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I am submitting herewith a thesis written by Stacy Lay entitled "Seedling quality and genetics in nursery and field plantings of northern red oak (*Quercus rubra* L.)." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

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Seedling Quality and Genetics in Nursery and Field Plantings of Northern Red Oak (*Quercus rubra* L.)

A Thesis

Presented for the

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Degree

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Abstract

This thesis addressed the problems associated with artificial regeneration of northern red oak (*Quercus rubra* L.) from nursery production to field plantings. The primary objective was to examine the effects of visual grading and genetics on nursery seedling quality and early survival and growth in the field. One year-old nursery seedlings grown at two nurseries were visually separated into two distinguishable grades for planting and approximately 60% of the seedlings were judged to be of unacceptable size for successful field regeneration. Genetic differences in growth performance of nursery seedlings indicate that families could be selected based on overall mean performance as well as the distribution and uniformity of their progeny. Eighteen northern red oak genetic tests were established in 1995 on sites (site $index_{50} \geq 70$) throughout the southeastern United States using quality-graded seedlings from 78 families. Family differences in three-year survival and height were apparent as nursery effects diminished. Overall survival and growth indicate that protection from damaging agents, primarily deer (*Odocoileus virginianus*), is critical for successful field regeneration of northern red oak.

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Part One: General Introduction

Background and Research Objectives

Oaks (*Quercus* L. spp.) are among the most economically and ecologically valuable hardwoods in eastern North America. Northern red oak (*Quercus rubra* L.) is the most widespread of the red oaks, subgenera *Erythobalanus*, occupying stands in northern, central and southern upland forests (Sander 1990). The wood of the northern red oak is well known for its beauty, durability and strength. Northern red oak acorns provide food for a variety of wildlife including squirrels, deer, mice, and some species of birds. Changes in the northern red oak component of eastern hardwood forests would critically affect utilization for consumptive, e.g., timber, and non-consumption, e.g., recreation, resources and impact forest ecosystem biodiversity. The ability to maintain the oak component in eastern hardwood forests will become increasingly important, as pressure intensifies for forested land to move to multiple value use.

Northern red oak is a common species in eastern hardwood forests, often regenerating after disturbances from fire (Abrams 1992). Frequent ground fires, primarily caused by Native Americans, helped to maintain the oak component in pre-settlement forests for thousands of years (Abrams 1992). The regime of logging, grazing, and fire used in settlement forests until the 1800's also maintained the oak component in eastern hardwood forests. Additionally, the disappearance of the American chestnut perpetuated the dominance of oak species.

The oak component in eastern hardwood forests is presently decreasing (Abrams 1992, Crow 1988, Lorimer 1993). Oak dominated stands are currently being replaced by other species, especially on good upland sites (site index $\geq$ 70) (Crow 1988, Lorimer

1993). The exclusion of fire primarily has been most influential on changes in forest composition (Lorimer 1985). The understory of many mesic oak forests excluded from fire are now dominated by late successional species, i.e., birch, maple, hemlock, and as mature oaks die, non-oak regeneration gains dominance (Abrams 1992, Lorimer 1993, McGee 1979).

Northern red oak regeneration has been unable to compete with faster growing pioneer species like yellow-poplar (*Liriodendron tulipifera* L.) and red maple (*Acer rubrum* L.) following clearcutting of good mesic sites (site index $\geq$ 70) in the Appalachian mountain region (Beck and Hooper 1986, Leopold *et al.* 1985, Smith 1979). The shelterwood method has been recommended to improve the growth of understory oak seedlings until time of overstory removal (Loftis 1990). This method has had limited success (Loftis 1990, Martin and Hix 1988, Sander 1979), however, and is expensive to implement due to the intensive site preparation required (Sander and Graney 1993). Additionally, ten to twenty years may be required before oaks become established and the overstory is removed (Loftis 1990, Sander and Graney 1993).

Artificial regeneration of oaks has been used with limited success to supplement natural regeneration on cutover or disturbed sites (Foster and Farmer 1970, McGee and Loftis 1986, Olson and Hooper 1972). Damage from mammals, insects and/or disease have limited the development of planted oak seedlings (Auchmoody and Walters 1992, Graveline 1997, Ward 1996). Herbicides, pesticides, and deer protection such as tree shelters and fencing have been used with success (Graveline 1997, McCormick *et al.* 1991, Ward 1996), but cost of such protection is often prohibitive (Kays 1996, Loftis

1978). Even with protection from damaging agents, oak plantings on good sites generally fail due to inability of nursery stock to compete with natural regeneration (Lorimer *et al.* 1994, Russell 1971).

Traditionally, nurseries have grown oak seedlings to a relatively small, uniform size to facilitate shipping and planting with little consideration of root system characteristics (Crow and Isebrands 1986). Nursery practices have recently been developed that concentrate on adjustment of fertilization and irrigation applications to produce the highest-quality oak seedlings possible (Kormanik *et al.* 1994a, Kormanik *et al.* 1994b). Additionally, grading of nursery stock has been shown to improve field performance of oak seedlings (Kormanik *et al.* 1995, Olson and Hooper 1972, Schultz and Thompson 1990). Seedling grading has been based on minimum height or diameter size recommendations, i.e., $\geq$ 8 mm in root collar diameter and 50 cm in height (Johnson 1981), and root system characteristics, i.e., $\geq$ 5 first-order lateral roots (Kormanik *et al.* 1995, Schultz and Thompson 1990). Unfortunately, these recommendations generally are not heeded by commercial nurseries, in part due to the lack of field performance data for quality-graded seedlings. Only a few studies have been established with graded seedlings that were grown under optimal nursery conditions (*sensu* Kormanik *et al.*.1994a and Kormanik *et al.* 1994b), and these studies are relatively young in age (Kormanik *et al.* 1995, Lay *et al.* 1997).

In addition to nursery practices and seedling size, seed source can affect survival and height of northern red oak nursery stock (Buchschacher *et al.* 1991, Kriebel 1965) and growth rates of seedlings several years in the field (Gall and Taft 1973, Houston

1987, Kriebel *et al.* 1988, Schlarbaum and Bagley 1981, Schreiner and Santamour 1961). Previous genetic studies, however, generally use seed collected from wild populations in various geographic origins (Kriebel 1965, Gall and Taft 1973, Schlarbaum and Bagley 1981). Field tests using seed collected from seedling seed orchards are very limited due to the small number of seed orchards (Schlarbaum *et al.* 1998, Remaley 1998).

This thesis addresses the problems associated with nursery production of high quality northern red oak seedlings and the effects of seedling quality and genetics on subsequent field performance. Specific objectives include:

1) Evaluate the effects of visual grading on quality of northern red oak seedlings from two state nurseries

2) Characterize differences among northern red oak seedling characteristics among open-pollinated families from a seedling seed orchard grown at a Tennessee nursery

3) Examine the survival and growth of three-year old northern red oak genetic tests established with nursery-graded seedlings.

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Part Two: Visual Grading and Quality of Northern Red Oak Seedlings Grown at Two State Nurseries

Abstract

Past research has used detailed measurements of various growth characteristics to determine seedling grades and quality of northern red oak nursery stock. This study evaluates the effectiveness of a visual grading process, similar to those found in commercial nursery operations, to distinguish high quality seedlings. Northern red oak (*Quercus rubra* L.) seedlings were grown for one year at two state nurseries and visually separated into three grades (cull, good, or premium) according to root and shoot characteristics. Approximately 60% of the seedlings grown at each nursery were judged to be of unacceptable size for successful field regeneration. Number of first-order lateral roots (FOLR), height, and root collar diameter (RCD) were measured for seedlings in the good and premium grades. Premium grade seedlings were significantly larger than the good grade seedlings for both nurseries. Phenotypic correlations of growth traits were highest between number of FOLR and RCD. The results demonstrate that high quality northern red oak nursery stock can be visually selected into two distinguishable grades.

Introduction

Many eastern North American stands currently dominated by oak (*Quercus* L. spp.) contain high proportions of non-oak species following natural mortality or harvesting (Lorimer 1993). This is particularly true on high quality mesic sites (site $index_{50} \geq 70$), where competition is intense (cf. Johnson 1993, Trimble 1973). Even with overstory removal, the smaller, slow-growing oak regeneration can not compete with more vigorous species such as red maple (*Acer rubrum* L.) or yellow-poplar (*Liriodendron tulipifera* L.) (Beck and Hooper 1986, Loftis 1983, Sander 1972) .

Historically, frequent natural and Native American-set fires created conditions favorable for regeneration of oak species (Buckner and Turrill In Press, Abrams 1992). Additional disturbances by settlers and the disappearance of the American chestnut (*Castanea dentata* (Marsh.) Borkh) maintained a significant oak component throughout much of eastern North American upland forests (Abrams 1992, Lorimer 1985). Fire reduction and suppression during this century has allowed other species that are less fire-resistant to achieve dominance in stands which previously contained a high proportion of oak species (Watt *et al.* 1992).

Artificial regeneration of different oak species has been attempted to supplement natural regeneration on high quality sites. Generally, these attempts have had limited success, as the oak seedlings were overtopped by faster growing vegetation. The resulting decrease in light caused suppression and senescence (Johnson 1976, McGee and Loftis 1986, Russell 1973). Planting failures can be partially attributed to the failure of commercial forest tree nurseries in providing nursery stock that can compete successfully in the field. Nurseries typically establish their own procedures for growing oak seedlings (Kormanik and Ruehle 1987), directed toward attaining a uniform size to facilitate handling, shipping, and planting procedures (Johnson 1981, Kormanik and Ruehle 1987).

Previous studies have tested if seedling quality could be determined by initial seedling size at planting. Northern red oak (*Quercus rubra* L.) seedlings with taller stems at planting had better height growth over time than smaller nursery seedlings (Foster and Farmer 1970, Johnson 1976, Zaczek *et al.* 1997). Nursery seedlings with the

highest numbers of first-order lateral roots (FOLR) generally were tallest after one growing season in the nursery (Kormanik *et al* 1994b, Ruehle and Kormanik 1986) and after 3 to 7 years in the field (Kormanik *et al.* 1995, Teclaw and Isebrands 1993, Thompson and Schultz 1995). A number of the above studies measured seedlings after lifting, separated them into size classes, and determined quality of each class based on field performance (Kormanik *et al.* 1995, Teclaw and Isebrands 1993, Thompson and Schultz 1995). Grading seedlings in a commercial nursery operation, in contrast, is generally not based on precise measurements, but on visual assessment of seedling size by relatively unskilled nursery workers. The effects of visual grading on seedling quality, as defined by stem and root characteristics, has not been well documented. This study was designed to resemble the visual grading processes used in commercial nursery operations. Specific objectives were: (1) to examine the quality of visually graded nursery stock grown from bulked seedlots at two state nurseries and (2) to examine correlations among growth characteristics of visually graded seedlings.

Materials and Methods

Acorn collection and sowing

A northern red oak (*Quercus rubra* L.) progeny test on the Watauga Ranger District of the Cherokee National Forest was thinned in 1987 to create a seedling seed orchard (LaFarge and Lewis 1987). Acorns were collected from individual trees in the seed orchard in the fall of 1995 for use in reforestation. The collected acorns were placed in water to separate sinking from floating acorns (Olson 1974). Only sinking acorns were distributed for propagation.

The acorns were bulked for sowing at two state nurseries: the Flint River Nursery operated by the Georgia Forestry Commission in Montezema, Georgia and the Ralph Edwards State Nursery operated by the North Carolina Division of Forest Resources in Morganton, North Carolina. The seed mix was different for each state nursery, reflecting the environmental differences of probable planting sites (Table 1A). The North Carolina (NC) nursery had more families from the Appalachian Mountain region, while the Georgia (GA) nursery had more families from the relatively warmer western Tennessee Valley region. There was an approximate 30 % overlap of genetic material between the two nurseries.

The acorns were sown by machine to achieve a desired density of six per ft^2. Later density checks confirmed that seedling density was at six per ft^2 for the GA nursery and 7.8 seedlings per ft^2 for the NC nursery.

Fertilization and irrigation applications

Fertilization and irrigation regimes for the GA nursery were developed by the USDA Forest Service's Institute for Tree Root Biology as delineated in Kormanik *et al.* (1994a) (Table 2A). Ammonium nitrate was applied every 10 to 12 days at a rate of 45 lbs/acre in May increasing over the growing season to a rate of 150 lbs/acre by October. In late July, one application of K-Mag was applied at a rate of 224 lbs/acre. The NC nursery applied similar rates of ammonium nitrate but adjusted applications to their shorter growing season (Table 2A). In addition, the NC seedlings received 2 applications of diammonium phosphate at a rate of 150 lbs/acre.

Lifting and storage

At both nurseries, a Fobra™ machine lifter was used to undercut (30 cm) and lift seedlings for grading. The trees were bundled in groups of approximately 100 seedlings and placed in cold storage until grading.

Visual grading

Approximately 1000 seedlings from each nursery were used as experimental material. A crew of 6 people, relatively unskilled in seedling grading, were instructed to consider the following seedling traits when visually grading seedlings: FOLR number, tap root size, RCD, and stem height. First, overall seedling quality of each nursery population was visually assessed. A few representative seedlings from each nursery that appeared to be of average size, considering the aforementioned characteristics, were chosen as the minimum size criteria for grading. Seedlings appearing to be below this minimum criteria were to be culled.

Originally, the best 360 seedlings (~36%) from each nursery were to be visually selected and used for an experimental planting. This seedling number was partially determined by the size of the planting site. Additionally, previous research has demonstrated that approximately 40 % of northern red oak nursery stock will have above-average growth, and therefore be of sufficient quality for planting (Kormanik and Ruehle 1987). As the visual grading proceeded, approximately 15 to 20 % of the seedlings from each nursery were observed to be of a higher quality than the rest of the seedlings. Based on these observations, two grades of seedlings, "good" and "premium" were distinguished. The premium grade seedlings appeared to be the largest in overall

seedling size. The seedlings graded as "good" appeared to be inferior in size to the seedlings in the "premium" grade but of sufficient size for planting. Cull seedlings appeared to have the smallest overall size and/or exhibited undesirable features, e.g., forked stem, broken top, or deformed tap root. From each nursery, approximately 18% of the seedlings were graded as premium, 18% were graded as good, and the remaining 64% were culled.

Seedling measurements

After grading, the number of FOLR, RCD, and height were measured and recorded for each seedling in the premium and good grades. A FOLR was defined as a suberized lateral root stemming from the main taproot that is at least 1 mm in size. The RCD was measured 2.54 cm above the root collar using a digital caliper. The height was measured to the nearest 0.5 cm using a meter stick.

Statistical analysis

The data were analyzed using statistical packages available in SAS version 6.11 (1996). Means of FOLR number, height, and RCD for seedlings in each grade (premium and good) and for seedlings in both grades combined were calculated for each nursery. The GLM procedure was used to determine significant differences between seedling grades for each nursery. Additionally, PROC CORR was used to calculate Pearson correlation coefficients among growth variables for seedlings in the premium and good grades and for seedlings in both grades combined. An error level of $\propto=0.05$ was chosen to indicate significant differences in all statistical procedures.

Results

Analysis with good and premium grade seedlings combined

The NC seedlings had heights, number of FOLR, and RCD ranging from 31 to 148 cm, 0 to 30, and 5.1 to 14.7 mm, respectively (Table 1). The Georgia seedlings had a similar range in height, but more numbers of FOLR and larger RCDs. For seedlings from both nurseries, correlations were significantly positive between all growth variables (r=0.15-0.67) (Table 2). The strongest correlations for both nurseries were between FOLR and RCD (r=0.54-0.64) and between height and RCD (r=0.54-0.67). The NC seedlings had slightly stronger correlations between all characteristics than the GA seedlings.

Analysis with good and premium grade seedlings separate

The premium grade seedlings from both nurseries had significantly more FOLR, taller heights, and bigger RCDs than the good grade seedlings. For the GA premium and good grade seedlings, the strongest correlations were between FOLR and RCD (r=0.31 and 0.52, respectively) (Table 2). The strongest correlations for the NC good seedlings were between FOLR and RCD (r=0.45) and between height and RCD (r=0.45). The strongest correlation for the NC premium seedlings were between FOLR and RCD (r=0.46) Only the NC premium grade seedlings had a significantly positive correlation between FOLR and height (r=0.29)

Discussion

Overall seedling quality

The selected seedlings generally met current recommendations for FOLR

Table 1. Means, ranges, and standard deviations (sd) for first-order lateral roots (FOLR), height, and root collar diameter (RCD) for good and premium grade and combined seedlings grown at the Flint River Nursery, Montezema, Georgia (GA) and the Ralph Edwards State Nursery, Morganton, North Carolina (NC).

	# of FOLR			Height (cm)			RCD (mm)		
Nursery/Grade	Mean	Range	sd	Mean	Range	sd	Mean	Range	sd
GA good	13a	2 - 29	4.6	71.5a	37.5 - 118.5	14.2	8.5a	5.8 - 12.0	1.2
GA premium	18b	7 - 35	4.7	85.0b	52.0 - 130.0	17.1	10.6b	7.1 - 19.4	1.6
GA combined	16	2 - 35	5.2	78.0c	37.5 - 130.0	17.1	9.6c	5.8 - 19.4	1.8
NC good	7a	0 - 24	4.0	64.6a	31.0 - 104.0	15.3	7.6a	5.1 - 12.1	1.1
NC premium	13b	1 - 30	4.6	89.0b	38.5 - 148.0	22.8	9.6b	7.1 - 14.7	1.3
NC combined	10	0 - 30	5.1	77.0c	31.0 - 148.0	22.9	8.6c	5.1 - 14.7	1.6

[1] Means followed by the same letter are not different within the same nursery and trait ($P<0.05$)

Table 2. Correlation among growth variables for good and premium grade and combined seedlings grown at the Flint River Nursery, Montezema, Georgia (GA) and the Ralph Edwards State Nursery, Morganton, North Carolina (NC).

Nursery and grade	FOLR-RCD	FOLR-Height	Height-RCD
GA good	0.52*	-0.01 NS	0.17 NS
GA premium	0.31*	-0.03 NS	0.04 NS
GA combined	0.54*	0.15*	0.54*
NC good	0.45*	0.01 NS	0.45*
NC premium	0.46*	0.29*	0.54*
NC combined	0.64*	0.43*	0.67*

* Correlation value is significant at $\alpha < 0.01$
NS Correlation value is not significant at $\alpha < 0.01$

numbers, size of RCD and stem height to be considered acceptable for field planting (Johnson 1981, Kormanik *et al.* 1994b, Thompson and Schultz 1989). Although the number of seedlings selected for each grade was influenced *a priori* by the size of the planting site, few additional seedlings, i.e. < 5% from each nursery, would have been considered acceptable for the good grade. The resulting cull proportion was relatively high (~60%), but corresponds to other nursery studies that found between 40 to 60% of nursery stock was of an unacceptable size for planting (Kormanik and Ruehle 1987, Kormanik *et al.* 1994b, Stroempl 1985).

Differences between good and premium grades

This study demonstrated that plantable stock can be further subdivided into two distinctive grades (good and premium) by visual grading. Although both grades generally met recommendations for identifying high quality nursery stock (Johnson 1981, Kormanik *et al.* 1994b, Thompson and Schultz 1989), the premium grade seedlings grew larger in the nursery and may outperform the good grade seedlings when planted in the field. Kormanik *et al.* (1995) reported findings from a study on a high quality site in North Carolina in which seedlings were divided into three grades based on numbers of FOLR. After five growing seasons, 52 percent of the seedlings with the greatest number of FOLR (>11) were classified as free of competition, followed by 28 and 6 percent of the seedlings with 7-11 and less than 7 FOLR respectively. The results of this study are parallel with those of Kormanik *et al.* (1995) indicating that plantable oak stock can be divided into two different grades.

