases the chance of dieback. For some sites (and some years), top-pruning will increase the probability of survival. Top-pruning hardwoods does not seem to reduce average heights after 5 years in the field and this practice will often increase early height growth. For several species, top-pruning before transplanting appears to have no long-term effect on stem form. There are no reported longterm effects of top-pruning on seedling physiology. This paper reviews research studies that have been published over the last 60 years. Tree Planters' Notes 47(1):34-40; 1996.

Top-pruning or top-clipping ("heading back" in horticultural terms) is a common practice employed by several nursery managers in the southern United States (figure 1). An informal survey of 13 hardwood nurseries determined that 9 managers used top-pruning as a routine practice. Some managers prune about 1 month before lifting, whereas others prune in early fall. There are three main reasons nursery managers top-prune hardwood seedlings:

- to decrease lifting, packing, and shipping costs
- to reduce the chance of stem dieback after planting
- to increase the chance of survival

Figure 1— *Top-pruning hardwoods (photograph courtesy of Sam Campbell, nursery manager, Kimberly-Clark Corp., Elberta, AL).*

In this paper, research studies published over the last 60 years are reviewed to enable managers to make informed decisions about top-pruning (figure 2). A sickle-bar mower is the favored type of mechanical pruner because it makes a relatively clean cut. The following statements from nursery managers describe the details of its use. Stauder (1995) tells us that:

> Some nurseries such as those in Wisconsin top prune hardwood seedlings. The 2-0 hardwood seedlings are top pruned, if necessary, to a height of 12 to 14 inches during the late summer or early fall. Some extremely fast growing species such as sycamore, elderberry or sumac may need to be top pruned during the 1st-year of growth to control height. No major problems have been observed by

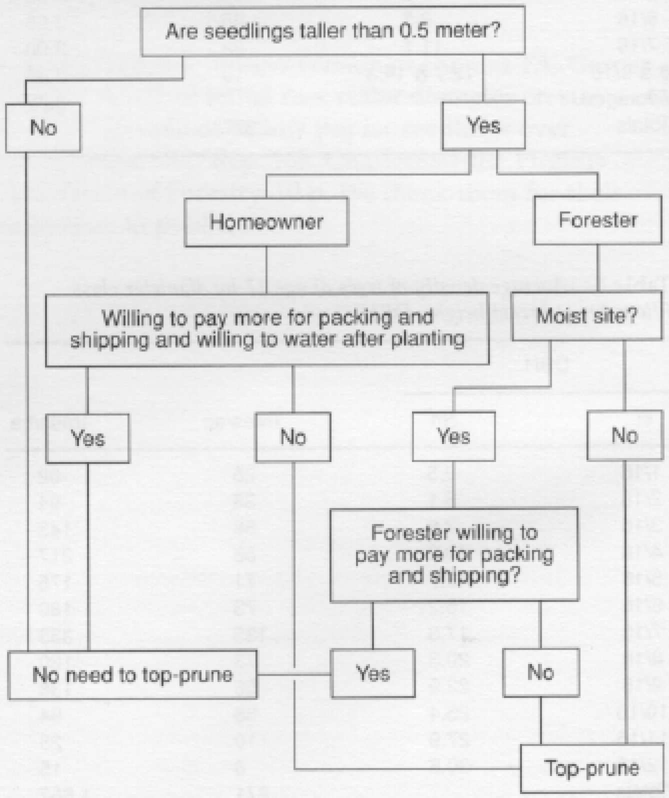

Figure 2—*Flow chart to assist in the decision to top-prune hardwoods.*

> top pruning alternate branching species; however, nursery managers do not top prune opposite branching species such as green ash or white ash, because severe forking may result.

Sam Campbell, a nursery manager with a nursery in south Alabama, recently wrote (1992) that:

> Top pruning is used to control the height growth of seedlings. A [sickle]-bar mower was modified to top clip seedlings at height of 2-2.5 feet above the seedbeds. Top pruning is performed throughout the growing season to maintain even height growth and reduce the number of overtopped and cull seedlings. The tractor speed and blade sharpness [are] critical to make clean cuts and not tear seedlings. After mowing we apply a fungicidal spray to reduce infections on freshly cut surfaces.