Correlations between growth variables

The stronger correlation (r=0.68) between FOLR and height that Ruehle and Kormanik (1986) found for a population of approximately 400 northern red oak seedlings was not as evident for seedlings from either nursery in this study. The weaker correlation values in this study are largely attributed to exclusion of the cull seedlings from the correlation calculations. Kormanik and Ruehle's (1986) correlation value was not influenced by seedling grade. A contributing factor is the manner of seedling selection used in this study, which was similar to grading operations performed by unskilled nursery workers. For example, seedlings with few FOLR, but large heights were selected as well as seedlings with relatively short heights and large FOLR numbers. Additionally, the slightly higher sowing density at the NC nursery may have reduced FOLR to height correlations for that nursery.

The positive correlations between RCD and other growth variables for the combined data (Table 2) demonstrates that RCD could be a good indicator of root mass (Johnson 1989) and height (Olson and Hooper 1972) when visually selecting plantable seedlings. When seedling grade was considered, however, RCD was not significantly correlated to height for either the GA good or premium grade seedlings (Table 2). Root collar diameter should be used in conjunction with other seedling characteristics when visually separating good from premium grades.

Application to nursery operations and field plantings

Nurseries will differ in length of growing season, moisture levels from precipitation, and temperature, and will typically implement different growing regimes

for northern red oak. Size and quality of nursery stock will probably vary among nurseries, and therefore visual grading should be relative to the overall seedling quality at each nursery. Although the GA seedlings had overall larger root systems and diameters than the NC seedlings, both nurseries had approximately the same percentage of cull, good, and premium grade seedlings. Additionally, both nurseries produced relatively large nursery stock, allowing for easy identification of the most competitive seedlings during grading.

In an unrelated study, seedlings at a Tennessee nursery were grown in 1996 with inadequate fertilization and irrigation procedures, and then visually graded for planting[1]. The seedlings generally were small and poorly developed, and visual grading was more difficult when compared with grading the larger seedlings from the GA and NC nurseries. The relatively poorer growth of these trees resulted in only two grades (cull and plantable), and premium grade could not be identified. Nursery practices should be adjusted to allow full development of the seedlings for nursery personnel to properly grade seedlings (Kormanik *et al* 1994a, Kormanik *et al* 1994b, Kormanik and Ruehle 1987).

The results indicate that the largest seedlings can be easily distinguished after briefing nursery workers on the important characteristics to consider when grading seedlings and showing representative seedlings exhibiting minimum size standards. Depending on the overall size of the nursery stock, plantable seedlings can be further

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[1]Lay, unpublished data

separated into two distinct grades. More research is needed, however, to determine the ability of visually graded northern red oak nursery stock to survive and compete successfully on a variety of sites under differing management practices. Evaluation of survival and growth in the outplanting from this study and other red oak progeny tests established in 1995 (Lay *et al.* 1997) should contribute information on the importance of visual grading to the artificial regeneration of oaks.

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Part Three: Nursery Performance of Northern Red Oak Seedlings Grown by Family in a Tennessee Nursery

Abstract

Thirty-eight northern red oak families were grown for one year in a commercial tree nursery in eastern Tennessee, and evaluated for number of first-order lateral roots (FOLR) and flushes, height, and root collar diameter (RCD) growth. Growth was negatively impacted by inadequate fertilization and irrigation practices at the nursery as well as heavy rains during the growing season. Average height and diameter growth were smaller than the previously published standards for minimum oak planting stock size of 50 cm in height and 8 mm for RCD. Except for number of flushes, provenance effects on nursery seedling growth for progeny that was one generation removed from the original seed source was non-significant. Family differences for seedling characteristics indicate that evaluation of progeny performance in the nursery can identify seed sources that produce progeny with a higher probability of survival after outplanting. Root collar diameter (RCD) was the best indicator of both height and number of FOLR. Certain families had relatively low within-family variation in RCD and high distributions of seedlings with above-average RCD growth indicating that the family mean should not be the sole criterion for selection of superior families. Mother trees consistently producing progeny with below-average growth will be identified through additional nursery and field tests and subsequently rogued from future seed collections.

Introduction

Artificial regeneration has had limited success in establishing oak (*Quercus* spp.) stands or enriching the oak component in existing stands (Pope 1993; Russell 1971). Planted oak seedlings often fail to maintain vigorous growth after outplanting and are quickly

overtopped by competing vegetation (Johnson 1976; McGee and Loftis 1986; Russell 1971) or lose vigor in heavy shade (Kormanik *et al.* 1995; Teclaw and Isebrands 1993). Traditionally, nursery oak seedlings have been grown to a relatively small (< 50 cm in height, < 8 mm in diameter), uniform size to facilitate shipping and planting with little consideration of root system characteristics (Crow and Isebrands 1986).

Recommendations have been made to adjust nursery practices for production of large nursery stock that can quickly become established in the field (Johnson 1985, Kormanik *et al.* 1994a). However, recommendations vary for identification of superior seedlings (Johnson 1981, Kaczmarek and Pope 1993, Ruehle and Kormanik 1986). Previous research has found that nursery seedlings with more numbers of first-order lateral roots (FOLR) (*sensu* Kormanik *et al.* 1990) had greater height and diameter growth in the nursery (Kaczmarek and Pope 1993, Kormanik *et al.* 1994b, Ruehle and Kormanik 1986) and better survival and growth in the field (Kormanik *et al.* 1995, Schultz and Thompson 1990, Teclaw and Isebrands 1993) than seedlings with fewer numbers of FOLR.

Kaczmarek and Pope (1993) reported that number of FOLR should be used in combination with other seedling characteristics to classify seedlings with different growth potential. Seedling height, diameter, and number of flushes, however, are significantly influenced by nursery practices, i.e., fertilization and irrigation. In contrast, number of FOLR were less affected by changes in fertilization treatments, although FOLR size was influenced by various nursery practices (Kormanik and Ruehle 1987). Therefore, to more easily identify competitive seedlings in the nursery, cultural practices should permit seedlings to attain their growth potential.

Provenance has been found to affect height growth of first-generation northern red oak nursery stock (Kriebel 1965) and growth rates of seedlings several years in the field (Gall and Taft 1973, Houston 1987, Kriebel *et al.* 1976). There are no published studies, however, examining if provenance effects exist in early growth of northern red oak progeny that is one generation removed from the original seed source, e.g., progeny collected in a seedling seed orchard. Information on the effect of the original mother tree on northern red oak progeny from half-sibling trees in a seedling seed orchard is also lacking.

Family differences have been shown to affect mean nursery height growth (Buchschacher *et al.* 1991, Kriebel 1965) and root growth (Ruehle and Kormanik 1986, Schultz and Thompson 1990). Seedling distributions around the mean number of FOLR has differed among families (Remaley 1998, Ruehle and Kormanik 1986). Past research has found large within-family variation in height growth (Farmer 1975), and in number of FOLR (Kormanik and Ruehle 1987). The distribution and uniformity of a provenance and/or family's progeny as well as their mean performance should be considered during selection for seed collection (Remaley 1998).

Oak seed orchards have the capacity to produce acorns for reforestation from specifically identified trees. Establishment of northern red oak seed orchards or plantings using vegetative propagation methods such as grafting, rooted cuttings, or tissue culture is difficult and has had limited success (Farmer 1973, Schlarbaum *et al.* 1993, Zaczek 1997). Seedling seed orchards have been used as alternatives for the production of genetically improved seed, although genetic gains may be reduced in comparison to clonal orchards.

This study examines variation in certain seedling characteristics among open-

pollinated progeny from a northern red oak (*Quercus rubra* L.) seedling seed orchard. The primary objective of this study was to evaluate the nursery performance of different families to refine selection of trees within the seedling seed orchard. Specifically, this study will: (1) determine if provenance and original mother tree effects are evident after one generation of recombination in a seed orchard, (2) analyze family effects on numbers of FOLR, height, RCD, and number of flushes, (3) examine correlations among these characteristics, and 4) examine distributions and uniformity among families for RCD growth.

Materials and Methods

Seed collection

A northern red oak open-pollinated half-sibling progeny test was established by the Tennessee Valley Authority (TVA) in 1973 on the Watauga Ranger District of the Cherokee National Forest. The test was converted in 1987 to a seedling seed orchard (LaFarge and Lewis 1987). Acorns were collected in the fall of 1995 from 38 individual orchard trees, and kept separate by family (Table 3A). Acorns less than 0.2 cm in diameter were culled. The acorns were placed in water to separate sinking acorns from floating acorns (Olson 1974), and the sinking acorns were placed in cold storage at a temperature of 42°F until time for sowing.

Nursery practices

The resulting seedlings were grown as the entire reforestation crop for northern red oak seedlings at the East Tennessee State Nursery in Delano, TN in April of 1996. Prior to sowing, the nursery beds were treated with 150 lbs per acre of triple super phosphate and 150 lbs per acre of muriate of potash. Families were kept separate during sowing with

approximately 4 feet of empty bed space between each seed lot. In contrast to experiments that use small replicated seedling blocks within each nursery bed, e.g. Buchschacher *et al.* 1991, this method of sowing was selected with the goal of evaluating large numbers of families over multiple years with minimal commitment of resources. The majority of the acorns experienced radicle emergence during cold storage and were subsequently hand sown to prevent radicle damage. Approximately 25% of the acorns (ungerminated) were sown with a machine sower specifically modified for heavy seeded hardwood planting.

The acorns germinated at a density of approximately 86 to 108 per m^2 (8 to 10 per ft^2), slightly higher than the desired 6 per ft^2 spacing recommended for northern red oak seedlings (Schultz and Thompson 1997). The seedlings were subsequently thinned in late May to 6 per ft^2. The seedlings received irrigation when necessary throughout the growing season, and fertilizer applications from late May to mid-August (Table 4A).

Blocks of seedlings (0.6 m by 1.2 m) were randomly selected for sampling within family seed lots. A large proportion of the nursery beds had abnormal or stunted seedlings due to a combination of *Phytophthora* root rot and misapplication of fertilizer, and were subsequently not sampled. Additionally, seedlings at the end perimeter of the seed lot were not sampled due to possible growth biases from lack of competition. One to four blocks per family seed lot were sampled, depending on size of the seed lot and area affected by disease or fertilizer misapplication. These blocks were bulked by family during lifting and measuring.

A Fobro™ machine lifter was used to undercut seedlings for lifting. The lifting commenced on four dates according to the amount of seedlings ordered and anticipated

delivery dates. Inadvertently, on November 15 and 19, the machine lifter was set at depths of 15 cm and 20 cm, respectively, instead of the desired depth of 30 cm. Seedlings lifted on December 11 and January 6, however, were undercut at a depth of 30 cm.

Experimental groups

Each family was assigned a provenance group by overlaying a map projection of the geographic origins of the TVA collection trees on a map projection of Bailey's Ecoregions of the United States (Bailey 1980) in ArcView® (ESRI 1994) (Figure 1). Previous studies have used geographic coordinates or man-made boundaries, i.e., states or counties, of the seed source as a definition of provenance (Kriebel *et al.* 1988, Gall and Taft 1973, Schlarbaum and Bagley 1981, Schreiner and Santamour 1961). Bailey's ecoregions (Bailey 1980), however, are based on dominant physical and biological parameters of the landscape and is a more refined system for delineating provenance boundaries.

A total of 5255 seedlings from 38 open-pollinated families were used for the study (Table 1). The four provenance groups in this study each contain differing numbers of individual seedlings and families (Table 2). The East Tennessee State Nursery is located in the Central Ridge and Valley Region (5), although no families in the study originated from that region.

Some of the individual orchard trees from which seed was collected were putative half-siblings, i.e., originated from the same mother tree. Progeny from these trees are related, i.e., putative quarter-siblings, and the related families are here collectively termed as a "family group" (Figure 2). Differences within family groups were investigated to detect

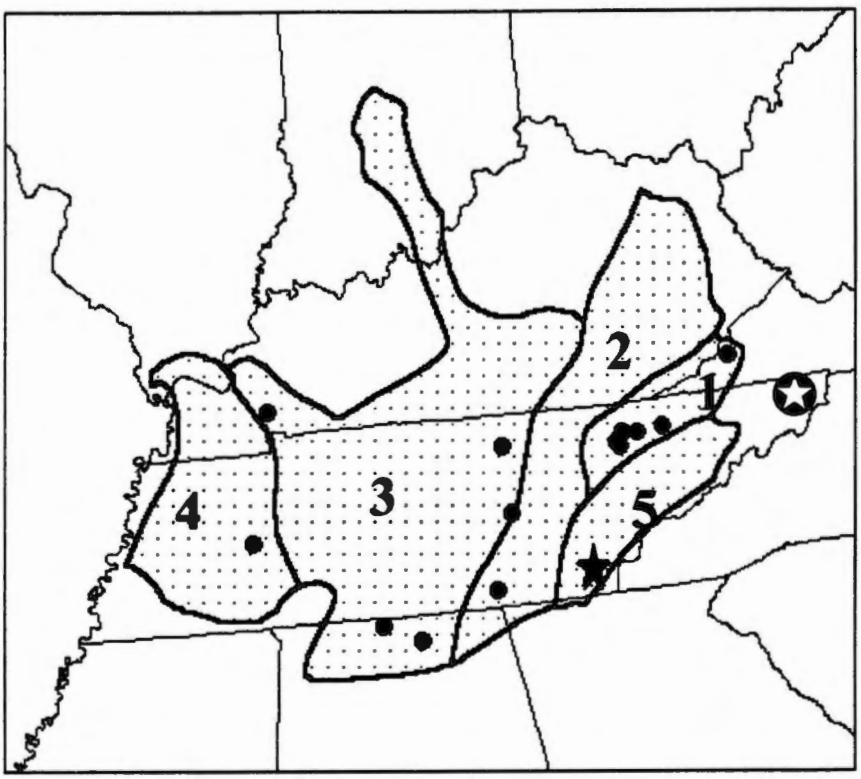


Figure 1. Provenance groups and origin of 38 families from the Watauga seedling seed orchard

1. Southern Cumberland Mountains
2. Northern Cumberland Plateau
3. Interior Low Plateau, Highland Rim
4. Upper Gulf Coastal Plain
5. Central Ridge and Valley

✪ Watauga Seed Orchard, Watauga Ranger District, Cherokee National Forest
★ East Tennessee State Nursery, Delano, Tennessee
• Origin of TVA collection tree in natural stand

Table 1. Number of seedlings, families, family groups, and provenance groups at each represented lifting depth.

Lifting depth (cm)	No. of seedlings	No. of families	No. of family groups	Provenance
15	454	6	1	1,3.4
20	1215	8	0	1,3,4
30	3586	26	5	1,2,3,4

Table 2. Northern red oak provenances with numbers of seedlings and families.

Provenance group	No. of seedlings	No. of families
(1) Southern Cumberland Mountain	1103	11
(2) Northern Cumberland Plateau	94	1
(3) Interior Low Plateau/Highland Rim	2331	16
(4) Upper Gulf Coastal Plain	1727	10

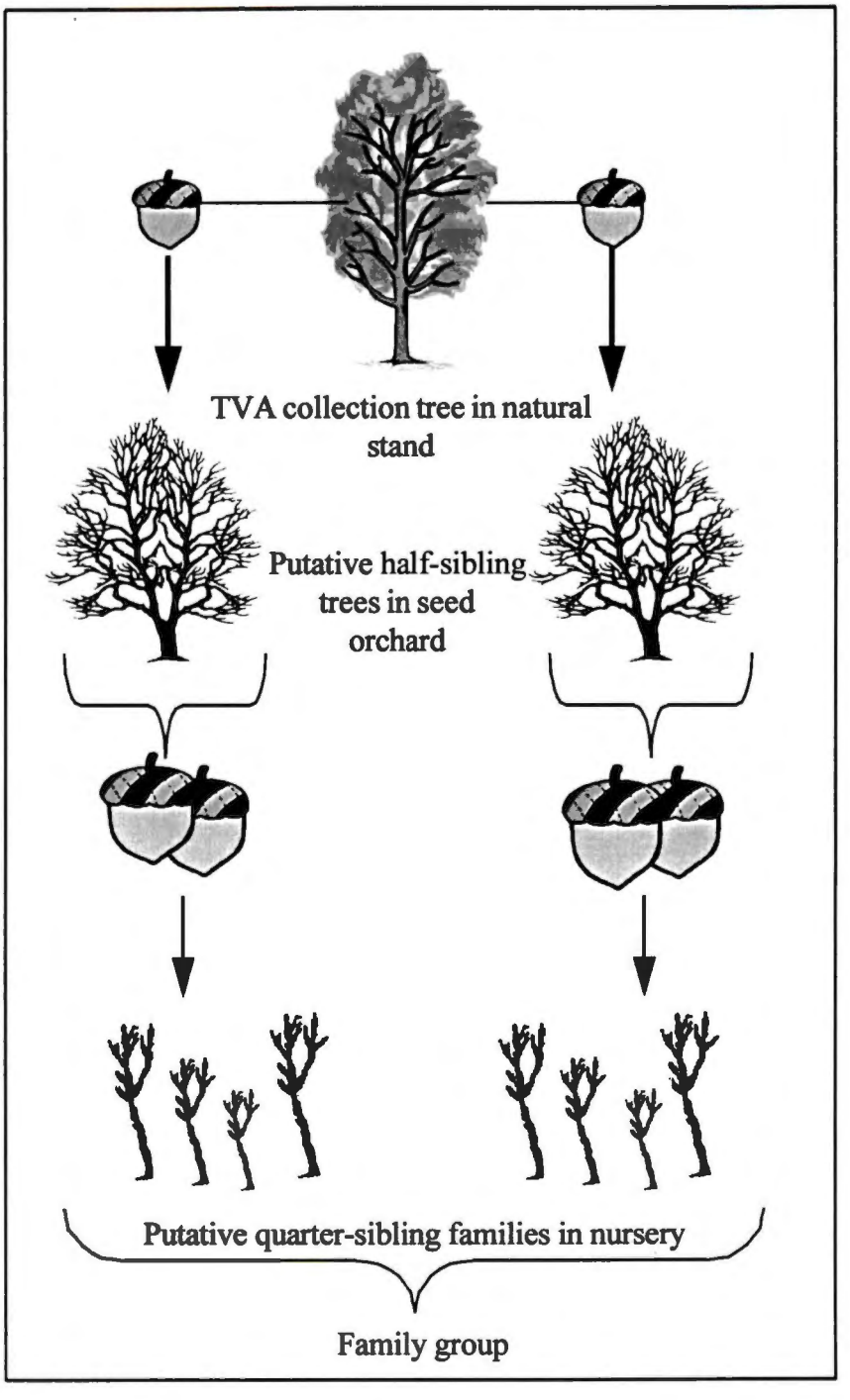


Figure 2. Graphical description of a family group from a northern red oak seedling seed orchard

original mother tree effects on progeny after recombination in the seedling seed orchard.

Seedling measurements

After lifting, the number of FOLR, height (cm), root collar diameter (mm) (RCD), and number of flushes were recorded for each seedling. A FOLR is defined as a lateral root stemming from the main taproot that is at least 1 mm in diameter at the proximal end (Kormanik *et al.* 1990). The RCD was measured 2.5 cm above the root collar using a digital caliper. Height was measured to the nearest 0.5 cm using a meter stick.

Statistical Analyses

All statistical procedures were conducted using SAS (SAS Institute 1985), and an error level of $\alpha=0.05$ was chosen to indicate significant differences in the analyses. Data from all lifting depths were combined and used to analyze the above ground characteristics (height, RCD, and number of flushes). The differences in undercutting depth could influence the number of FOLR counted on each seedling. Therefore, separate statistical analyses for each lifting depth were used to evaluate FOLR data.

A mixed model analysis (PROC MIXED) was used to detect provenance and family effects on number of FOLR, height, RCD, and number of flushes for a completely randomized design. The analysis of variance was based on the assumption that each provenance and family group was a fixed, as opposed to a random, effect. Significant differences among the least-square means of families within a family group were detected using F-tests generated with the PDIFF option.

Limited sampling of mother trees and geographic origins within provenances 2 and 4 was apparent. Provenance 2 contained one family (Table 2), which is too limited of a

sample to be representative of the entire provenance. Additionally, provenance 4 represented several families (Table 2), but the original mother trees all were from a single geographic origin (Figure 2). Provenances 2 and 4, therefore, were not included in the analysis of variance to determine provenance effects. The analyses of variance to detect differences among provenances 1 and 3 were adjusted for differences among families within a provenance.

Pearson correlation coefficients among all seedling characteristics were generated using PROC CORR.

Distribution analysis was conducted to determine the frequency of seedlings greater than or equal to the combined mean for each characteristic. In addition, the percentage of seedlings within a family that were greater than or equal to the family mean RCD and to the combined mean RCD, respectively, were calculated for each family. The variance of seedlings within a family greater than or equal to the family mean was also calculated.

Pearson correlation coefficients between family mean RCD and the percentage of seedlings within a family greater than or equal to the family mean RCD, the percentage of seedlings within a family greater than or equal to the combined mean RCD, and the variance of seedlings within a family greater than or equal to the family mean RCD were calculated using PROC CORR.

Results

Growth and seedling distributions

The mean number of FOLR was 6.3, 4.3, and 5.9 for the 15, 20, and 30 cm lifting depth, respectively (Table 3). Means for height, RCD, and number of flushes for all

Table 3. Means for seedling characteristics with associated standard deviations, ranges, and percentages of seedlings ≥ the combined mean. FOLR=number of first-order lateral roots; RCD=root collar diameter.

Characteristic	Mean ± s.d.	Range	% of seedlings ≥ mean
FOLR (15 cm)	6.3±4.1	0 - 19	43
FOLR (20 cm)	4.3±3.1	0 - 20	39
FOLR (30 cm)	5.9±4.0	0 - 30	47
Height(cm)	38.1±19.2	2.5 - 114.5	45
RCD (mm)	6.8±2.1	1.3 - 20.0	49
No. of flushes	2.9±0.8	1.0 - 7.0	75

seedlings were 38.1 cm, 6.8 mm, and 2.9, respectively. Fewer than 50% of the seedlings from each of the three lifting depths had above-average numbers of FOLR. Similarly, fewer than 50% of the seedlings in the combined analysis had above-average heights and RCDs. However, 74% of the seedlings had above-average number of flushes.

Provenance effects

Differences in FOLR number between seedlings from provenances 1 and 3 were significant for only the 15 cm lifting depth (Table 4). Provenance differences were not detected for height, RCD, but families from provenance 1 had significantly more flushes than families from provenance 3 (Table 4).

Family effects

Family differences were significant for number of FOLR for each lifiting depth, and for height, RCD, and number of flushes (Table 4). Mean number of FOLR for each family ranged from 4.1 to 8.2 for the 15 cm lifting depth, 3.6 to 5.7 for the 20 cm lifting depth, and 3.4 to 7.8 for the 30 cm lifting depth. Mean height, RCD, and number of flushes for each family ranged from 25.5 cm to 50.0 cm, 5.1 mm to 8.5 mm, and 2.4 to 3.5, respectively.

Differences between family groups

Although certain family groups had families that were similar in one or more characteristics, there were no family groups that had all families with similar growth performance for every measured characteristics (Tables 5 and 6). Four of six family groups had half-sibling families that differed in mean number of FOLR. Approximately half of the family groups had half-sibling families that differed in mean height, RCD, and number of

Table 4. Differences among provenance and family groups for number of first-order lateral roots (FOLR), height, root collar diameter (RCD), and number of flushes.

	Lifting Depth	Number of FOLR	Height	RCD	Number of flushes
Provenance	15 cm	Y	-	-	-
	20 cm	N	-	-	-
	30 cm	N	-	-	-
	combined	-	N	N	Y
Family	15 cm	Y	-	-	-
	20 cm	Y	-	-	-
	30 cm	Y	-	-	-
	combined	-	Y	Y	Y

Table 5. Differences in mean numbers of first-order lateral roots (FOLR) among families within a family group for northern red oak nursery seedlings lifted at two depths*.

Family group	Family	Lifting depth (cm)	Mean FOLR
2459	2459-1	15	7 a
2459	2459-2	15	8 a
100	100-1	30	7.6 a
100	100-2	30	5.7 b
200	200-1	30	7.0 a
200	200-2	30	5.6 b
882	882-1	30	6.9 a
882	882-2	30	6.5 ab
882	882-3	30	5.6 b
885	885-1	30	6.6 a
885	885-2	30	3.4 b
913	913-1	30	5.9 a
913	913-2	30	4.6 b

*Family means within the same family group followed by the same letter are not significantly different ($\propto \leq 0.05$).

Table 6. Differences in mean height, root collar diameter (RCD), and number of flushes among families within a northern red oak family group*.

Family group	Family	Mean height (cm)	Mean RCD (mm)	Mean number of flushes
100	100-1	47.3 a	7.6 a	3.2 a
100	100-2	41.2 b	7.6 a	3.0 ab
100	100-3	38.0 b	7.5 a	2.8 b
200	200-1	37.6 a	7.3 a	3.1 a
200	200-2	37.2 a	6.5 b	3.0 a
2459	2459-1	50 a	7.2 a	3.5 a
2459	2459-2	41.5 a	7.0 a	2.8 b
584	584-1	36.5 a	6.0 a	3.0 a
584	584-2	30.5 b	5.6 a	2.9 a
882	882-1	45.8 a	7.1 a	3.2 a
882	882-2	40.8 b	6.7 b	2.9 b
882	882-3	35.6 b	6.2 b	2.7 b
885	885-1	42.6 a	6.9 a	3.0 a
885	885-2	36.2 a	6.8 a	3.0 b
903	903-1	39.1 a	6.4 a	3.4 a
903	903-2	32.3 b	5.6 b	2.7 b
913	913-1	31.3 a	6.4 a	2.9 a
913	913-2	31.3 a	6.1 b	2.5 b

*Family means within the same family group followed by the same letter are not significantly different ($\propto \leq 0.05$).

flushes (Table 5).

Phenotypic correlations

Phenotypic correlations between FOLR number and the above-ground variables were generally similar for each lifting depth (r=0.26-0.68) (Table 7). The strongest correlations were between FOLR number and RCD for all lifting depths (r=0.63-0.68). The weakest correlations were between FOLR number and number of flushes (r=0.26-0.37).

Seedling distributions for RCD

Seventeen of 38 families (45%) had mean RCDs greater than or equal to the combined mean RCD (Table 8). Within a family, the percentage of seedlings with RCDs greater than or equal to the family RCD mean ranged from 42 to 64%. The percentage of seedlings with RCDs greater than or equal to the combined mean RCD ranged from 20 to 77%. Variances of RCD, for seedlings in a family that were greater than or equal to the family mean RCD, ranged from 0.63 to 3.60.

Family RCD mean was more strongly correlated with percentage of seedlings greater than or equal to the combined mean RCD (r=0.96) than with the percentage of seedlings greater than or equal to the family mean RCD (r=0.56). The correlation between family mean RCD and variance of seedlings greater than the family mean RCD was not significant (r=-0.29).

Discussion

Seedling quality

Seedling quality appeared to be negatively influenced by irregular fertilization practices coupled with heavy rains and overwatering during the growing season. The

Table 7. Phenotypic correlations between first-order lateral root number (FOLR), height, root collar diameter (RCD), and number of flushes for seedlings from each lifting date and for all seedlings combined.

	Lifting Depth			
	15 cm	**20 cm**	**30 cm**	**Combined data**
FOLR-Flush	0.26	0.35	0.37	-
FOLR-Height	0.52	0.51	0.56	-
FOLR-RCD	0.65	0.63	0.68	-
Height-Flush	-	-	-	0.75
Height-RCD	-	-	-	0.80
RCD-Flush	-	-	-	0.59

Table 8. Ranking of northern red oak families according to mean root collar diameter (RCD), percentage of seedlings within a family greater than the family mean and the combined mean, and variance of seedlings within a family that are greater than the family mean.

Family ranking	Family	Family mean RCD (mm)	% of seedlings >/= the family mean	% of seedlings >/= combined mean	Variance of seedlings >/= the family mean
1	902	8.5	52	77	2.20
2	850	7.9	51	67	2.32
3	100-1	7.6	50	63	1.97
4	100-2	7.6	54	61	2.22
5	878	7.5	56	65	1.08
6	100-3	7.5	48	67	1.77
7	323	7.4	53	69	1.14
8	576	7.4	55	64	0.86
9	200-1	7.3	46	60	0.90
10	2459-1	7.2	64	72	0.63
11	882-1	7.1	52	56	1.44
12	2459-2	7.0	43	48	1.00
13	885-1	6.9	52	55	1.25
14	704	6.9	48	52	1.00
15	885-2	6.8	52	52	1.53
16	906	6.8	52	52	1.70
17	329	6.8	48	48	1.35
18	882-2	6.7	48	47	1.69
19	540	6.7	48	48	1.49
20	595	6.6	47	42	1.80
21	907	6.6	51	48	1.33
22	726	6.6	43	40	2.00
23	915	6.6	47	44	1.34
24	200-2	6.5	50	44	2.30
25	9031	6.4	49	42	1.69
26	913-1	6.4	50	44	1.12
27	330	6.3	49	41	1.72
28	510	6.3	48	38	1.64
29	735	6.3	46	42	1.34
30	716	6.2	49	37	1.16
31	882-3	6.2	45	35	2.15
32	905	6.2	46	37	1.96
33	913-2	6.1	45	28	2.51
34	856	6.1	49	41	1.45
35	584-1	6.0	49	31	1.21
36	584-2	5.6	46	29	1.65
37	903-2	5.6	49	22	0.94
38	911	5.4	42	20	3.60

average height (38 cm) and RCD (6.8 mm) was below recommended standards for minimum size of planting stock (Johnson 1981), and the seedlings had fewer number of flushes (2.9) than seen in similar nursery studies (Kormanik *et al* 1994b). Kormanik *et al.* (1994a) recommended nitrogen fertilization every 10 to 14 days to maintain continuous growth of oak seedlings. Without regular fertilizer applications, the elongation phase of seedling development is interrupted, and seedlings may cease to grow or prematurely set terminal buds (Kormanik *et al* 1994a). To avoid excessive watering or moisture stress, irrigation should be scheduled and monitored using tension meters (Kormanik *et al.* 1994a). Watering for this experiment was done without the use of tension meters, and probably contributed to the reduction of effectiveness of the applied fertilizer through excessive leaching.

Although the seedlings were relatively poor in quality, they exhibited a typical distribution in pattern around the mean FOLR number. In previous studies, approximately 40% to 50% of northern red oak nursery stock were distributed above the population mean for numbers of FOLR, regardless of nursery practices (excluding changes in seedbed density) (Kormanik *et al.* 1994b, Kormanik and Ruehle 1987). The FOLR distributions in this study (Table 3) are similar to those found by Kormanik *et al.* (1994b) and Kormanik and Ruehle (1987). Additionally, the height and RCD distributions around the combined mean were similar to the distributions for numbers of FOLR (Table 3).

The number of FOLR did not increase with lifting depth as might be expected. The decrease in mean number of FOLR from the 15 cm to the 20 cm and to the 30 cm lifting depths could be attributed to differences in genetic material among the lifting depths.

Provenance effects

Provenance differences in height among first-generation progeny found in previous studies (Gall and Taft 1973, Houston 1987, Schlarbaum and Bagley 1981), were not detected in this study. The similarity in growth characteristics between provenances 1 and 3 may be due to the limited sample of families used in the analyses or a dilutant of provenance effects after one generation of recombination in the seed orchard. The results suggest that provenance effects on FOLR number, RCD, and height may not carry over to second-generation progeny. Number of flushes did significantly differ between provenances 1 and 3. A number of field studies have shown that date of flushing is under strong genetic control (Gall and Taft 1973, McGee 1974, Schlarbaum and Bagley 1981), but little research has been conducted to examine provenance and/or family effects on number of flushes. A more thorough analysis of provenance effects on nursery seedling growth is needed before final conclusions on provenance effects in seed orchard progeny can be made.

Family effects

The growth variation among families concurs with other results that found family differences in FOLR number (Ruehle and Kormanik 1986), height (Buchschacher *et al.* 1991, Kriebel 1965), and RCD (Buchschacher *et al.* 1991) in nursery seedlings. The ranges in family least-square means for each characteristic demonstrates that seedlings should be grown by family until a decision can be made on the breeding value of the mother tree. Mother trees that consistently produce progeny exhibiting below-average growth when compared to the population means increase nursery costs if grading for quality is practiced. These mother trees should be rogued from the orchard or eliminated from future field

collections if the acorns were collected from natural or urban settings.

Differences within family groups

Some families within family groups had a higher degree of similarity, hence relatedness, for certain characteristics. Other families within a family group were as diverse as a random group of families, indicating that the original mother tree effects have been somewhat diluted. Differences among families within a family group are attributable to unknown genetic or environmental factors with one possible exception. Within each family group, the putative half-sibling trees in the orchard may have the same pollen source and actually be full-siblings. Their subsequent progeny may more resemble half-siblings than quarter-siblings, thereby accounting for the higher degree of similarity in growth performance in some family groups than in other family groups. Families within family groups can not be expected to have similar growth performance, and should be grown and analyzed separately regardless of genetic relatedness to other families in the orchard.

Phenotypic correlations

Past research has found that field performance is positively related to a seedling's number of FOLR at planting, and therefore, identification of competitive seedlings in the field should use FOLR as the primary grading criterion (Kormanik and Muse 1986, Kormanik *et al.* 1995, Schultz and Thompson 1990). Height and RCD are important, however, in ensuring that the seedling is competitive in a natural environment. In this study, number of FOLR did not exhibit the highest correlation values with height, RCD, or number of flushes (Table 4). The lack of proper fertilization may have reduced the size of the FOLRs on the seedlings, thus reducing the number of FOLR counted during measurements.

Subsequently, correlations involving number of FOLR were lower than expected.

The sporadic fertilization treatments may have yielded a stronger relationship between number of flush and height than found in similar nursery studies (Kormanik and Ruehle 1987). An irregular fertilization schedule will influence the number of flushes produced as well as interrupt stem elongation between flushes. Continuous fertilization applications, in contrast, will result in uninterrupted pattern of flushing followed by height growth. Stem elongation between flushes, as opposed to number of flushes, is more important in determining height (Kormanik *et al.* 1994a).

The RCD correlations suggest that selection of seedlings with large root-collar diameters would result in the best chance of indirectly selecting seedlings with tall heights and large number of FOLR. However, not every seedling with large RCD will have high numbers of FOLR and/or tall height. Grading of seedlings should, therefore, not be based solely on one seedling characteristic, but on a combination of attributes (Kaczmarek and Pope 1993).

RCD distributions

Distribution analysis of FOLR could not be meaningfully conducted in this study due to the differences in lifting depths. Root collar diameter had the strongest correlations with both number of FOLR and height. Therefore, seedling distributions around the family mean RCD and within-family variation in RCD growth were examined for each family to understand potential selection potential.

Families ranked 1 through 17 had above-average RCD growth (Table 5), and would be the most desirable families for selection, in terms of average RCD growth. In addition,

the correlations of family mean RCD with the percentage of seedlings greater than or equal to the family mean (r=0.56) or the combined mean (r=0.96), suggest that higher ranked families are more likely to have larger proportions of seedlings with above average RCD growth. However, certain high ranked families had less than 50% of their seedlings with RCDs greater than or equal to the family mean, i.e., families ranked 6 or 9, which may lower their breeding value depending on selection criterion. A family like 2459-1 (ranked 10th) might be more desirable than a higher ranked family, due to its high distribution of seedlings greater than or equal to the family mean (64%) and combined mean (72%).

The eventual selection of families with both above-average RCD growth and a high amount of seedlings distributed above the family mean and/or combined mean RCD would increase the average size of nursery stock while also reduce the percentage of below-average seedlings. Nurseries could, therefore, more efficiently use bed space while simultaneously lower cull rates.

Although there was no meaningful relationship between family ranking and variance (r=-0.29), some families, i.e., 576, 200-1, 2459-1, 2459-2, and 704 had low amounts of variation (<1.0) and above-average RCD growth (>6.8 mm) (Table 7). If seedling uniformity is judged to be important, a reduction in seedling quality for increased uniformity may be justified.

Applications to selection in a seedling seed orchard

The study demonstrated that information on family performance in an unreplicated nursery planting has the potential to contribute to decisions on selection in a seedling seed orchard. Prior to making roguing decisions in the seedling seed orchard, however, nursery

data should be generated over a number of growing seasons. A single year's data is not sufficient to select families with high breeding values for different seedling characteristics, i.e. families producing progeny with means above the combined mean for height, diameter, and/or number of FOLR, due to variation within and among nursery beds.

Multiple-year testing was the original intent of this study. Unfortunately, in the years subsequent to this study, a significant acorn crop has not been harvested from the orchard due to predation of acorns by weevils (*Curculio* spp.) and fox squirrels (*Sceirus niger*) and late season frost damage to oak flowers. When sufficient acorns are collected, the families will be reevaluated in a similar nursery study.

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Part Four: Three-year Survival and Growth Performance of Northern Red Oak Genetic Tests with Nursery-graded Seedlings

Abstract

An extensive study was initiated in 1993 to evaluate the effectiveness of planting large, quality-graded northern red oak (*Quercus rubra*, L.) seedlings on good upland sites (site index $\geq$ 70) in the southeastern United States. Acorns from 73 families were grown for one year at the Georgia Forestry Commission's Flint River Nursery in Montezuma, Georgia. Seedlings were visually graded within family plots according to number of first order lateral roots (FOLR), tap root size, basal caliper, and stem height. In the late winter of 1995, 18 plantations were established on southern National Forests (16), a Kentucky State Forest (1), and the Ames Plantation in West Tennessee (1). Initial measurements taken at three of the plantations indicate that average seedling size at planting was approximately 80 cm in height and 10.0 mm in root collar diameter. Eight of the 18 plantations were considered to be successfully established after three growing seasons. Planting failures can primarily be attributed to deer, insect, and/or vole damage. Additionally, survival and height growth were poor at two plantations located on the edge of the range for the species, and one plantation had substantial fire damage. Third year plantation survival ranged from 74% to 94%, and mean height ranged from 99 cm to 147 cm for eight of the plantations. Nursery effects on family height growth appeared to diminish from the second to third growing season. Provenance effects were less evident than family effects in the combined analysis and at individual plantations and generally were diluted after one genetic recombination in the seedling seed orchard. Family differences in survival and height were evident in the combined analysis and at the majority of the plantations through the third growing season. In the absence of

severe damage, initial family size at planting was positively related to second and third year height growth, but was not related to survival in any year. Height growth was best for plantations that were not affected by animal or insect damage, had a high site index ($\geq$ 80), and/or had some degree of competition control. The occurrence of damage noticed at the majority of the plantations indicates that protection from damaging agents is critical for successful artificial regeneration of northern red oak on good upland sites. Damage assessments at each plantation, however, could not be quantitatively analyzed due to lack of consistency in recording seedling damage among the various personnel. For future measurements, a damage rating system should be developed, and field training on damage identification should be implemented.