One rationale for top-pruning is that few hardwood nursery managers have the luxury of knowing in advance the types of sites where their seedlings will be shipped. Even fewer can accurately predict the weather that will occur after their seedlings are outplanted. Therefore, many managers use various nursery practices that will improve the likelihood of achieving good survival on droughty sites or with spring droughts. As a form of insurance, many nursery managers will top-prune their seedlings to improve the chance of survival and growth under stressful conditions. Typically for hardwood species, the taller the seedling in the nursery, the more difficult it is to get enough roots lifted to minimize transplant shock. The harvested ratio of root dry weight to tree dry weight is higher for top-pruned seedlings than for non-top-pruned seedlings. "Usually the amateur is disinclined to cut back a plant for fear of injuring it, but this pruning is essential in order to promote vigor, and better growth will follow" (Duruz 1953). For some hardwoods, top-pruning (to a height of 20 cm above the root-collar) is a recommended nursery practice (Johnson and others 1986; Ladrach 1992). Therefore, in some studies, all seedlings are routinely top--pruned before outplanting (Filer and Nelson 1987, Hix and others 1994, Mohan and others 1990, Woessner 1972).

Expense of Lifting, Storing, and Shipping Tall Hardwoods

Tall bareroot hardwoods are often cumbersome to lift and expensive to bundle, transport and plant (Woessner 1972). Several researchers have suggested the solution to this problem is top-pruning (Briscoe 1969, Limstrom 1963, Woessner 1972). How much money foresters and companies are willing to spend to plant non-pruned seedlings may depend largely on the size of the area planted. If the area is small, then the nuisance of planting a few tall seedlings is minimal. However, as the acreage increases, the nuisance increases. For example, if it costs $8/thousand more to bundle and store, and an additional $35/ha to ship and plant, then it only costs about $45/ha more. This might not seem like much for 10 ha ($450 more), but it would amount to $45,000 for 1,000 ha. As acreage increases, questions about the need to spend extra money for non-pruned seedlings increases. The following quote by Limstrom (1963) can be found in the handbook "Forest Planting Practice in the Central States."

> Top pruning has no detrimental effect on survival and growth of yellow-poplar and perhaps most other hardwoods; however, some forked trees may develop after top pruning of opposite-budded species such as ash and maple. Packing and shipping are cheaper if hardwood seedlings are top-pruned just after lifting in the nursery. And more top-pruned than unpruned trees can be carried in a planting tray.

Nursery managers who sell seedlings to the public may choose to leave some hardwoods unpruned. Often the uninformed consumer is more concerned with the appearance of the seedling than with reducing the risk of mortality or dieback. Most homeowners irrigate newly transplanted seedlings, which reduces the risk of transplanting stress. Therefore, managers who wish to sell to the public may decide to offer two different stock types (tall unpruned seedlings and short top-pruned seedlings). Tall seedlings might be sold to homeowners for 33 cents each and top-pruned seedlings for reforestation might be sold for 30 cents each. A flowchart like the one in figure 1 can aid nursery managers in deciding if they should top-prune hardwoods.

Timing of Top-Pruning

In the southern United States, the typical season for top-pruning pines is during the summer months (from June through September) whereas fall (October to December) is the traditional time for top-pruning hardwoods. For fast growing species like sycamore (*Platanus occidentalis* L), some nursery managers will begin top-pruning in July (Briscoe 1969). In Alabama, 2 managers top-prune hardwoods several times throughout the summer months (figure 1). However, there are only a few studies that report the effects of timing on subsequent growth after transplanting. In a study of northern red oak *(Quercus rubra* L.), seedlings were given a severe top-pruning treatment (cutting stems back to the groundline). By April (1 month after transplanting), green weights of roots were reduced by 60% or more if top-pruning was done from August to October. However, there was little or no reduction in root growth due to top-pruning if it was done in November, December, or January. Therefore, researchers tend to top-prune seedlings after lifting at time of transplanting (Adams 1985, Johnson and others 1984, Meadows and Toliver 1987, McCreary and Tecklin 1993, Russell 1973, Smith and Johnson 1981, Zaczek and others 1993). Top-pruning woody shoots after leaf fall appears to have no adverse effects (Briscoe 1969) and allows hardwood seedlings to develop large root systems in the nursery.