Introduction

The perpetuation of northern red oak (*Quercus rubra* L) on good upland sites, i.e., site index 70+, in the southern Appalachian mountains has represented a serious silvicultural and management problem (Beck and Hooper 1986, McGee and Hooper 1975, Martin and Hix 1988). Under shaded conditions, northern red oak seedlings can persist, but do not gain appreciable height growth until released (Beck 1970). After natural disturbance or harvesting, regeneration from seed and sprouts usually can not compete with faster growing pioneer species like yellow-poplar (*Liriodendron tulipifera* L.) or red maple (*Acer rubrum* L.) (Johnson and Krinard 1983, Leopold *et al.* 1985, Wendel 1975).

Artificial regeneration of northern red oak has had limited success in establishing oak stands or enriching the oak component in existing stands (cf. Pope 1993, Russell

1971). Planting failures can be partially attributed to poor quality seedlings, which are quickly overtopped by faster growing natural regeneration (Johnson 1976, McGee and Loftis 1986, Russell 1971).

The establishment of oak plantings has been hindered by damaging agents such as foraging mammals, insects or disease (Auchmoody and Walters 1992, Graveline 1997, Ward 1996). Control measures such as tree shelters, fencing, and repellents have been used with success (Graveline 1997, Ward 1996), but cost of protection is often prohibitive (Kays 1996).

A number of studies have shown that nursery-grown seedlings with larger stems and/or root collar diameters have better survival and growth than smaller stock (Foster and Farmer 1970, Olson and Hooper 1972, Zaczek *et al.* 1997). Other studies have shown that number of first-order lateral roots was correlated with height and diameter growth in the nursery (Ruehle and Kormanik 1986) and critical to competitiveness in the field (Kormanik *et al.* 1995, Schultz and Thompson 1990).

Variation in size and quality of northern red oak nursery stock has been partially attributed to differences in provenance and mother tree seed source (Buchschacher *et al.* 1991, Kriebel *et al.*1965). Field performance has been shown to be significantly influenced by provenances, stands, genetic families, and/or individual trees within families (Houston 1987, Farmer *et al.* 1981, Kriebel *et al.* 1976, Schlarbaum and Bagley 1981). Research has shown that height growth differences among families are generally significant in early years of seedling growth, but these effects decrease with age (Farmer *et al.* 1981, Gall and Taft 1973, Houston 1987). Provenance effects on height growth

were significant in the earliest years of outplanting (Gall and Taft 1973, Kriebel 1965, Schlarbaum and Bagley 1981), and height growth trends among provenances generally remained consistent over time (Gall and Taft 1973, Kriebel *et al.* 1976).

Progeny testing of grafted northern red oak seed orchards has not been a viable option, due to the limited production of acorns from the few existing orchards (Schlarbaum *et al.* 1993). Northern red oak is a difficult species to successfully graft and resulting grafts often do not grow well or bear acorns (Schlarbaum, personal observation, Schlarbaum *et al.* 1993).

Seedling seed orchards are an alternative approach to grafted orchards, although genetic gains will be reduced in comparison. Progeny tests established in the early 1970's have been converted to seedling seed orchards. An open-pollinated northern red oak seedling seed orchard in Tennessee was established in 1987 and has been utilized for research and reforestation purposes since 1992. Acorn production was sparse until 1993, when a survey for second-year acorns revealed a heavy crop on a large number of trees. Following harvests, a cooperative study was initiated to establish experimental plantations of various open-pollinated families grown under specific protocols to achieve optimal size (*sensu* Kormanik *et al.* 1994a and Kormanik *et al.* 1994b), and were visually graded for quality (Lay *et al.* 1997). The objectives for this study were to: 1) determine provenance effects on early survival and growth of progeny that is one generation removed from original seed source, 2) analyze family effects on survival and growth over time, and 3) evaluate age to age relationships between seedling size at planting to height and survival in subsequent years.

Materials and Methods

Creation of the seedling seed orchard

The Tennessee Valley Authority (TVA) initiated a large upland hardwood improvement program in the Tennessee Valley region in the late 1960's . A northern red oak progeny test was established in 1973 on the Watauga Ranger District of the Cherokee National Forest (Figure 1). This plantation was thinned in 1987 to establish an open-pollinated seedling seed orchard (LaFarge and Lewis 1987). In the fall of 1993, acorns were collected from 73 individual orchard trees (Table 5A). Approximately 1000 acorns from each collection tree were selected for sowing based on size and appearance. The smallest acorns, ca. > 1.3 cm, and/or acorns exhibiting characteristic signs of disease, insect, or animal damage were discarded.

Nursery practices

The acorns were sown by family at the Georgia Forestry Commission's Flint River Nursery in Montezuma, Georgia. The seedlings were grown according to prescriptions developed by the USDA Forest Service's Institute for Tree Root Biology (*sensu* Kormanik *et al.* 1994a and Kormanik *et al.* 1994b). After one growing season, the seedlings were lifted with a Fobro™ machine lifter, and undercut to a depth of 25 cm. During lifting, the seedlings were kept separate by family.

Visual grading

After lifting, a visual assessment of overall seedling quality in each family was made by examining number of FOLR, tap root size, root collar diameter, and stem height. A crew of 5 to 6 people initially selected seedlings from each family based on

these characteristics. The smallest seedlings and/or seedlings with deformed/broken stems or tap roots were subsequently discarded. The roots of the selected seedlings were cleaned of attached soil and debris and clipped to within 15 cm of the main tap root. A final grading of the selected seedlings from each family was made by another visual assessment of the aforementioned characteristics. The second visual grade ensured that only the highest quality seedlings from each family were used as experimental material. After grading, the seedlings selected for planting from each family were bundled into groups of five and sorted for planting. The selected seedlings were stored in coolers until planting.

The number of seedlings graded as acceptable for planting from each family was partially determined through requirements of the experimental planting design. Previous research has indicated that 40 to 60 percent of northern red oak bulked planting stock will be larger than average, and thus of adequate size for planting (Kormanik and Ruehle 1987, Lay *et al.* submitted, Stroempl 1985). Certain families, however, have higher proportions of above-average seedlings, and will subsequently have lower cull rates than other families.

Plantation establishment

In the early spring of 1995, plantations were established on southern National Forests (16), a Kentucky State Forest (1), and the Ames Plantation in West Tennessee (1) (Figure 1). There were 22,500 seedlings planted in the study with 1250 seedlings planted at each site. The planting sites generally consisted of a 3 to 4 acre clearcut using various planting preparation practices (Table 1). Each planting site had a relatively high site

index (≥70) and differed in species occupying the site prior to cutting (Table 1). The seedlings were planted using a shovel or an auger in holes that were approximately 25 to 30 cm deep and wide. Site maintenance procedures varied for each plantation dependent on the viability of each planting site and resources for such practices (Table 1).

Provenance groups

Each family was assigned a provenance group by overlaying a map projection of the geographic origins of the TVA collection trees with a map projection of Bailey's Ecoregions of the United States (Bailey 1980) in ArcView® GIS (ESRI 1994) (Figure 2). Previous studies have used geographic coordinates or man-made boundaries, i.e., states or counties, of the seed source as a definition of provenance (Kriebel *et al.* 1988, Gall and Taft 1973, Schreiner and Santamour 1961). Bailey's ecoregions (Bailey 1980), however, were based on dominant physical and biological characteristics of the landscape and are a more refined system for delineating provenance boundaries.

Experimental design

An incomplete block design was used to assign 73 genetic families to the 18 planting locations, with 25 families at each location. Within a location, a resolvable incomplete block design was used to assign the 25 families to 10 replications, each containing 5 incomplete blocks of 5 families each. Each family had 5 tree plots.

Data collection

Initial measurements of height and diameter growth were recorded for seedlings at the Watuaga (4), Wayah (14), and Grandfather (15) plantations. Survival was recorded for 13 plantations after the first growing season. Second- and third-year

Figure 1. Locations of northern red oak genetic tests.

1. Ames Plantation, University of Tennessee Agricultural Experiment Station, Fayette County, Tennessee
2. Hiwassee Ranger District, Cherokee National Forest, Etowah, Tennessee
3. Nolichucky Ranger District, Cherokee National Forest, Greenville, Tennessee
4. Watauga Ranger District, Cherokee National Forest, Elizabethton, Tennessee
5. Pennyrile State Forest, Dawson Springs, Kentucky
6. Somerset Ranger District, Daniel Boone National Forest, Somerset, Kentucky
7. Stanton Ranger District, Daniel Boone National Forest, Stanton, Kentucky
8. Bankhead Ranger District, Talladega National Forest, Double Springs, Alabama
9. Shoal Creek Ranger District, Talladega National Forest, Heflin, Alabama
10. Brasstown Ranger District, Chattahoochee National Forest, Blairsville, Georgia
11. Oconee Ranger District, Chattahoochee National Forest, Eatonton, Georgia
12. Long Cane Ranger District, Sumter National Forest, Edgefield, South Carolina
13. Cheoah Ranger District, Nantahala National Forest, Robbinsville, North Carolina
14. Wayah Ranger District, Nantahala National Forest, Franklin, North Carolina
15. Grandfather Ranger District, Pisgah National Forest, Marshall, North Carolina
16. Clinch Ranger District, George Washington-Jefferson National Forest, Wise, Virginia
17. Glenwood Ranger District, George Washington-Jefferson National Forest, Natural Bridge Station, Virginia
18. Deerfield Ranger District, George Washington-Jefferson National Forest, Staunton, Virginia

★ Watauga Northern Red Oak Seed Orchard, Watauga Ranger District, Cherokee National Forest

✪ Flint River Nursery, Georgia Forestry Commission, Montezuma, Georgia

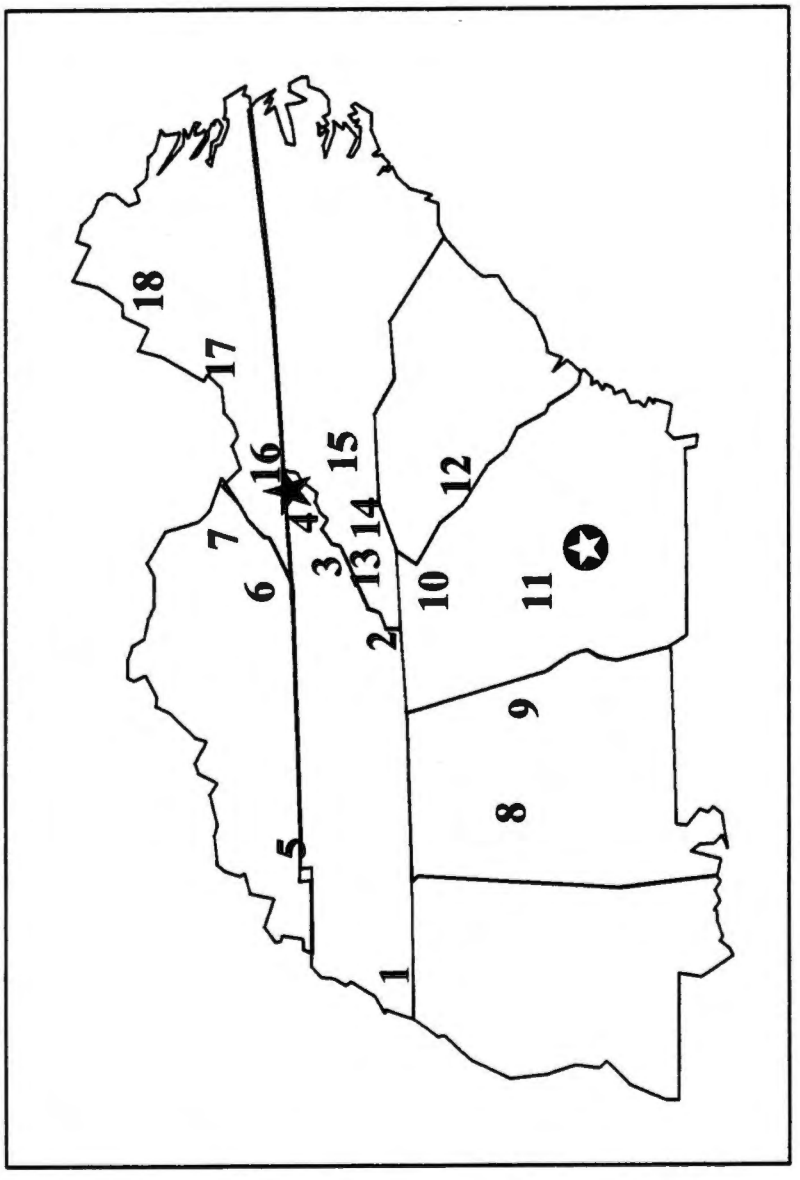

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Table 1. Site information and post-planting practices for northern red oak genetic tests planted on 18 locations throughout the southeastern United States in 1995.

	Site index (feet at 50 years) for northern red oak	Species occupying site prior to cutting (in order of importance)	Site preparation	Date of planting	Post-planting site maintenance
1. Ames Plantation, University of Tennessee Agriculture Experiment Station	80-85	Perennial grasses and weeds; fallow soybean field for 5 years prior to planting	Mowed to clear weeds and grasses	3/95	1995 - direct spray of Roundup™ used to kill weeds around each tree
2. Hiwassee Ranger District, Cherokee National Forest	80	*Q. rubra, Q. prinus, Carya* spp., and *L. tulipifera*	Clearcut and cleared site with dozer	2/95	Released seedlings by mowing every year
3. Nolichucky Ranger District, Cherokee National Forest	80	*Q. velutina, Q. coccinea, Q. prinus, Q. rubra, and L. tulipifera*	Clearcut and residuals were chainsawed	2/95	1995 - hand released around each seedling with chainsaws
4. Watauga Ranger District, Cherokee National Forest	85-90	*Q. alba, Q. prinus, Q. coccinea, Q. rubra, Q. velutina,* and *Pinus strobus*	Clearcut and dozer pushed brush off	4/95	None
5. Pennyrile State Forest, Kentucky	80 - 86	Fescue (*Festuca* spp.), blackberry (*Rubus* spp.), sumac (*Rhus* spp.), *Fraxinus americana* L., and other mixed hardwoods	Broadcast sprayed with Roundup™ to kill fescue. Bushhogged and broadcast sprayed with Roundup™ to kill broadleaf weeds and woody brush	3/95	1995 - sprayed broadleaf weeds with Roundup™
6. Somerset Ranger District, Daniel Boone National Forest	80	*Q. velutina, Q. alba,* and *Carya* spp.	Clearcut and cut stump treatment of Garlon 3A™, prescribed burn, and slash clearing with dozer	3/95	1995 - Installed Garlic Sticks™ to reduce deer browse

7. Stanton Ranger District, Daniel Boone National Forest	80*	Perennial weeds and grasses	Plowed and disked field and seeded it to winter wheat in 1994. Placed circular filter fabrics around each seedling to reduce grass and weed competition	2/95	Mowed several times every year
8. Bankhead Ranger District, Talladega National Forest	70-75**	*P. taeda, Q. alba, Q. coccinea, Q. prinus*, and *Quercus falcata*	Clearcut and brush raked	3/95	1996 - Manually released with power saws
9. Shoal Creek Ranger District, Talladega National Forest	70	*P. taeda*, and mixed hardwoods	Clearcut followed by shearing and windrowing	3/95	1996- mowed once
10. Brasstown Ranger District, Chattahoochee National Forest	90	*Liriodendron tulipifera* L., *Quercus rubra* L., *Q. alba* L., *Q. velutina* Lam., *Cornus florida* L., *Acer* spp., and *Oxydendrum arboreum* (L.) DC.	Clearcut and cleared with a dozer	3/95	1995, 1996, and 1997 - Released with brushsaws; 1997 - Sprayed Roundup™ on sprouting competition
11. Oconee Ranger District, Chattahoochee National Forest	80	Various *Quercus* and *Carya* species	Salvage harvested in 1993 from tornado damage in 1992, and windrowed	3/95	1995 - during growing season, installed Garlic Sticks™ to reduce deer browse
12. Long Cane Ranger District, Sumter National Forest	80-85*	*Pinus taeda* L.	Clearcut and cleared with drum chopper	2/95	1995 - hand release by cutting out surviving
13. Cheoah Ranger District, Nantahala National Forest	75	*Q. coccinea* Muenchh., *Q. prinus* L., and *Q. velutina*	Clearcut and root raked to remove brush	2/95	1996 and 1997 - Released by basal spraying with Garlon™ 4

14. Wayah Ranger District, Nantahala National Forest	80 - 90	*L. tulipifera, Q. rubra, Q. prinus, F. americana, Carya* spp., *Tilia americana* L., and *Betula lenta* L.	Harvested by skyline yarding and felled some residuals with chainsaws. Left residual basal area of 10-15 sq. ft./acre of primarily yellow poplar	2/95	1996 - Released with streamline application of Garlon™ 4 solution.
15. Grandfather Ranger District, Pisgah National Forest	70 - 80	Six year-old clearcut site regenerated with various upland	Cleared site with dozer	3/95	1995 and 1997 - Released with Roundup™
16. Clinch Ranger District, George Washington-Jefferson National Forest	90	*Q. rubra, Q. prinus, Q. velutina, Q. alba, Acer rubrum* L., *L. tulipifera, Magnolia acuminata* L.,	Clearcut and tractor piled. Piles were placed outside planting and burned	3/95	1996 and 1997 - mowed with weed eaters
17. Glenwood Ranger District, George Washington/ Jefferson National Forest	80	*Pinus virginia* Mill. that was killed by the southern pine beetle (*Dendroctonus frontalis* Zimm.)	Salvage logged in 1994, and cleared with bulldozer or chainsaw	3/95	None
18. Deerfield Ranger District, George Washington-Jefferson National Forest	77†	*Q. alba,* and mixed hardwoods	Clearcut and residual natural regeneration was chainsawed	4/95	None

*Derived by converting from *L. tulipifera* to *Q. rubra* using site index species comparison curve found in Doolittle (1958).

** Derived by first converting from *P. taeda* to *P. echinata* Mill. using site index conversion equation in Coile, T.S. (1953), and then converting from *P. echinata* to *Q. rubra* using site index comparison table in Olson and Della Bianca (1959).

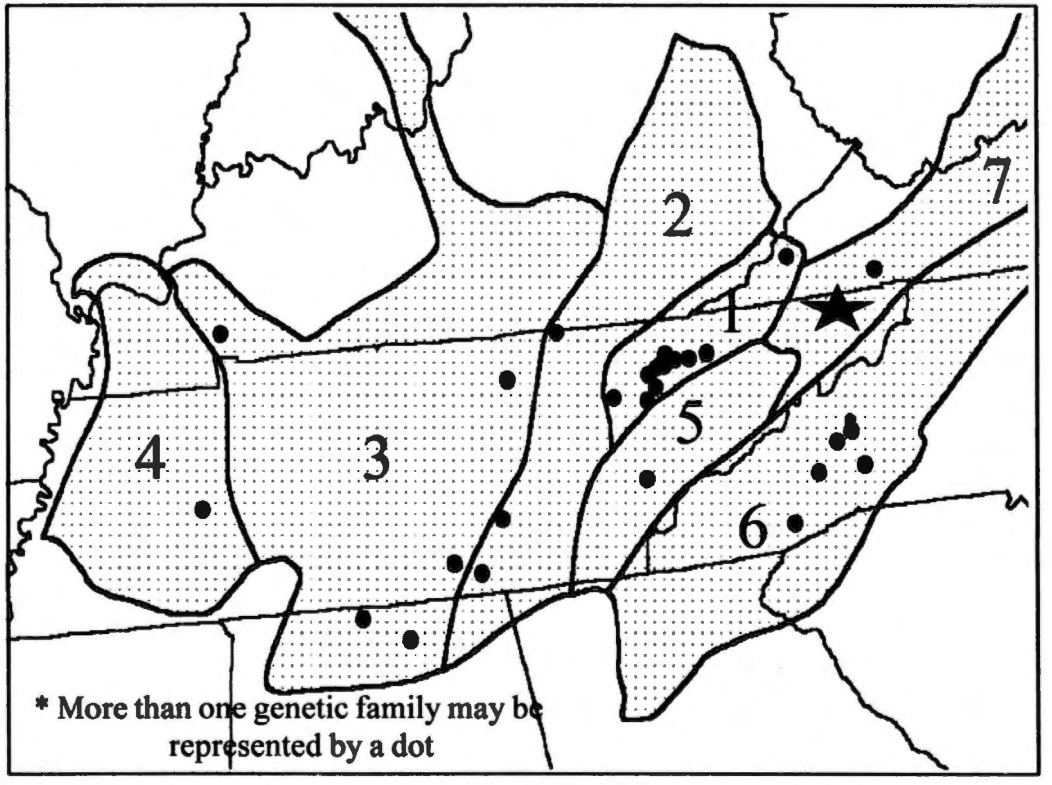
†Derived by converting from *Q. alba* to *Q. rubra* using site index species comparison curve found in Hampf, F.E. (1965).

Figure 2. Origins and designated provenance group, delineated using Bailey's Ecoregions (Bailey 1980), of 73 mother trees in the Watauga seedling seed orchard, Cherokee National Forest, Tennessee.

Bailey's Ecoregions:
1. Southern Cumberland Mountains
2. Northern Cumberland Plateau
3. Interior Low Plateau/Highland Rim
4. Upper Gulf Coastal Plain
5. Central Ridge and Valley
6. Blue Ridge Mountains
7. Northern Ridge and Valley

● Origin of family

★ Watauga northern red oak seed orchard


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* More than one genetic family may be represented by a dot

survival and height were recorded for 11 plantations. Data were recorded by different personnel from cooperating agencies at each plantation. Survival and/or height were not recorded for several plantations due to lack of resources, and/or because the plantation suffered heavy damage, e.g., deer browse, cicada damage (Table 2).

During first-year survival counts, cause of death, if known, was recorded. For the second and third growing seasons, visual damage, e.g., deer browse, insect damage, disease, was recorded for live seedlings according to condition codes that were described to each data collector. Dieback on the dominant stem was recorded as well as basal sprouting. In addition, plantation supervisors, were asked to cite general observations on damage of seedlings for the first three years.

Somerset fire

The Somerset planting suffered from an escaped prescribed fire in the late winter of the second dormant season. The fire occurred before second-year survival and height measurements were taken. Post fire survival and height growth was recorded after the third growing season.

Statistical analysis

All statistical procedures were conducted using SAS (SAS Institute 1990) for each plantation individually and for all plantations combined. An error level of 0.05 was selected to indicate statistical significance in all procedures. Analyses of variance were conducted using the MIXED procedure to detect provenance and family effects on first-year survival, and second- and third- year survival and height. For the analysis of

Table 2. Data collection for 18 northern red oak plantations .

Plantation	Measurements at planting	1st-year data	2nd-year data	3rd-year data
Ames (1)				
Hiwassee (2),		X	X	X
Nolichucky (3)		X	X	X
Watauga (4)	X	X		X
Pennyrile (5)			X	
Somerset (6)		X		X
Stanton (7)		X	X	X
Bankhead (8)		X		
Shoal Creek (9)		X	X	X
Brasstown (10)		X	X	X
Oconee (11)				
Long Cane (12)		X		
Cheoah (13)		X	X	X
Wayah (14)	X	X	X	X
Grandfather (15)	X		X	X
Clinch (16)		X	X	X
Glenwood (17)				
Deerfield (18)				

variance to detect provenance effects, provenances 4, 5, and 7 were deleted, as they contained families from only one geographic origin each which was not considered to be representative of the entire provenance. Provenance 2 contained 5 families, and was deleted from the provenance analysis to prevent biases resulted from undersampling.

The analyses of variance were conducted on data from all locations combined using the following model for expected mean squares:

Source	Expected Mean Squares
location	$\sigma^2_e + rb\sigma^2_{lf(p)} + fp\sigma^2_{b(lr)} + fpb\sigma^2_{r(l)} + fprb\sigma^2_l$
rep(location)	$\sigma^2_e + fp\sigma^2_{b(lr)} + fpb\sigma^2_{r(l)}$
block(location*rep)	$\sigma^2_e + fp\sigma^2_{b(lr)}$
location*family(provenance)	$\sigma^2_e + rb\sigma^2_{lf(p)}$
provenance	$\sigma^2_e + Q_{p,f(p)} + Q_{lf(p)}$
family(provenance)	$\sigma^2_e + Q_{f(p)} + Q_{lf(p)}$
Error	σ^2_e

Analyses of variance for each individual plantation were conducted using the following model for expected mean squares:

Source	Expected Mean Squares
rep	$\sigma^2_i + i\sigma^2_{b(r)} + bi\sigma^2_r$
block(rep)	$\sigma^2_i + i\sigma^2_{b(r)}$
provenance	$\sigma^2_i + Q_{f(p)} + Q_{p,f(p)}$
family(provenance)	$\sigma^2_i + Q_{f(p)}$
Error	σ^2_i

Least-square means were computed for each provenance and for each family in the combined analyses and in analyses for each plantation. Differences among the least-square means were determined using F-tests generated with the PDIFF option. The least-square survival and height means of each provenance and family in the combined analyses were converted to relative survival and heights, expressed as a percentage of the

combined mean. Additionally, at each plantation, the least-square survival and height means of each provenance and family were converted to relative survival and heights, expressed as a percentage of the plantation mean (Table 6A).

PROC CORR was used to calculate year to year Spearman correlation coefficients using least-square family means for survival and height. Correlations between initial height and diameter to subsequent survival and height were calculated for the Watuaga (4), Wayah (14), and Grandfather (15) plantings. Correlation coefficients were also calculated between second-year height to third-year survival and height for individual and combined plantations.

Simple linear regression analyses using PROC REG were calculated to compute regression coefficients between initial or second-year height to survival and height in subsequent years using individual tree measurements. Regression analyses between initial height and diameter measurements to subsequent height and survival were conducted for the Watuaga (4), Wayah (14), and Grandfather (15) plantings. Regression analyses between second-year height and third-year survival and height were calculated for nine plantations that had data for both the second and third growing seasons. Regression analyses between second-year height to third-year survival and height was also conducted using combined plantation data.

The dependent variables in the above regression models were first adjusted for variation associated with the random variables, i.e., location (for the combined analysis), family, rep, and block, using an analysis of variance. The adjusted dependent variables were then used in the regression models.

Results

Damage

All plantations were impacted by damaging agents to varying degrees throughout the three growing seasons, with the exception of the Bankhead (8) planting (Table 3). However, identification of damage was not consistent across plantations due to the magnitude of the study and the different personnel who collected data. Correspondingly, a quantitative measure of damage at each plantation could not be determined.

White-tailed deer (*Odocoileus virginianus*) browse was the most common damaging agent in the study with intensity of deer browse varying among plantations. Other forms of seedling damage included: stem feeding from an unknown species of cicada (Homoptera: Cicadidae) and rabbit (*Sylvilogus* spp.), vole (*Microtus* spp.) feeding on roots, late season frost damage to plant tissue, ice damage to terminal leaders, and heat damage to the root collar diameter by an escaped prescribed burn. Four plantations, Ames (1), Oconee (11), Glenwood (17), and Deerfield (18) were terminated from the study prior to first-year measurements due to poor survival and recovery from various damaging agents (Table 3). The Long Cane (12) planting was removed from the study after the first-growing season because of severe browsing by deer coupled with vole damage. Third-year data was not collected at the Pennyrile (5) planting due to poor recovery from heavy deer browse during the second growing season.

The Hiwassee (2), Nolichucky (3), Shoal Creek (9), and Grandfather (15) plantings received moderate to heavy deer browse in the first and second growing

Table 3. Occurrence of damage observed for 18 northern red oak plantations during the first three growing seasons.

Plantation (no.)	Year 1	Year 2	Year 3
Ames plantation (1)	Deer	--	--
Hiwassee (2)	Deer	Deer	*
Nolichucky (3)	*	Deer	*
Watauga (4)	Cicada	--	Deer
Pennyrile (5)	Deer	Deer	--
Somerset (6)	*	Fire	*
Stanton (7)	*	Deer	Deer
Bankhead (8)	*	--	--
Shoal Creek (9)	Deer, Japanese Beetle	Deer	-
Brasstown (10)	Deer, Vole	Deer, Vole, Frost	Deer
Oconee (11)	Deer	--	--
Long Cane (12)	Deer, Vole	--	--
Cheoah (13)	Rabbit	*	*
Wayah (14)	Vole	Vole	*
Grandfather (15)	Deer	Deer, Frost	*
Clinch (16)	*	Deer, Rabbit	Deer, Rabbit ,Ice
Glenwood (17)	Cicada	--	--
Deerfield (18)	Cicada	--	--

--Damage not assessed

* No damage present

seasons, but the overall survival and growth warranted continuance in the study. The Watauga (4) planting suffered serious damage by cicada during the first year and recovery was poor. The Brasstown (10) and Wayah (14) plantings suffered light to moderate vole damage throughout each growing season. Early-season frost damaged seedlings at the Brasstown (10) and the Grandfather (15) during the third year. Japanese beetle (*Popillia japonica* Newman) defoliated the majority of the trees at the Shoal Creek (9) planting during the first year.

The Somerset (6) planting was affected by a ground fire during the second dormant season, burning approximately 80% of the plantation. The fire varied in intensity relative to the amount of litter layer across the site. In areas where the fire reach the hottest temperature, the planted seedlings' were burned completely through the stem. In other areas with a cooler burn, the fire did not generate sufficient heat to seriously damage the phloem..

Dieback and Sprouting

Stem dieback at each plantation generally was more prevalent in year 3 when compared to year 2 (Table 4). However, the Shoal Creek (9) planting had 60% dieback in dieback in the year 3. Compared to other plantations, the Watauga (4) and the Stanton (7) plantings had the most dieback in year 3 with 68% and 52%, respectively. One growing season after the fire at the Somerset (6) (year 3), 76% of the trees had top dieback, and 61% were from basal sprouts.

Survival

Overall first-year, second-year, and third-year mean survival was 87, 81, and

Table 4. Occurrence of stem dieback and basal sprouting in the second- and third-growing season for 12 northern red oak plantations.

	Year 2		Year 3	
Plantation (no.)	**% Dieback**	**% Sprouts**	**% Dieback**	**% Sprouts**
Hiwassee (2)	8	<1	21	2
Nolichucky (3)	9	<1	17	<1
Watauga (4)	--	--	68	5
Pennyrile (5)	12	2	--	--
Somerset (6)	--	--	76	61
Stanton (7)	2	<1	52	3
Shoal Creek (9)	63	<1	45	5
Brasstown (10)	13	<1	8	<1
Cheoah (13)	12	<1	7	<1
Wayah (14)	16	<1	29	<1
Grandfather (15)	23	2	15	<1
Clinch (16)	12	1	16	3

--Data not taken

75%, respectively (Table 5). First-year survival at individual plantations ranged from 71% for the Bankhead (8) planting to 100% for the Clinch (16) planting. The Bankhead (8) planting was deleted from the study prior to second-year measurements due to poor growth and survival during the second growing season. Second-year survival at each planting ranged from 46% for the Pennyrile (5) planting to 95% for the Cheoah (13) planting. Third-year survival at each plantation ranged from 36% at the Somerset (6) planting to 94% for both the Cheoah (13) and the Grandfather (15) plantings.

Provenance effects on survival for the combined analysis were non-significant for all three years (Table 6). With respect to individual plantations, only the Shoal Creek (9) plantation exhibited differences among provenances for the first growing season (Table 6), with trees from provenance 3 having higher survival rates (Table 7). Five and six individual plantations exhibited provenance effects on survival in year 2 and 3, respectively (Table 6). Generally, trees from provenance 3 had higher second- and third-year relative survival than trees from provenances 1 or 6 (Table 7). At the Watauga (4) planting, however, provenance 6 had 29% and 22% higher relative survival than provenances 1 or 3, respectively.

Family effects were significant for survival in the combined analysis for all three years (Table 6). Six of thirteen plantations had significant family effects in year 1 (Table 6). Eight of ten plantations had family differences in survival during the second year, and all but three plantations had significant family effects in year 3 (Table 6). Relative survival of each family in the combined analysis ranged from 90 to 110% around the combined mean (87%) for the first growing season, from 84 to 120%

Table 5. Mean height (cm) and survival (%) for individual and combined northern red oak plantations with associated standard deviations.

	Year 1	Year 2		Year 3	
Plantation (no.)	**Survival**	**Survival**	**Height**	**Survival**	**Height**
Hiwassee (2)	97 (0.18)	78 (0.42)	103 (24.3)	74 (0.44)	110 (39.1)
Nolichucky (3)	91 (0.29)	84 (0.37)	99 (29.4)	78 (0.41)	123 (40.7)
Watauga (4)	79 (0.41)	--	--	55 (0.50)	93 (41.5)
Pennyrile (5)	--	46 (0.50)	82 (28.0)	--	--
Somerset (6)	86 (0.35)	--	--	36 (0.48)	68 (32.2)
Stanton (7)	93 (0.25)	92 (0.27)	95 (21.7)	87 (0.34)	105 (31.0)
Bankhead (8)	71 (0.45)	--	--	--	--
Shoal Creek (9)	93 (0.25)	65 (0.48)	84 (25.3)	59 (0.49)	86 (24.2)
Brasstown (10)	96 (0.19)	83 (0.38)	114 (28.2)	79 (0.41)	133 (37.6)
Long Cane (12)	68 (0.48)	--	--	--	--
Cheoah (13)	99 (0.03)	95 (0.21)	114 (27.4)	94 (0.23)	136 (34.8)
Wayah (14)	87 (0.34)	79 (0.41)	116 (29.8)	76 (0.43)	147 (36.2)
Grandfather (15)	--	94 (0.23)	90 (27.4)	94 (0.23)	99 (30.5)
Clinch (16)	100 (0)	92 (0.27)	111 (32.7)	89 (0.31)	118 (36.3)
Combined	87 (0.34)	81 (0.39)	102 (30.0)	75 (0.43)	114 (40.7)

--Data not taken

Table 6. Significance of family and provenance differences from analysis of variance (P = 0.05) for survival and height at individual and combined northern red oak plantations.

Plantation (no.)	1st-year survival		2nd-year survival		2nd-year height		3rd-year survival		3rd-year height	
	Family differences	Provenance differences	Family differences	Provenance differences	Family differences	Provenance differences	Family differences	Provenance differences	Family differences	Provenance differences
Hiwassee (2)	N	N	Y	N	Y	N	Y	Y	Y	N
Nolichucky (3)	N	N	Y	N	Y	Y	Y	N	Y	Y
Watauga (4)	Y	N	--	--	--	--	N	N	Y	Y
Pennyrile (5)	--	--	Y	N	Y	N	--	--	--	--
Somerset (6)	N	N	--	--	--	--	N	N	Y	Y
Stanton (7)	Y	N	Y	Y	Y	Y	Y	N	Y	N
Bankhead (8)	Y	N	--	--	--	--	--	--	--	--
Shoal Creek (9)	Y	Y	Y	Y	Y	N	Y	Y	Y	N
Brasstown (10)	N	N	N	Y	Y	N	Y	Y	Y	N
Long Cane (12)	Y	N	--	--	--	--	--	--	--	--
Cheoah (13)	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Wayah (14)	N	N	Y	N	Y	N	Y	N	Y	Y
Grandfather (15)	--	--	N	Y	Y	Y	N	Y	Y	Y
Clinch (16)	N	N	Y	N	Y	N	Y	N	Y	N
Glenwood (17)	Y	N	--	--	--	--	--	--	--	--
Combined	Y	N	Y	N	Y	Y	Y	N	Y	Y

--Data not taken

Table 7. Relative first-, second-, and third-year survival, expressed as a percentage (%) of the plantation mean or combined mean, of three provenances at individual and combined northern red oak plantations.

	Provenance								
	1			3			6		
Plantation (no.)	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Hiwassee (2)	100	99	97	100	105	107	-	-	-
Nolichucky (3)	102	104	105	101	98	101	99	98	91
Watauga (4)	100	*	98	105	*	105	104	*	127
Pennyrile (5)	*	104	*	*	76	*	*	100	*
Somerset (6)	100	*	103	102	*	128	103	*	106
Stanton (7)	99	98	98	101	104	102	100	100	102
Bankhead (8)	101	*	*	111	*	*	96	*	*
Shoal Creek (9)	97	97	95	104	112	110	-	-	-
Brasstown (10)	100	102	103	101	95	97	96	87	78
Long Cane (12)	100	*	*	102	*	*	97	*	*
Cheoah (13)	100	95	96	101	102	102	101	102	101
Wayah (14)	100	100	99	102	108	109	105	104	99
Grandfather (15)	*	101	101	*	101	101	*	94	95
Clinch (16)	100	99	100	100	107	108	100	102	106
Combined	100	100	100	102	102	103	105	98	99

* Data not taken

– Provenance not represented at plantation

around the combined mean (81%) for the second growing season, and from 81 to 111% around the combined mean (75%) for the third growing season (Table 8). Within individual plantations, the range in relative family survival means is generally larger in year 2 than year 1. From year 2 to year 3, however, the range in relative family survival means within a plantation is generally similar.

Height

Over all plantations, height for the second and third growing seasons was 102 cm and 114 cm, respectively (Table 5). For individual plantations, second year mean height ranged from 82 cm for the Pennyrile planting (5) to 116 cm for the Wayah (14) planting. Third-year mean height at individual plantations ranged from 68 cm at the burned Somerset planting (6) to 147 cm Wayah (14) planting. Provenance effects on height were significant for year 2 and 3 in the combined analysis (Table 6). Four plantations exhibited provenance height differences in year 2, and six plantations had provenance effects on height in year 3 (Table 6). In the combined analysis and within individual plantations, families from provenance 3 generally outperformed families from other provenances in height growth in years 2 and 3 (Table 9).

Family effects on height were significant for year 2 and year 3 in the combined analysis (Table 6), with relative family heights ranged from 78% to 118% around the combined mean (102 cm) for year 2 and from 81% to 117% around the combined mean (114 cm) for year 3 (Table 8). All plantations had significant family effects on height in year 2 and year 3, and ranges in relative family heights at individual plantations were similar from the second to the third year (Table 8).

Table 8. Ranges in relative survival and height, expressed as a percentage (%) of the plantation mean or combined mean, of families at individual and combined northern red oak plantations.