Short-Term Effects on Physiology

There is only limited information on the effects of top-pruning on hardwood seedling physiology and the results vary with each study. Some researchers have employed extreme top-pruning treatments in order to show a significant treatment effect. However, most studies show ephemeral effects on seedling physiology. Because data are limited, it may be prudent not to generalize the results to all hardwood species. The following is a summary of a few reports.

Crunkilton and others (1992) examined the effects of top-pruning on northern red oak physiology (photosynthetic photon flux density, photosynthesis, transpiration, stomatal conductance, leaf water potential at predawn, and leaf temperature). Shoots of unpruned bareroot seedlings were 56 cm tall. At time of planting, these were top-pruned to 20 cm. Top-pruning seedling shoots before planting had little effect on measured physiological processes.

Transpiration, stomatal conductance and total water use were recorded in a greenhouse study using root or shoot-pruned seedlings of apple *(Males pumila* Mill.), littleleaf linden *(Tilia cordata* Mill.), and silver birch *(Betula pendula* Roth) (Abod and Webster 1990). In this study, top-pruning (removing two-thirds of the shoot) reduced water use for the first 5 weeks after potting. All seedlings were watered twice each day, so apparently all 24 seedlings/ species survived. Top-pruning had no significant effect on stomatal conductance of the linden and birch. For 2 of the 5 sampling periods, top-pruned apple seedlings had more conductance than did control seedlings. Partly because there were only 6 seedlings/ treatment combination, there was no significant effect of toppruning on either shoot growth or root growth of birch. However, shoot-pruning did reduce new root growth of both apple and linden.

Johnson and others (1984) examined the effect of top-pruning on root growth potential of northern red oak. Unpruned (large) 1+0 seedlings were 99 cm tall and toppruned seedlings were 15 cm tall. Top-pruning had no significant effect on new roots, new root weight, or new shoot length. However, only 8 trees were used for each treatment. Larson (1975) reported similar results with root growth when shoots were pruned to 46 cm above the root collar at time of lifting.

The effects of top-pruning on budbreak of black cherry *(Prunes serotina* Ehrh.) was examined in a greenhouse in Tennessee (Farmer and others 1975). Unpruned 1+0 seedlings (heights not reported) were compared to seedlings that were pruned to 6 cm above the rootcollar. Top-pruning significantly increased rate of budbreak.

Dieback After Outplanting Unpruned Hardwoods

Under certain conditions, bareroot hardwood seedlings will die back during the first year after outplanting. For example, northern red oak seedlings (ranging in height from 45 to 66 cm) exhibited dieback on 3 sites for 2 years after planting (Kaczmarek and Pope 1993). On 1 site, the amount of dieback was almost half the original height. Overall, root pruning after lifting resulted in an increase in dieback. To reduce the chance of dieback on this site, it may be appropriate to increase the root weight ratio by top-pruning rather than decrease the ratio by root pruning after lifting. For some species such as yellow-poplar *(Liriodendron tulipifera* L.), new root growth of seedlings transplanted in May can be increased by top-pruning to a height of 15 or 30 cm (Kelly and Moser 1983). This might occur if a tall "unbalanced" seedling produced less foliage than a shorter, top-pruned seedling. If foliage production is reduced (due to moisture stress or dieback), there would likely be a reduction in the amount of current photosynthate available for new root growth. This might explain why roots of top-pruned yellow-poplar seedlings grew more during May, June, and July than at other times (Kelly and Moser 1983).

Tall, non-top-pruned sweetgum *(Liquidambar styraci*flua L.) may die-back when planted on sandy soils. In a study by Kormanik (1986), the percentage dieback in June was related to root-collar diameter (RCD) and the number of lateral roots. Large-diameter seedlings with 13- to 14-mm RCD and more than 6 lateral roots have greater survival and less dieback than small diameter seedlings with 7- to 8-mm RCD and less than 4 lateral roots. However, for a given RCD, taller seedlings tend to die back more (and have less survival) than shorter seedlings. When outplanting 14-mm-RCD sweetgum that were 1.1 m tall, the average length of dieback ranged from 40 to 55 cm. At the end of the first growing season, heights were less than at time of planting. Dieback is nature's way of top-pruning transplanted hardwoods.

Growth from these dead tops would likely be no different than if the sweetgum seedlings were top-pruned 4 months after outplanting (in June) to a height of 55 to 70 cm. It is conjectured that pruning to this height in the nursery would allow: (1) reduced transplanting stress; (2) greater seedling survival; and (3) positive height growth from planting till June.

Increases in Survival From Top-Pruning

On moist sites where survival is high (>90%), top-pruning of hardwoods will likely not increase survival. In many research trials, there is no significant effect of top-pruning on survival. However, as site conditions worsen and as survival decreases, top-pruning in the nursery can improve the chances of survival (table 1). Selected top-pruning studies are summarized in the following paragraphs.

In Oklahoma, Smith and Johnson (1981) found that top-pruning at transplanting (50% top removal) increased survival of pecan by 25%. In Louisiana, Meadows and Toliver (1987) top-pruned pecan— *Carya illinoensis* Wangenh. (Koch)— seedlings back to a height of 25 cm immediately after planting. On one site, there was no difference in survival (91 %) but on another site with more competition, survival of top-pruned seedlings was 94% whereas the check exhibited 85% survival.

In Saskatchewan, green ash *(Fraxinus pennsylvariica* Marsh.)) and choke cherry *(Prunus virginiana* L.) seedlings are pruned to a uniform height of 46 cm to facilitate mechanical harvesting and sorting operations (Anonymous 1984). Although this practice has been carried out at the Indian Head Nursery for many years, there was no information on the effect of top-pruning on outplanting performance. Therefore, a study was established where 2+0 seedlings were top-pruned to a height of 46 cm. First-year survival of the top-pruned green ash (97%) was significantly higher than that of the non-pruned seedlings (80%). The rate of bud break was significantly higher for the top-pruned seedlings. Top-pruning of choke cherry seedlings had no significant effect on survival or bud break.

In Mississippi, Meginnis (1940) examined several top-pruning treatments for black locust *(Robinia pseudoacacia* L.). The best survival was obtained from seedlings pruned to 23 cm in the fall at lifting (82%); seedlings cut back to 23 cm in the spring at planting (82%); and the 46 cm unpruned checks (79%). Top-pruning seedlings all the way back to the root-collar caused a significant decrease in survival (55 to 70%). Although top-pruning back to the root-collar has been studied by several researchers, this severe treatment is neither a common nursery practice nor a recommended practice.

Table 1—*Effect of top-pruning of bareroot seedlings on field survival of various hardwood species*

	Outplanting height (cm)		% Survival				
Species	Control	Top-pruned	Control	Top-pruned	Difference	Significance	Reference
pecan	?	15	99	93	-6	ns	Toliver and others (1980)
willow oak	?	15	97	97	0	ns	Toliver and others (1980)
green ash	30-46	10	96?	96?	?	—	Woessner & van Hicks (1973)
water oak	?	15	94	100	+6	ns	Toliver and others (1980)
pecan	?	25	91	91	0	ns	Meadows & Toliver (1987)
yellow-poplar	46	10	90+	90+	?	—	Sterling & Lane (1975)
yellow-poplar	45	30	92	92	0	ns	Dierauf & Garner (1993)
yellow birch	?	8	90	79	-11	—	Godman & Mattson (1972)
n. red oak	21-57	10-12	85	85	0	ns	Zaczek and others (1993)
pecan	21	25?	85	93	+8	ns	Meadows & Toliver (1987)
blue oak	25-30	15	81	81	0	ns	McCreary & Tecklin (1994)
green ash	?	45	80	97	+17	**	Anonymous (1984)
choke cherry	?	45	80	78	-2	ns	Anonymous (1984)
black locust	46	23	79	82	+3	ns	Meginnis (1940)
black walnut	45	15	74?	74?	?	—	Russell (1979)
pecan	150	75	75	100	+25	—	Smith and Johnson (1981)
yellow birch	?	8	50	92	+42	—	Godman & Mattson (1972)
yellow poplar	60	15	0	0	0	—	Kelly & Moser (1983)