Plantation (no.)	Year 1	Year 2		Year 3	
	Survival	Survival	Height	Survival	Height
Hiwassee (2)	91-103	82-118	69-117	81-122	68-120
Nolichucky (3)	90-108	81-114	81-121	85-118	81-123
Watauga (4)	81-114	--	--	76-127	64-115
Pennyrile (5)	--	59-137	78-121	--	--
Somerset (6)	80-110	--	--	56-164	73-141
Stanton (7)	81-108	83-107	86-119	76-110	85-111
Bankhead (8)	56-124	--	--	--	--
Shoal Creek (9)	86-108	69-135	82-118	64-136	76-115
Brasstown (10)	95-104	87-111	86-117	78-114	82-115
Long Cane (12)	71-135	--	--	--	--
Cheoah (13)	99-100	88-105	84-114	87-104	85-116
Wayah (14)	82-108	81-115	77-123	71-121	83-123
Grandfather (15)	--	85-106	77-115	91-113	77-115
Clinch (16)	100-100	85-109	80-118	83-111	82-121
Combined	90-110	84-120	78-118	81-111	81-117

-- Data not taken

Table 9. Relative second- and third-year height, expressed as a percentage (%) of plantation mean or combined mean, of three provenances at individual and combined northern red oak plantations.

	Provenance					
	1		3		6	
Plantation (no.)	Year 2	Year 3	Year 2	Year 3	Year 2	Year 3
Hiwassee (2)	102	101	102	105	*	*
Nolichucky (3)	101	99	111	116	98	98
Watauga (4)	--	95	--	109	--	86
Pennyrile (5)	102	--	102	--	100	--
Somerset (6)	--	106	--	134	--	97
Stanton (7)	100	100	104	105	98	97
Shoal Creek (9)	100	100	100	98	*	*
Brasstown (10)	102	102	100	102	108	114
Cheoah (13)	104	102	103	105	90	97
Wayah (14)	103	101	103	110	98	95
Grandfather (15)	99	99	111	108	91	90
Clinch (16)	100	99	103	108	97	97
Combined	100	96	102	104	94	93

-- Data not taken

* Provenance not represented at plantation

Initial measurements

Mean heights and diameters ranged from 73 cm to 85 cm and from 9.1 mm to 10.7 mm, respectively, at the three locations with initial measurement data (Table 10). Provenance effects on initial height and diameter size were significant for the Watauga (4) and Grandfather (15) plantings, but were not significant for the Wayah (14) planting. Trees from provenance 6 had the largest height and diameters at the Watuaga (4) planting , while trees from provenance 3 had the largest height and diameters at the Grandfather (15) planting. Height and diameter differences among families were significant for all three plantations. Ranges in relative family means were larger for height than diameter at all three plantations.

At all three plantations, the family mean correlations between initial size and subsequent survival were not significant (Table 11). The Watauga (4) planting had no significant correlations between initial family size and subsequent family survival and height. At the Wayah (14) and Grandfather (15) plantings, the strongest correlations were between initial family height and second-year family height (r=0.83-0.84) (Table 11). Correlations between initial family size and subsequent family height growth weakened from the second to the third growing season. At all three plantations, correlations involving initial family diameter were not as strong as correlations involving initial family height. At all three plantations, regression using individual tree measurements showed that less than 5 percent of the variation in field survival and height growth could be explained by initial seedling size (Table 12).

Table 10. Initial height and root collar diameter (RCD) statistics for three northern red oak plantations.

			Plantation		
			Watauga (4)	Wayah (14)	Grandfather (15)
Height		Overall mean (cm)	85	84	73
		Ranges in Relative Family Means*	80-116	73-126	74-127
		Significant differences among families	Y	Y	Y
	Relative Mean*	Provenance 1	98	101	100
		Provenance 3	100	101	111
		Provenance 6	116	108	89
		Significant differences among provenances	Y	N	Y
RCD		Overall mean (mm)	10.7	10.2	9.1
		Ranges in Relative Family Means*	92-116	83-113	88-116
		Significant differences among families	Y	Y	Y
	Relative Mean*	Provenance 1	99	101	99
		Provenance 3	103	101	110
		Provenance 6	104	99	97
		Significant differences among provenances	Y	N	Y

* Expressed as a percentage of the plantation mean

Table 11. Spearman correlation coefficients* between initial height and root collar diameter (RCD) to subsequent survival and height for three northern red oak plantations.

Age comparison	Watauga (4)	Wayah (14)	Grandfather (15)
Initial height to 1st year survival	-0.16	0.06	--
Initial height to 2nd year survival	--	-0.05	-0.15
Initial height to 3rd year survival	0.08	0.05	-0.30
Initial diameter to 1st year survival	-0.03	0.11	--
Initial diameter to 2nd year survival	--	-0.20	-0.23
Initial diameter to 3rd year survival	0.12	0.09	-0.31
Initial height to 2nd year height	--	0.84**	0.83**
Initial height to 3rd year height	0.35	0.64**	0.77**
Initial diameter to 2nd year height	--	0.65**	0.59**
Initial diameter to 3rd year height	0.28	0.50**	0.48**

--Data not taken

*Correlation coefficients were derived from least-square family means for each plantation

**Correlation coefficients were significant (P = 0.05)

Table 12. Estimated regression coefficients*(not in parenthesis) and associated slopes (in parenthesis) between initial height and initial diameter with first-, second-, and third- year survival and height at three northern red oak plantations.

	Watauga (4)		Wayah (14)		Grandfather (15)	
	Initial height	Initial diameter	Initial height	Initial diameter	Initial height	Initial diameter
1st-year survival	0 (0)	0 (0)	0 (0)	1 (0.01)	--	--
2nd-year survival	--	--	0 (0)	0 (0.01)	0 (0)	0 (0)
2nd-year height	--	--	1 (0.24)	3 (4.25)	3 (0.27)	2 (2.75)
3rd-year survival	0 (0)	0 (0.03)	0 (0)	0 (0.013)	0 (0)	0 (0)
3rd-year height	1 (0.25)	2 (4.29)	0 (0.17)	1 (3.90)	4 (0.34)	2 (3.70)

-- Data not taken

*Coefficients are expressed as a percent; regression was calculated using individual tree measurements.

Relationships between first, second and third year survival and height

Generally, the year to year survival correlations were strongest between second-year family survival and third-year family survival in the combined (0.68) and individual plantation analysis (r=0.55-1.00) (Table 13). The correlation between second-year family height to third-year family height was 0.92 in the combined analysis, and ranged from 0.71 (Stanton (7)) to 0.96 (Grandfather (15)) for individual plantations. The correlations between second-year family height and third-year family survival were not significant in the combined analysis and at each plantation.

In the combined analysis, regression using individual seedling measurements showed that second-year seedling height accounted for one percent of the variation in third-year seedling survival and for 20 percent of the variation in third-year seedling height (Table 14). For individual plantations, seedling height at age 2 generally had a stronger relationship with seedling height at age 3 than with seedling survival at age 3. The association between height at age 2 to height at age 3 was strongest for the Wayah (14) planting (r^2=0.64) and weakest for the Stanton (7) planting (r^2=0.19). The Grandfather (15) planting had the weakest relationship between height at age 2 to survival at age 3 (r^2=0.11), while the Wayah (14) planting had the strongest (r^2=0.75).

Discussion

Damage effects on survival and height

Survival rates and height growth at specific plantations were clearly affected by various damaging agents, although quantitative assessment of damage was not taken.

Table 13. Spearman correlation coefficients* between for survival and height at individual and combined northern red oak plantations.

Plantation	1st-year survival to 2nd-year survival	1st-year survival to 3rd-year survival	2nd-year survival to 3rd-year survival	2nd-year height to 3rd-year height	2nd-year height to 3rd-year survival
Hiwassee (2)	0.71**	0.72**	0.91**	0.85**	0.13
Nolichucky (3)	0.59**	0.67**	0.82**	0.88**	0.39
Watauga (4)	--	0.42**	--	--	--
Somerset (6)	--	0.70**	--	--	--
Stanton (7)	0.74**	0.50**	0.55**	0.71**	-0.11
Shoal Creek (9)	0.63**	0.70**	0.90**	0.90**	-0.20
Brasstown (10)	0.23	0.00	0.80**	0.87**	-0.08
Cheoah (13)	0.35	0.32	0.82**	0.85**	0.32
Wayah (14)	0.61**	0.61**	0.85**	0.87**	0.06
Grandfather (15)	--	--	1.00**	0.96**	0.10
Clinch (16)	0.00	0.00	0.87**	0.95**	0.07
Combined	0.42**	0.50**	0.68**	0.92**	0.15

-- Data not taken

*Correlation coefficients were derived from least-square family means for each plantation

**Correlation coefficients were significant (P = 0.05)

Table 14. Estimated regression coefficients* (not in parenthesis) and associated slopes (in parenthesis) between second-year height to third-year survival and height at individual and combined northern red oak plantations.

Plantation (no.)	2nd-year height to 3rd-year height	2nd-year height to 3rd-year survival
Hiwassee (2)	52 (0.75)	44 (0.005)
Nolichucky (3)	55 (0.90)	45 (0.006)
Stanton (7)	19 (0.50)	12 (0.003)
Shoal Creek (9)	52 (0.65)	42 (0.006)
Brasstown (10)	58 (0.89)	49 (0.005)
Cheoah (13)	60 (0.92)	34 (0.004)
Wayah (14)	64 (0.93)	75 (0.006)
Grandfather (15)	28 (0.55)	11 (0.002)
Clinch (16)	58 (0.74)	36 (0.004)
Combined	20 (0.41)	1 (0.001)

* Coefficients are expressed as a percent; regression was calculated using individual tree measurements.

By the end of the third growing season, six of eighteen plantations were discontinued due to severe deer, cicada and/or vole damage, i.e., reduced survival by > 30%: Ames (1), Pennroyl (5) Oconee (11), Long Cane (12), Glenwood (17), and Deerfield (18). The Watauga (4) planting would have been discontinued, but was retained to evaluate the relationship between initial seedling size and recovery from cicada attack. Previous studies also have shown reductions in survival rates and height growth attributed to deer and insect damage at northern red oak plantations (Auchmoody and Walters 1992, Graveline *et al.* 1997, Myers *et al.* 1989, Rink and Coggeshall 1995, Zaczek *et al.* 1997). There was not a clear relationship between occurrence of moderate or light damage and survival. Inspection of survival and height means at each plantation indicate that effects of damage on survival and height growth were confounded by site quality and site preparation and maintenance.

The Wayah (14) planting had the greatest height growth from year 2 to year 3, due to the high site index (80-90), release treatment (Table 1), and absence of deer pressure (Table 3). The high third year survival (94%) and average height growth (136 cm) at the Cheoah (13) planting can be attributed to the minimal occurrence of damage (Table 3), coupled with good site index (75) and two herbicide release treatments (Table 1). The Brasstown (10) planting maintained relatively high average three year height growth (133 cm) despite suffering from various forms of damage (Table 3). The vole and frost damage negatively affected survival at the Brasstown (10) planting, but deer browse was generally localized and not severe. Additionally, the Brasstown (10) relatively high site index (90) and yearly herbicide treatments helped the surviving

seedlings recover from damage. Competition control through herbicide and manual release methods has maintained good height growth in previous oak plantings, if damage was not severe (Auchmoody and Walters 1992, Gordon *et al.* 1995, Teclaw and Isebrands 1993, Zaczek *et al.* 1997). However, if damage is severe, control of competition did not appear to benefit growth of planted oak seedlings (Gordon *et al.* 1995).

The relatively poor survival and growth of the Bankhead (8) and Shoal Creek (9) plantings can be partially attributed to site conditions and geographic locations of the plantations. Both plantations are located on old pine sites that are on the edge of the natural range for northern red oak (Sander 1990), and the more northerly genotypes used in this study may not be well adapted to these sites (Table 1 and Figure 1). The survival and growth at the Shoal Creek (9) planting was further hindered by severe defoliation by the Japanese beetle and browse by deer. The Oconee (11) and Long Cane (12) plantings are also located on the edge of the species natural range, but heavy deer/vole damage prevented evaluation of location effects on seedling survival and development.

Protection from damaging agents would have likely increased survival and height growth at specific plantations as shown by previous studies (Auchmoody and Walters 1992, Graveline 1997, Ward 1996). Graveline (1997) found that specific deer repellents and tree shelters were effective in reducing deer browse, but these methods can be expensive to implement (Kays 1996, McConnell 1993). Insect damage generally can be controlled using insecticides, if the problem is detected before critical damage is done and resources exist for treatment application. Unfortunately, damage by small mammals,

i.e., voles, to oak plantings has not been widely studied, and an efficient method of protection does not currently exist.

Effects of fire at the Somerset (6) planting

Frequent low intensity fires have historically helped to establish and maintain natural oak stands (Abrams 1992, Crow 1988, Lorimer 1985). In contrast, the effects of fire in young oak plantations is not well understood. Gordon *et al.* (1995) obtained a 71% survival rate six years after a controlled burn in a northern red oak underplanting . Survival rates were lower one year after the fire at the Somerset site (36%), indicating that Gordon *et al.*'s (1995) fire was probably of less intensity. The high occurrence of basal sprouting (61%) of the surviving seedlings subsequent to the fire at the Somerset (6) planting also was observed in Gordon *et al.*'s (1995) study. After six years, however, seedling sprouts in Gordon *et al.*'s (1995) had slow growth in comparison to competing vegetation. Sprouting growth at the Somerset (6) site may be more vigorous than in the Gordon *et al.* (1995) study. The seedlings in Gordon *et al.*'s (1995) study were smaller in height and root collar diameter (Gordon 1988) when compared to the early measurements of seedlings used in this study (Table 10). Additionally, in contrast to grading procedures used in this study, the seedlings in the Gordon *et al.* (1995) study were graded with minimal consideration of numbers of first-order lateral roots or tap root size (Gordon 1988). The recovery of the surviving seedlings following the fire at the Somerset (6) planting will continue to be evaluated.

Provenance effects

Provenance effects on survival and height growth generally were not as evident as

family effects in the combined analysis and at individual plantations (Table 6), particularly for survival. Additionally, provenance differences in survival and height growth were not as evident in this study as in studies that tested samples from natural populations (Farmer *et al.* 1981, Houston 1987, Kriebel *et al.* 1976). This indicates that provenance effects appear to diminish after genetic recombination in the seed orchard.

The better survival and growth of provenance 3 trees in the combined analysis and at the majority of the plantations suggests provenance effects can not be entirely discounted. Families from this provenance appear to be less sensitive to planting location than families from other provenances. Remaley (1998) found that certain families exhibited a greater genotype/environment interaction while other families performed similarly at various geographic locations. Further testing is needed before reaching a conclusion on provenance effect, as there was a relatively smaller sample of families from provenance 3 and selection of families for this study was not originally made to study provenance differences. Collection trees were selected based on availability of acorns, not on origin of the mother tree. Future field testing should be designed to test specifically for provenance effects on orchard progeny.

Family effects

Family differences in the combined analysis and at individual plantations became more apparent with age as nursery effects disappeared as shown by previous studies (Houston 1987, Kriebel *et al.* 1976). Bare-root oak seedlings, up to three years after planting, will experience planting shock while rebuilding a root system damaged from nursery handling and planting (Kormanik *et al.* 1995). Therefore, early selection of

families would not be beneficial until nursery effects diminish (Houston 1987, Kriebel *et al.* 1988). The quality of nursery stock used in this study was probably better compared to seedlings used in studies established before optimal nursery practices were developed, which may allow for earlier family selection than previously possible.

Initial size and subsequent survival and growth

The seedlings at the Watauga (4), Wayah (14), and the Grandfather (15) plantings were comparable in overall initial mean height and RCD (Table 10). Initial seedling size was above the minimum nursery stock size recommended for successful establishment of northern red oak plantations (Johnson 1981). Despite similarities in size of nursery stock, however, the three plantations differed in three-year survival and growth performance (Table 5) due to a combination of site quality differences (Table 1), damage (Table 3), and genetic differences (Table 6A) among plantations.

Provenance and family differences in initial size were apparent (Table 10), as found in previous nursery studies (Kriebel 1965, Buchschacher *et al.* 1991), but was not related to early survival at the three plantings. Early family survival was more related to effects of stress factors at the local site, i.e., damage, planting shock, and/or weather, than to initial family size. Initial family height and diameter had a positive relationship with subsequent family height growth at the Wayah (14) and Grandfather (15) plantings, in the absence of severe damage. In comparison, the relatively weaker correlations between initial size and subsequent survival and height found at the Watauga planting is related to the severe cicada damage that impacted the plantation during the first growing season. After removal of the smallest seedlings from each family during grading, initial size of

individual seedlings within a family was not related to subsequent field performance (Table 12). Individual seedlings within a family appear to be randomly affected by damaging agents and/or planting shock, regardless of seedling size at planting.

Relationships between first, second, and third survival and height

Age to age family mean correlations for survival were strongest between year 2 and year 3 (Table 13), indicating family ranks in survival were more stabile in year 3 than previous years. Previous studies found family rankings stabilize by age 5 to10 (Farmer *et al.* 1981, Houston 1987), but the relatively high quality of seedlings used in this study may result in earlier stabilization of family mean performance.

The regression coefficients between seedling size at age two to survival and height at age three were strongest for plantations that did not have significant deer damage, i.e., Cheoah (13), and Wayah (14) plantations. In the absence of severe damage, seedling height growth in a given year can be positively related to seedling height growth in the following year. For individual trees, second year height had a stronger relationship with three year height than with three year survival, again indicating that survival is more related to factors such as damage or planting shock than by seedling size.

Application to field plantings

Unfortunately, damage at each plantation was subjectively recorded according to an individual's recorder's ability to detect and interpret damage to each seedling. This type of damage assessment limited the ability to analyze damage and its effects on seedling performance. Personal communication with plantation supervisors and with personnel who collected data provided the most meaningful assessment on damage at

each plantation, as opposed to data collected in the field. To improve the usefulness of damage data, the same person should record damage at all plantations or all personnel should receive the same field training on identification of the various types of damage.

The production of large oak seedling under optimal conditions for growth, followed by grading for quality, has been recommended to improve growth performance in field plantings (Foster and Farmer 1970, Johnson 1981, Kaczmarek and Pope 1993, Kormanik *et al.* 1995, Schultz and Thompson 1990). However, the graded seedlings at seven plantations in this study, Ames (1), Pennyrile (5), Somerset (6), Oconee (11), Long Cane (12), Glenwood (17), and Deerfield (18), were not able to recover from various forms of damage. From an economic standpoint, the resources used to produce such high quality graded oak seedlings were substantial when compared to production of ungraded smaller nursery stock, and were not recovered.

Protection of the seedlings' terminal leader from animal or insect damage is critical until seedlings can attain heights above browse level (~1.5 m). Damage to the terminal leader from deer browse promotes lateral, as opposed to terminal growth, and predisposes the seedling for repeated browsing in subsequent growing seasons. Repeated browse damage to seedlings will eventually increase management costs by lengthening the time needed to obtain sufficient seedling size for successful field establishment. Protection from deer and competition control, however, can be expensive, and costs increase with the time needed to achieve sufficient seedling height, i.e., $\geq$ 1.5 m. The use of faster-growing, quality-graded nursery stock, can reduce establishment costs associated with protection and competition control. Individual seedlings at the

Nolichucky (3), Watauga (4), and Wayah (14) plantations that have escaped damage attained third-year heights of 3+ meters, with the terminal leader safely above deer browse level and successfully competing with surrounding vegetation.