** = significant at the 1% level of probability; ns = no significant difference; — = statistics not reported; ? = data not reported.

Increases in Growth From Top-Pruning

Top-pruning of bareroot hardwoods before transplanting will often increase early height growth. In many cases, total height after 3 or more years in the field is no different for top-pruned than for non-pruned seedlings (Briscoe 1969). However, in a few studies, the growth of top-pruned seedlings surpasses that of non-pruned seedlings. This might result on sites where tall, non-pruned seedlings never fully recovered from the shock of transplanting. When "natural" top-pruning occurs (for example, deer browse after outplanting), hardwoods often grow well after winter browsing (Jacobs 1969, Wilson 1993). Selected studies in which height growth was increased are reviewed in the following paragraphs.

In California, McCreary and Tecklin (1994) conducted a top-pruning study on blue oak– *Quercus douglasii* Hook. & Arn. Seedlings were immediately top-pruned after planting to a 15-cm height and were compared with unpruned seedlings (25 to 30 cm tall). Survival was the same for both treatments (table 1). After 2 years of growth, the top-pruned seedlings were 10 cm taller than the unpruned seedlings because they grew more during the first and second year after outplanting. The top-pruned seedlings were also larger in diameter.

In Louisiana, water oak (*Quercus nigra* L.) seedlings were planted and then were either left unpruned (46 cm tall) or pruned to 23 cm or 2.5 cm from the root-collar (Adams 1985). After 2 years, the 2.5-cm treatment had not yet equaled the total height of the check (were 12 cm shorter), but they were growing at a much faster rate and appeared to be in a higher state of vigor than unpruned seedlings. For this treatment, height growth during the first 2 years was 52% greater than for the unpruned seedlings.

In South Carolina, yellow-poplar seedlings were lifted and then either left unpruned or were pruned 10, 15, or 20 cm from the root-collar (Sterling and Lane 1975). After 1 year in the field, growth of seedlings receiving no root-pruning was inversely related to height after top-pruning. On the better site, the 10-cm treatment had the most height growth (107 cm) and the control treatment had the least (93 cm). Overall, height growth was reduced by pruning roots after lifting.

In Tennessee, black walnut *(Juglans nigra* L.) seedlings were top-pruned immediately before planting to 15 cm above the root-collar, whereas control seedlings were about 46 cm tall. Annual growth of top-pruned seedlings was significantly better during the first 3 years after planting. During these dry years, top-pruned seedlings grew almost 5 times faster than unpruned seedlings (Russell 1979).

In Tennessee, northern red oak seedlings were toppruned at time of planting to 13 cm above the root-collar whereas control seedlings were about 25 cm tall (Russell 1973). Annual growth of top-pruned seedlings was as good as control seedlings. On a plateau site, both treatments were 1.3 m tall after 5 years. On a cove site, top-pruned seedlings were 1.2 m tall and control seedlings were 1.3 m tall. Top-pruning of tops stimulated the formation of multiple leaders but this had no serious long-term effects.

In Texas, green ash seedlings were top-pruned to 10 cm or 20 cm above the root-collar at time of planting. Control seedlings were about 30 to 46 cm tall (Woessner and van Hicks 1973). After 3 years, height of top-pruned seedlings (3.23 m) was as good as control seedlings (3.20 m).