Collectively, the establishment of eighteen northern red oak genetic plantations using nursery graded seedlings was the largest study of its kind in the United States. Future trends in survival and growth of various provenances and families will be monitored and the feasibility of planting high quality, graded oak seedlings in different geographic areas and site conditions will be examined in the forthcoming years.

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Appendix

Table 1A. Northern red oak genetic material collected from the Watauga seedling seed orchard, Cherokee National Forest, Tennessee, and bulked and sown at the Georgia Forestry Commission's Flint River Nursery in Montezuma, Georgia and the North Carolina Division of Forest Resource's Ralph Edwards State Nursery in Morganton, North Carolina.

Orchard family number	Origin of orchard parent tree (county and state)	Percentage of bulked seed sown at Georgia State Nursery	Percentage of bulked seed sown at North Carolina Nursery
24597122	Claiborne, TN	0	6.28%
2471329	Henderson, TN	1.67%	0
247275	Henderson, TN	3.00%	0
32334	Trigg, KY	7.00%	3.31%
323726	Trigg, KY	5.00%	4.96%
33088	Trigg, KY	6.00%	0
501613	Union, TN	0	0.33%
50936	Anderson, TN	0	1.32%
510712	Anderson, TN	0	1.32%
516327	Campbell, TN	0	1.98%
522215	Campbell, TN	0	4.13%
52633	Morgan, TN	3.33%	3.31%
526411	Morgan, TN	0	0.66%
526892	Morgan, TN	0	0.33%
528216	Morgan, TN	0	0.17%
5403351	Union, TN	2.33%	0
5403352	Union, TN	0	2.98%
540520	Union, TN	0	3.31%
55067	Campbell, TN	0	3.31%
550811	Campbell, TN	1.67%	1.65%
55879	Campbell, TN	3.50%	0
565333	Grundy, TN	10.00%	0
584819	Claiborne, TN	0	1.32%
595619	Van Buren, TN	0.17%	0
626612	Campbell, TN	5.00%	0
630619	Campbell, TN	2.33%	0
637312	Union, TN	0	5.95%
701511	Anderson, TN	1.33%	0
70285	Anderson, TN	0	2.64%
70532	Anderson, TN	0	3.14%
715612	Campbell, TN	2.00%	0
716621	Campbell, TN	0	3.31%
718725	Campbell, TN	0	0.99%
735121	Campbell, TN	2.00%	0
73526	Campbell, TN	0	4.96%
7353201	Campbell, TN	0	2.64%
7353202	Campbell, TN	0	4.30%
735411	Campbell, TN	0	7.27%

Orchard family number	Origin of orchard parent tree (county and state)	Percentage of bulked seed sown at Georgia State Nursery	Percentage of bulked seed sown at North Carolina Nursery
735520	Campbell, TN	0	3.97%
88244	Madison, AL	2.33%	0
8826172	Madison, AL	4.00%	0
882712	Madison, AL	2.00%	0
889715	Madison, AL	3.67%	0
902620	Henderson, TN	14.67%	0
90285	Henderson, TN	0	1.65%
90767	Henderson, TN	0	1.65%
911617	Henderson, TN	1.33%	0
913126	Henderson, TN	5.67%	4.96%
913523	Henderson, TN	0.33%	0
91362	Henderson, TN	6.33%	6.61%
914124	Henderson, TN	1.33%	0
915214	Henderson, TN	1.33%	0
91537	Henderson, TN	0.67%	0
915713	Henderson, TN	0	5.29%

Table 2A. Fertilization applied at the North Carolina Division of Forest Resource's Morganton State Nursery, Morganton, North Carolina, and at the Georgia Forestry Commission's Flint River Nursery, Montezema, Georgia for northern red oak seedlings grown in 1996.

Nursery	Date applied	Fertilizer applied	Rate applied
North Carolina	5-02-96	Ammonium Nitrate	45 lbs/acre
North Carolina	5-14-96	Ammonium Nitrate	45 lbs/acre
North Carolina	5-24-96	Ammonium Nitrate	45 lbs/acre
North Carolina	6-05-96	Ammonium Nitrate	90 lbs/acre
North Carolina	6-18-96	Ammonium Nitrate	90 lbs/acre
North Carolina	6-28-96	Ammonium Nitrate	150 lbs/acre
North Carolina	7-10-96	Ammonium Nitrate	150 lbs/acre
North Carolina	7-22-96	Ammonium Nitrate	150 lbs/acre
North Carolina	7-24-96	K-Mag	224 lbs/acre
North Carolina	7-31-96	Ammonium Nitrate	150 lbs/acre
North Carolina	8-9-96	Ammonium Nitrate	165 lbs/acre
North Carolina	8-20-96	Ammonium Nitrate	150 lbs/acre
North Carolina	9-12-96	Ammonium Nitrate	150 lbs/acre
Georgia	5-13-96	Ammonium Nitrate	50 lbs/acre
Georgia	5-24-96	Ammonium Nitrate	75 lbs/acre
Georgia	6-03-96	Ammonium Nitrate	75 lbs/acre
Georgia	6-13-96	Ammonium Nitrate	75 lbs/acre
Georgia	6-21-96	Ammonium Nitrate	135 lbs/acre
Georgia	7-01-96	Ammonium Nitrate	135 lbs/acre
Georgia	7-09-96	Ammonium Nitrate	135 lbs/acre
Georgia	7-17-96	Ammonium Nitrate	135 lbs/acre
Georgia	7-24-96	Dap 18-46-0	150 lbs/acre
Georgia	8-05-96	Dap 18-46-0	150 lbs/acre
Georgia	8-14-96	Ammonium Nitrate	150 lbs/acre

Table 3A. Parent tree information for progeny collected from 38 genetic fam in the Watauga seedling seed orchard, Cherokee National Forest, Tennessee and grown at the East Tennessee State Nursery, Delano, Tennessee.

Orchard Tree Number	County and State	Latitude	Longitude	Elevation	Provenance
100110	Wise, VA	36°52'	82°45'	1500	1
100427	Wise, VA	36°52'	82°45'	1500	1
100610	Wise, VA	36°52'	82°45'	1500	1
2006141	Limestone, AL	34°55'	86°55'	700	3
2006142	Limestone, AL	34°55'	86°55'	700	3
2459214	Claiborne, TN	36°20'	83°35'	1200	3
2459414	Claiborne, TN	36°20'	83°35'	1200	3
323726	Trigg, KY	36°30'	85°00'	500	3
329616	Trigg, KY	36°30'	85°00'	500	3
330231	Trigg, KY	36°30'	85°00'	500	3
510615	Anderson, TN	36°13'	84°05'	1100	1
540210	Union, TN	36°19'	83°53'	1100	1
576324	Marian, TN	35°10'	86°45'	1700	2
584224	Claiborne, TN	36°20'	83°35'	1100	1
584715	Claiborne, TN	36°20'	83°35'	1100	1
595619	Van Buren, TN	35°45'	85°23'	1300	3
70477	Anderson, TN	36°13'	84°05'	1100	1
716621	Campbell, TN	36°16'	84°10'	1200	1
726720	Franklin, TN	35°12'	86°03'	1500	3
7353202	Campbell, TN	36°15'	84°08'	1200	1
850821	Overton, TN	36°20'	85°25'	1000	3
856619	Overton, TN	36°20'	85°25'	1000	3
878231	Madison, AL	34°45'	86°30'	1500	3
88226	Madison, AL	34°45'	86°30'	1500	3
88244	Madison, AL	34°45'	86°30'	1500	3
8826172	Madison, AL	34°45'	86°30'	1500	3
885315	Madison, AL	34°45'	86°30'	1500	3
885615	Madison, AL	34°45'	86°30'	1500	3
902333	Henderson, TN	35°43'	88°17'	500	4
90312	Henderson, TN	35°43'	88°17'	500	4
90368	Henderson, TN	35°43'	88°17'	500	4
905522	Henderson, TN	35°43'	88°17'	500	4
906228	Henderson, TN	35°43'	88°17'	500	4
90767	Henderson, TN	35°43'	88°17'	500	4
911617	Henderson, TN	35°43'	88°17'	500	4
913126	Henderson, TN	35°43'	88°17'	500	4
91362	Henderson, TN	35°43'	88°17'	500	4
915114	Henderson, TN	35°43'	88°17'	500	4

Table 4A. Fertilization applied at the Tennessee Division of Forestry's East Tennessee Nursery, Delano, Tennessee for northern red oak seedlings grown in 1996.

Date Applied	Fertilizer Applied	Rate Applied
5-21-96	Ammonium nitrate	150 lbs/acre
6-10-96	Ammonium nitrate	150 lbs/acre
6-21-96	Ammonium nitrate	150 lbs/acre
7-02-96	Ammonium nitrate	150 lbs/acre
7-17-96	Ammonium nitrate	150 lbs/acre
7-31-96	Ammonium nitrate	150 lbs/acre
8-08-96	Ammonium nitrate	150 lbs/acre
8-19-96	Ammonium nitrate	150 lbs/acre
9-06-96	K-Mag	200 lbs/acre
9-11-96	So-Po-Mag	200 lbs/acre

Table 5A. Parent tree information for progeny collected from 73 genetic famili in the Watauga seedling seed orchard, Cherokee National Forest, Tennessee, and planted in genetic tests at 18 locations in the southeastern United States.

Orchard Family Number	County and State	Latitude	Longitude	Elevation	Provenance
1001101	Wise, VA	36° 52'	82° 45'	1500	1
1004271	Wise, VA	36° 52'	82° 45'	1500	1
1007121	Wise, VA	36° 52'	82° 45'	1500	1
200271	Limeston, AL	34° 55'	86° 55'	700	3
2006141	Limeston, AL	34° 55'	86° 55'	700	3
2419661	Buncombe, NC	35° 28'	82° 42'	3000	5
2451151	Anderson, TN	36° 10'	84° 05'	1000	1
24512111	Anderson, TN	36° 10'	84° 05'	1000	1
24515131	Anderson, TN	36° 10'	84° 05'	1000	1
24517331	Anderson, TN	36° 10'	84° 05'	1000	1
24592281	Claiborne, TN	36° 20'	83° 35'	1200	1
24594141	Claiborne, TN	36° 20'	83° 35'	1200	1
24597122	Claiborne, TN	36° 20'	83° 35'	1200	1
25492141	Claiborne, TN	36° 20'	83° 35'	1200	1
323341	Trigg, KY	36° 50'	88° 00'	500	3
3237261	Trigg, KY	36° 50'	88° 00'	500	3
4075181	Pickett, TN	36° 30'	85° 00'	1500	2
5003331	Union, TN	36° 17'	83° 59'	1200	1
5071101	Union, TN	36° 19'	83° 45'	1400	1
5264112	Morgan, TN	36° 08'	84° 28'	2000	1
5267141	Morgan, TN	36° 08'	84° 28'	2000	1
5302101	Morgan, TN	36° 08'	84° 28'	2000	1
530321	Morgan, TN	36° 08'	84° 28'	2000	1
5402101	Union, TN	36° 19'	83° 53'	1100	1
550671	Campbell, TN	36° 17'	84° 03'	1100	1
5508111	Campbell, TN	36° 17'	84° 03'	1100	1
5653331	Grundy, TN	35° 27'	85° 35'	1500	2
565451	Grundy, TN	35° 27'	85° 35'	1500	2
5714101	Grundy, TN	35° 27'	85° 35'	1500	2
5764171	Marian, TN	35° 10'	86° 45'	1700	2
5824171	Claiborne, TN	36° 20'	83° 35'	1200	1
5842241	Claiborne, TN	36° 20'	83° 35'	1100	1
5848191	Claiborne, TN	36° 20'	83° 35'	1100	1
6004151	Buncombe, NC	35° 42'	82° 22'	3500	5
6022191	Buncombe, NC	35° 48'	82° 22'	4000	5
6024201	Buncombe, NC	35° 48'	82° 22'	4000	5
602591	Buncombe, NC	35° 48'	82° 22'	4000	5
6027121	Buncombe, NC	35° 48'	82° 22'	4000	5
6057151	Buncombe, NC	35° 58'	82° 08'	3500	5
6088151	Buncombe, NC	35° 28'	82° 42'	3000	5
6134241	Transylvania, NC	35° 10'	82° 58'	3500	5
6171151	Monroe, TN	35° 35'	84° 15'	800	5
6243191	Transylvania, NC	35° 10'	82° 58'	3500	5

Orchard Family Number	County and State	Latitude	Longitude	Elevation	Provenance
6254121	Henderson, NC	35° 28'	82° 17'	2500	5
6258171	Henderson, NC	35° 28'	82° 17'	2500	5
630191	Campbell, TN	36° 18'	84° 01'	1200	1
6302191	Campbell, TN	36° 18'	84° 01'	1200	1
630891	Campbell, TN	36° 18'	84° 01'	1200	1
7015112	Anderson, TN	36° 05'	84° 10'	1000	1
7055161	Anderson, TN	36° 00'	84° 10'	1000	1
7166211	Campbell, TN	36° 16'	84° 10'	1200	1
728251	Franklin, TN	35° 12'	86° 03'	1500	3
728711	Franklin, TN	35° 12'	86° 03'	1500	3
7351211	Campbell, TN	36° 15'	84° 08'	1200	1
7354111	Campbell, TN	36° 15'	84° 08'	1200	1
7355201	Campbell, TN	36° 15'	84° 08'	1200	1
8502231	Overton, TN	36° 20'	85° 25'	1000	3
8508211	Overton, TN	36° 20'	85° 25'	1000	3
8827121	Madison, AL	34° 45'	86° 30'	1500	3
895521	Washington, VA	36° 42'	81° 58'	2100	7
896671	Washington, VA	36° 42'	81° 58'	2100	7
902421	Henderson, TN	35° 43'	88° 17'	500	4
903121	Henderson, TN	35° 43'	88° 17'	500	4
903541	Henderson, TN	35° 43'	88° 17'	500	4
903681	Henderson, TN	35° 43'	88° 17'	500	4
903721	Henderson, TN	35° 43'	88° 17'	500	4
9053241	Henderson, TN	35° 43'	88° 17'	500	4
9054271	Henderson, TN	35° 43'	88° 17'	500	4
9055221	Henderson, TN	35° 43'	88° 17'	500	4
9118121	Henderson, TN	35° 43'	88° 17'	500	4
913621	Henderson, TN	35° 43'	88° 17'	500	4
9151141	Henderson, TN	35° 43'	88° 17'	500	4
9154121	Henderson, TN	35° 43'	88° 17'	500	4

Table 6A. Relative three year survival and height (expressed as a percentage of the plantation mean and combined mean) of families at each plantation an for combined data.

*** Data not taken**

- Family not represented at plantation

Plantation	Ames (1)					Hiwassee (2)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	*	*	*	*	*	-	-	-	-	-
417	*	*	*	*	*	111	114	103	115	119
418	*	*	*	*	*	-	-	-	-	-
419	*	*	*	*	*	-	-	-	-	-
420	*	*	*	*	*	-	-	-	-	-
421	*	*	*	*	*	-	-	-	-	-
422	*	*	*	*	*	69	68	101	87	93
423	*	*	*	*	*	-	-	-	-	-
424	*	*	*	*	*	-	-	-	-	-
425	*	*	*	*	*	-	-	-	-	-
426	*	*	*	*	*	-	-	-	-	-
427	*	*	*	*	*	-	-	-	-	-
428	*	*	*	*	*	-	-	-	-	-
429	*	*	*	*	*	-	-	-	-	-
430	*	*	*	*	*	-	-	-	-	-
431	*	*	*	*	*	-	-	-	-	-
432	*	*	*	*	*	116	117	97	92	95
433	*	*	*	*	*	-	-	-	-	-
434	*	*	*	*	*	-	-	-	-	-
435	*	*	*	*	*	-	-	-	-	-
436	*	*	*	*	*	100	90	99	86	88
437	*	*	*	*	*	87	92	103	110	108
438	*	*	*	*	*	-	-	-	-	-
439	*	*	*	*	*	-	-	-	-	-
440	*	*	*	*	*	-	-	-	-	-
441	*	*	*	*	*	-	-	-	-	-
442	*	*	*	*	*	-	-	-	-	-
443	*	*	*	*	*	-	-	-	-	-
444	*	*	*	*	*	-	-	-	-	-
445	*	*	*	*	*	96	102	101	108	97
446	*	*	*	*	*	-	-	-	-	-
447	*	*	*	*	*	-	-	-	-	-
448	*	*	*	*	*	92	108	100	95	89

Plantation	Ames (1)					Hiwassee (2)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
449	*	*	*	*	*	97	99	95	87	78
450	*	*	*	*	*	107	99	101	87	92
451	*	*	*	*	*	-	-	-	-	-
452	*	*	*	*	*	-	-	-	-	-
453	*	*	*	*	*	110	102	91	82	81
454	*	*	*	*	*	112	115	103	118	114
455	*	*	*	*	*	110	120	100	112	108
456	*	*	*	*	*	-	-	-	-	-
457	*	*	*	*	*	-	-	-	-	-
458	*	*	*	*	*	-	-	-	-	-
459	*	*	*	*	*	-	-	-	-	-
460	*	*	*	*	*	-	-	-	-	-
461	*	*	*	*	*	-	-	-	-	-
462	*	*	*	*	*	-	-	-	-	-
463	*	*	*	*	*	-	-	-	-	-
464	*	*	*	*	*	-	-	-	-	-
465	*	*	*	*	*	-	-	-	-	-
466	*	*	*	*	*	-	-	-	-	-
467	*	*	*	*	*	-	-	-	-	-
468	*	*	*	*	*	-	-	-	-	-
469	*	*	*	*	*	-	-	-	-	-
470	*	*	*	*	*	90	89	101	115	114
471	*	*	*	*	*	95	92	101	92	89
472	*	*	*	*	*	84	83	99	85	89
473	*	*	*	*	*	-	-	-	-	-
474	*	*	*	*	*	-	-	-	-	-
475	*	*	*	*	*	-	-	-	-	-
476	*	*	*	*	*	112	107	101	103	111
477	*	*	*	*	*	96	95	99	100	97
478	*	*	*	*	*	84	89	97	95	100
479	*	*	*	*	*	102	99	101	97	100
480	*	*	*	*	*	-	-	-	-	-
481	*	*	*	*	*	-	-	-	-	-
482	*	*	*	*	*	-	-	-	-	-
483	*	*	*	*	*	103	102	103	115	122
484	*	*	*	*	*	-	-	-	-	-
485	*	*	*	*	*	77	81	103	110	116
486	*	*	*	*	*	117	116	97	95	95
487	*	*	*	*	*	109	96	101	108	103
488	*	*	*	*	*	94	83	99	85	92