In Oklahoma, pecan seedlings were top-pruned to 75 cm above the root-collar at time of transplanting. Control seedlings were about 150 cm tall (Smith and Johnson 1981). After 2 years, total shoot growth of top-pruned seedlings (3.1 m) was greater than non-pruned seedlings (1.97 m).

Top-Pruning and Tree Form

Some have expressed the view that top-pruning hardwoods will always result in poor tree form. However, field checks with sycamore have failed to show that top-pruning increases the proportion of forked stems (Briscoe 1969). Stem form will likely be unimportant for pulpwood. For example, some organizations use short-rotations where 6-year-old sweetgum are top-pruned (that is, harvested) to a 15-cm stump and allowed to sprout back. These sprouts are later harvested for pulpwood. According to Dr. Stienbeck at the University of Georgia, sweetgum has strong apical dominance. After 6-year-old trees are coppiced, a stump may have 12 to 24 sprouts the first year; 6 to 8 sprouts the second year; and 1 to 3 sprouts the third year. Top-pruning in the nursery would likely not result in many sweetgum trees with 2 dominant stems after 10 years of growth. Even if it did, this treatment would not decrease volume growth per hectare.

Apparently top-pruning does not cause poor tree form for northern red oak (Russell 1973, Zaczek and others 1993). Even where deer browsing is heavy, the formation of a strong central shoot will occur as long as seedlings are undergoing rapid growth. When grown for sawlog production, several top-pruned hardwoods will have adequate tree form after 22 years (Stout 1986).

Because of the strong apical dominance of eastern cottonwood— *Populus deltoides* Bartr. Ex Marsh.)— many foresters are not concerned about the stem form when planting cuttings. Unrooted cuttings are stem segments that have had their tops removed (equivalent to severe top-pruning). A side bud near the top of the cutting forms a shoot and this side-branch develops into the main leader. This species can also be regenerated using taller seedlings (Phares and White 1972) or rooted whips with intact terminal buds (Burkhardt and King 1983). Use of seedlings or whips would avoid the sprouting that occurs with unrooted cuttings. However, because stem form resulting from sprouting is not a problem, unrooted cuttings are the preferred stock type for this species.

Some suggest that forked trees may develop after top-pruning of opposite-budded species such as green ash (Campbell 1992, Limstrom 1963, Stauder 1995). Many nursery managers have seen a double-leader develop after top-pruning green ash. However, we do not know for how long the double-leader persists. Some claim the effect is ephemeral; and for this reason, nursery managers in Oklahoma and Saskatchewan routinely top-prune green ash.

Further Research

Top-pruning studies have not been conducted on every hardwood species. Therefore, some foresters may question if field survival of all hardwood species is increased by top-pruning. A simple way to determine the effects of top-pruning on a specific species is to outplant equal amounts of top-pruned and non-pruned seedlings on various sites. To be an effective comparison, the difference in height after top-pruning should be at least 30 cm (both height of controls and height of pruning treatment should be reported). The study should be well replicated with more than 100 seedlings/ treatment. Dieback can be recorded in midsummer following outplanting and survival can be measured after 1 year. However, form and growth should be measured 5 years after outplanting. This information would provide a good data base from which sound recommendations could be made. Conclusions based on only 6 trees/treatment might not be very meaningful.

Conclusions

Top-pruning in the nursery is a way to reduce the costs involved with lifting, bundling, packing, storing, shipping, and planting hardwoods. The flow-chart in figure 2 can help nursery managers make decisions about top-pruning. Top-pruning hardwoods can decrease the chance of dieback. For some sites (and in some years), top-pruning will increase the probability of survival. Height growth during the first 2 years after transplanting can be greater for top-pruned seedlings than for taller non-pruned seedlings. Therefore, top-pruning hardwoods does not seem to reduce average heights after 5 years in the field. Top-pruning is recommended for species like northern red oak (Johnson and others 1986), sycamore (Briscoe 1969) and for some tropical species (Djapilus 1990, Ladrach 1992, Mohan and others 1990). For field foresters, there are economic reasons to top-prune hardwoods that are taller than 0.5 m.

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