Plantation	Nolichucky (3)					Watauga (4)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	-	-	-	-	-	*	-	-	*	-
417	-	-	-	-	-	*	113	109	*	109
418	-	-	-	-	-	*	103	111	*	102
419	103	107	108	98	100	*	-	-	*	-
420	-	-	-	-	-	*	109	89	*	84
421	-	-	-	-	-	*	-	-	*	-
422	88	97	92	100	97	*	-	-	*	-
423	-	-	-	-	-	*	80	101	*	102
424	-	-	-	-	-	*	-	-	*	-
425	-	-	-	-	-	*	-	-	*	-
426	-	-	-	-	-	*	-	-	*	-
427	81	85	97	98	85	*	-	-	*	-
428	-	-	-	-	-	*	-	-	*	-
429	99	96	95	98	90	*	-	-	*	-
430	121	114	97	95	97	*	115	91	*	84
431	-	-	-	-	-	*	-	-	*	-
432	-	-	-	-	-	*	-	-	*	-
433	-	-	-	-	-	*	95	101	*	98
434	-	-	-	-	-	*	98	96	*	109
435	-	-	-	-	-	*	-	-	*	-
436	-	-	-	-	-	*	76	99	*	76
437	-	-	-	-	-	*	-	-	*	-
438	-	-	-	-	-	*	-	-	*	-
439	-	-	-	-	-	*	-	-	*	-
440	-	-	-	-	-	*	-	-	*	-
441	98	100	105	112	110	*	-	-	*	-
442	-	-	-	-	-	*	-	-	*	-
443	-	-	-	-	-	*	-	-	*	-
444	-	-	-	-	-	*	-	-	*	-
445	-	-	-	-	-	*	-	-	*	-
446	88	90	103	88	95	*	83	114	*	89
447	-	-	-	-	-	*	94	106	*	102
448	-	-	-	-	-	*	80	94	*	116
449	93	98	97	90	92	*	-	-	*	-
450	110	106	103	114	118	*	-	-	*	-
451	-	-	-	-	-	*	-	-	*	-
452	-	-	-	-	-	*	105	101	*	113
453	99	93	103	107	108	*	102	81	*	91
454	-	-	-	-	-	*	102	94	*	84
455	115	123	99	100	108	*	107	114	*	127
456	114	119	97	95	97	*	-	-	*	-
457	-	-	-	-	-	*	-	-	*	-
458	103	99	90	86	85	*	64	-	*	-
459	105	97	105	110	115	*	-	-	*	-
460	-	-	-	-	-	*	-	-	*	-
461	96	97	105	107	110	*	-	-	*	-
462	-	-	-	-	-	*	-	-	*	-
463	-	-	-	-	-	*	-	-	*	-

Plantation	Nolichucky (3)					Watauga (4)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	-	-	-	-	-	*	-	-	*	-
465	-	-	-	-	-	*	104	86	*	91
466	-	-	-	-	-	*	-	-	*	-
467	98	96	99	95	105	*	111	104	*	98
468	86	91	90	102	97	*	-	-	*	-
469	-	-	-	-	-	*	-	-	*	-
470	91	88	101	105	108	*	83	94	*	87
471	-	-	-	-	-	*	99	106	*	91
472	91	94	101	102	105	*	113	91	*	109
473	115	113	101	98	97	*	86	104	*	127
474	-	-	-	-	-	*	-	-	*	-
475	-	-	-	-	-	*	-	-	*	-
476	-	-	-	-	-	*	107	106	*	95
477	-	-	-	-	-	*	101	104	*	98
478	-	-	-	-	-	*	-	-	*	-
479	-	-	-	-	-	*	-	-	*	-
480	-	-	-	-	-	*	101	104	*	120
481	-	-	-	-	-	*	-	-	*	-
482	118	107	101	110	115	*	-	-	*	-
483	116	110	101	102	103	*	-	-	*	-
484	-	-	-	-	-	*	104	86	*	84
485	81	81	95	81	87	*	-	-	*	-
486	100	99	99	105	103	*	-	-	*	-
487	-	-	-	-	-	*	-	-	*	-
488	89	93	103	107	97	*	-	-	*	-

Plantation	Pennyroyl (5)					Somerset (6)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	102	*	*	74	*	*	-	-	*	-
417	-	*	*	-	*	*	-	-	*	-
418	-	*	*	-	*	*	-	-	*	-
419	-	*	*	-	*	*	-	-	*	-
420	-	*	*	-	*	*	-	-	*	-
421	-	*	*	-	*	*	-	-	*	-
422	78	*	*	98	*	*	-	-	*	-
423	-	*	*	-	*	*	-	-	*	-
424	-	*	*	-	*	*	96	80	*	86
425	106	*	*	93	*	*	114	101	*	94
426	-	*	*	-	*	*	97	107	*	117
427	95	*	*	89	*	*	73	105	*	100
428	91	*	*	98	*	*	-	-	*	-
429	-	*	*	-	*	*	108	98	*	89
430	-	*	*	-	*	*	-	-	*	-
431	-	*	*	-	*	*	-	-	*	-
432	-	*	*	-	*	*	-	-	*	-
433	-	*	*	-	*	*	-	-	*	-
434	-	*	*	-	*	*	-	-	*	-
435	-	*	*	-	*	*	99	100	*	94
436	95	*	*	59	*	*	-	-	*	-
437	94	*	*	137	*	*	-	-	*	-
438	-	*	*	-	*	*	-	-	*	-
439	-	*	*	-	*	*	-	-	*	-
440	-	*	*	-	*	*	-	-	*	-
441	-	*	*	-	*	*	106	99	*	108
442	-	*	*	-	*	*	91	101	*	108
443	101	*	*	89	*	*	105	107	*	133
444	98	*	*	91	*	*	-	-	*	-
445	101	*	*	87	*	*	-	-	*	-
446	89	*	*	109	*	*	-	-	*	-
447	84	*	*	91	*	*	105	-	*	-
448	-	*	*	-	*	*	-	-	*	-
449	99	*	*	100	*	*	96	98	*	64
450	121	*	*	107	*	*	109	96	*	89
451	-	*	*	-	*	*	92	96	*	56
452	112	*	*	133	*	*	-	-	*	-
453	-	*	*	-	*	*	-	-	*	-
454	-	*	*	-	*	*	100	-	*	-
455	-	*	*	-	*	*	132	103	*	128
456	-	*	*	-	*	*	-	-	*	-
457	-	*	*	-	*	*	-	-	*	-
458	-	*	*	-	*	*	-	-	*	-
459	-	*	*	-	*	*	-	-	*	-
460	-	*	*	-	*	*	118	97	*	114
461	93	*	*	126	*	*	-	-	*	-
462	-	*	*	-	*	*	104	105	*	94
463	94	*	*	137	*	*	96	95	*	83

Plantation	Pennyroyl (5)					Somerset (6)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	96	*	*	67	*	*	82	98	*	92
465	-	*	*	-	*	*	-	-	*	-
466	102	*	*	72	*	*	-	-	*	-
467	115	*	*	65	*	*	-	-	*	-
468	-	*	*	-	*	*	114	110	*	133
469	-	*	*	-	*	*	108	107	*	117
470	-	*	*	-	*	*	89	85	*	72
471	-	*	*	-	*	*	-	-	*	-
472	-	*	*	-	*	*	99	108	*	117
473	107	*	*	107	*	*	-	-	*	-
474	-	*	*	-	*	*	-	-	*	-
475	-	*	*	-	*	*	-	-	*	-
476	115	*	*	143	*	*	123	95	*	103
477	-	*	*	-	*	*	85	101	*	78
478	-	*	*	-	*	*	-	-	*	-
479	-	*	*	-	*	*	-	-	*	-
480	-	*	*	-	*	*	96	103	*	83
481	-	*	*	-	*	*	-	-	*	-
482	113	*	*	126	*	*	141	107	*	158
483	104	*	*	74	*	*	-	-	*	-
484	-	*	*	-	*	*	-	-	*	-
485	78	*	*	117	*	*	-	-	*	-
486	-	*	*	-	*	*	-	-	*	-
487	-	*	*	-	*	*	-	-	*	-
488	-	*	*	-	*	*	-	-	*	-

Plantation	Stanton (7)					Bankhead (8)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	113	111	105	107	105	*	*	-	*	*
417	-	-	-	-	-	*	*	-	*	*
418	-	-	-	-	-	*	*	-	*	*
419	101	104	103	107	92	*	*	116	*	*
420	94	99	99	104	101	*	*	107	*	*
421	-	-	-	-	-	*	*	117	*	*
422	90	100	95	95	92	*	*	-	*	*
423	97	95	103	100	106	*	*	-	*	*
424	-	-	-	-	-	*	*	-	*	*
425	-	-	-	-	-	*	*	99	*	*
426	104	99	93	97	98	*	*	98	*	*
427	93	97	103	104	108	*	*	-	*	*
428	-	-	-	-	-	*	*	91	*	*
429	-	-	-	-	-	*	*	56	*	*
430	-	-	-	-	-	*	*	-	*	*
431	90	88	106	104	106	*	*	-	*	*
432	119	101	108	109	102	*	*	81	*	*
433	99	102	101	100	99	*	*	-	*	*
434	101	100	91	92	90	*	*	-	*	*
435	101	98	100	101	108	*	*	-	*	*
436	90	91	101	102	101	*	*	99	*	*
437	101	99	107	100	94	*	*	-	*	*
438	-	-	-	-	-	*	*	106	*	*
439	107	99	99	100	99	*	*	96	*	*
440	92	95	103	99	105	*	*	-	*	*
441	-	-	-	-	-	*	*	-	*	*
442	-	-	-	-	-	*	*	-	*	*
443	-	-	-	-	-	*	*	-	*	*
444	-	-	-	-	-	*	*	-	*	*
445	-	-	-	-	-	*	*	111	*	*
446	-	-	-	-	-	*	*	119	*	*
447	-	-	-	-	-	*	*	-	*	*
448	-	-	-	-	-	*	*	-	*	*
449	101	102	105	107	108	*	*	87	*	*
450	106	106	98	102	106	*	*	-	*	*
451	103	105	97	96	94	*	*	108	*	*
452	-	-	-	-	-	*	*	-	*	*
453	-	-	-	-	-	*	*	-	*	*
454	-	-	-	-	-	*	*	-	*	*
455	110	104	99	101	110	*	*	-	*	*
456	-	-	-	-		*	*	-	*	*
457	103	105	95	96	90	*	*	-	*	*
458	-	-	-	-	-	*	*	-	*	*
459	-	-	-	-	-	*	*	-	*	*
460	-	-	-	-	-	*	*	-	*	*
461	-	-	-	-	-	*	*	98	*	*
462	-	-	-	-	-	*	*	87	*	*
463	-	-	-	-	-	*	*	124	*	*

Plantation	Stanton (7)					Bankhead (8)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	-	-	-	-	-	*	*	-	*	*
465	-	-	-	-	-	*	*	-	*	*
466	86	85	102	98	106	*	*	-	*	*
467	-	-	-	-	-	*	*	-	*	*
468	-	-	-	-	-	*	*	-	*	*
469	94	94	107	107	106	*	*	-	*	*
470	-	-	-	-	-	*	*	105	*	*
471	-	-	-	-	-	*	*	-	*	*
472	-	-	-	-	-	*	*	-	*	*
473	-	-	-	-	-	*	*	-	*	*
474	-	-	-	-	-	*	*	89	*	*
475	-	-	-	-	-	*	*	-	*	*
476	-	-	-	-	-	*	*	103	*	*
477	102	100	80	83	76	*	*	-	*	*
478	-	-	-	-	-	*	*	-	*	*
479	-	-	-	-	-	*	*	-	*	*
480	-	-	-	-	-	*	*	81	*	*
481	-	-	-	-	-	*	*	-	*	*
482	-	-	-	-	-	*	*	-	*	*
483	-	-	-	-	-	*	*	-	*	*
484	107	100	101	104	101	*	*	95	*	*
485	-	-	-	-	-	*	*	107	*	*
486	-	-	-	-	-	*	*	-	*	*
487	-	-	-	-	-	*	*	91	*	*
488	-	-	-	-	-	*	*	-	*	*

Plantation	Shoal Creek (9)					Brasstown (10)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	101	98	103	86	88	-	-	-	-	-
417	-	-	-	-	-	-	-	-	-	-
418	111	114	109	135	136	-	-	-	-	-
419	105	103	107	120	115	96	103	101	108	109
420	-	-	-	-	-	90	89	102	89	89
421	-	-	-	-	-	110	108	100	101	99
422	-	-	-	-	-	-	-	-	-	-
423	99	90	97	102	112	91	95	100	99	96
424	-	-	-	-	-	-	-	-	-	-
425	-	-	-	-	-	-	-	-	-	-
426	-	-	-	-	-	-	-	-	-	-
427	-	-	-	-	-	-	-	-	-	-
428	-	-	-	-	-	-	-	-	-	-
429	-	-	-	-	-	-	-	-	-	-
430	-	-	-	-	-	-	-	-	-	-
431	-	-	-	-	-	-	-	-	-	-
432	-	-	-	-	-	-	-	-	-	-
433	92	94	106	126	115	-	-	-	-	-
434	-	-	-	-	-	-	-	-	-	-
435	-	-	-	-	-	96	95	95	92	91
436	-	-	-	-	-	-	-	-	-	-
437	102	100	100	123	115	91	91	98	104	106
438	-	-	-	-	-	95	104	103	111	96
439	116	108	89	92	88	111	106	100	106	111
440	86	85	108	111	112	-	-	-	-	-
441	99	100	95	102	92	94	101	100	104	109
442	-	-	-	-	-	105	108	104	106	111
443	103	106	96	106	105	103	102	99	106	104
444	-	-	-	-	-	-	-	-	-	-
445	-	-	-	-	-	-	-	-	-	-
446	-	-	-	-	-	-	-	-	-	-
447	93	91	99	98	112	-	-	-	-	-
448	-	-	-	-	-	86	90	103	96	94
449	-	-	-	-	-	-	-	-	-	-
450	-	-	-	-	-	113	110	99	94	86
451	-	-	-	-	-	104	103	100	104	106
452	-	-	-	-	-	-	-	-	-	-
453	-	-	-	-	-	-	-	-	-	-
454	-	-	-	-	-	-	-	-	-	-
455	-	-	-	-	-	-	-	-	-	-
456	-	-	-	-	-	-	-	-	-	-
457	-	-	-	-	-	-	-	-	-	-
458	-	-	-	-	-	-	-	-	-	-
459	-	-	-	-	-	101	93	101	92	89
460	-	-	-	-	-	-	-	-	-	-
461	-	-	-	-	-	-	-	-	-	-
462	96	98	108	111	125	-	-	-	-	-
463	98	93	110	111	112	-	-	-	-	-

Plantation	Shoal Creek (9)					Brasstown (10)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	88	93	101	111	105	-	-	-	-	-
465	118	115	90	80	75	-	-	-	-	-
466	87	92	100	102	102	-	-	-	-	-
467	114	114	102	77	81	-	-	-	-	-
468	-	-	-	-	-	93	86	103	104	109
469	-	-	-	-	-	93	82	95	101	111
470	97	100	103	98	105	-	-	-	-	-
471	-	-	-	-	-	-	-	-	-	-
472	-	-	-	-	-	-	-	-	-	-
473	-	-	-	-	-	107	113	95	87	78
474	111	111	102	89	92	103	105	102	99	91
475	87	91	96	69	64	-	-	-	-	-
476	-	-	-	-	-	-	-	-	-	-
477	107	110	86	80	75	-	-	-	-	-
478	82	76	100	108	98	-	-	-	-	-
479	-	-	-	-	-	114	113	100	89	94
480	-	-	-	-	-	97	92	105	101	96
481	-	-	-	-	-	88	88	99	106	114
482	-	-	-	-	-	117	115	101	108	111
483	-	-	-	-	-	113	108	100	94	99
484	-	-	-	-	-	98	91	97	101	101
485	-	-	-	-	-	-	-	-	-	-
486	108	111	99	108	98	-	-	-	-	-
487	113	100	94	74	85	-	-	-	-	-
488	82	90	96	86	78	-	-	-	-	-

Plantation	Oconee (11)					Long Cane (12)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	*	*	*	*	*	*	*	82	*	*
417	*	*	*	*	*	*	*	-	*	*
418	*	*	*	*	*	*	*	-	*	*
419	*	*	*	*	*	*	*	-	*	*
420	*	*	*	*	*	*	*	-	*	*
421	*	*	*	*	*	*	*	-	*	*
422	*	*	*	*	*	*	*	-	*	*
423	*	*	*	*	*	*	*	-	*	*
424	*	*	*	*	*	*	*	-	*	*
425	*	*	*	*	*	*	*	-	*	*
426	*	*	*	*	*	*	*	-	*	*
427	*	*	*	*	*	*	*	-	*	*
428	*	*	*	*	*	*	*	71	*	*
429	*	*	*	*	*	*	*	-	*	*
430	*	*	*	*	*	*	*	-	*	*
431	*	*	*	*	*	*	*	85	*	*
432	*	*	*	*	*	*	*	74	*	*
433	*	*	*	*	*	*	*	-	*	*
434	*	*	*	*	*	*	*	-	*	*
435	*	*	*	*	*	*	*	-	*	*
436	*	*	*	*	*	*	*	-	*	*
437	*	*	*	*	*	*	*	-	*	*
438	*	*	*	*	*	*	*	126	*	*
439	*	*	*	*	*	*	*	91	*	*
440	*	*	*	*	*	*	*	-	*	*
441	*	*	*	*	*	*	*	-	*	*
442	*	*	*	*	*	*	*	-	*	*
443	*	*	*	*	*	*	*	-	*	*
444	*	*	*	*	*	*	*	91	*	*
445	*	*	*	*	*	*	*	-	*	*
446	*	*	*	*	*	*	*	-	*	*
447	*	*	*	*	*	*	*	103	*	*
448	*	*	*	*	*	*	*	-	*	*
449	*	*	*	*	*	*	*	-	*	*
450	*	*	*	*	*	*	*	76	*	*
451	*	*	*	*	*	*	*	-	*	*
452	*	*	*	*	*	*	*	88	*	*
453	*	*	*	*	*	*	*	74	*	*
454	*	*	*	*	*	*	*	-	*	*
455	*	*	*	*	*	*	*	103	*	*
456	*	*	*	*	*	*	*	100	*	*
457	*	*	*	*	*	*	*	-	*	*
458	*	*	*	*	*	*	*	-	*	*
459	*	*	*	*	*	*	*	100	*	*
460	*	*	*	*	*	*	*	-	*	*
461	*	*	*	*	*	*	*	-	*	*
462	*	*	*	*	*	*	*	97	*	*
463	*	*	*	*	*	*	*	91	*	*

Plantation	Oconee (11)					Long Cane (12)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	*	*	*	*	*	*	*	92	*	*
465	*	*	*	*	*	*	*	-	*	*
466	*	*	*	*	*	*	*	-	*	*
467	*	*	*	*	*	*	*	-	*	*
468	*	*	*	*	*	*	*	-	*	*
469	*	*	*	*	*	*	*	-	*	*
470	*	*	*	*	*	*	*	-	*	*
471	*	*	*	*	*	*	*	-	*	*
472	*	*	*	*	*	*	*	-	*	*
473	*	*	*	*	*	*	*	112	*	*
474	*	*	*	*	*	*	*	109	*	*
475	*	*	*	*	*	*	*	88	*	*
476	*	*	*	*	*	*	*	-	*	*
477	*	*	*	*	*	*	*	-	*	*
478	*	*	*	*	*	*	*	-	*	*
479	*	*	*	*	*	*	*	94	*	*
480	*	*	*	*	*	*	*	79	*	*
481	*	*	*	*	*	*	*	-	*	*
482	*	*	*	*	*	*	*	91	*	*
483	*	*	*	*	*	*	*	-	*	*
484	*	*	*	*	*	*	*	88	*	*
485	*	*	*	*	*	*	*	135	*	*
486	*	*	*	*	*	*	*	-	*	*
487	*	*	*	*	*	*	*	-	*	*
488	*	*	*	*	*	*	*	-	*	*

Plantation	Cheoah (13)					Wayah (14)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	111	116	100	101	102	-	-	-	-	-
417	111	111	100	103	104	111	123	103	114	118
418	106	112	100	103	104	-	-	-	-	-
419	97	101	100	99	100	-	-	-	-	-
420	97	101	100	103	104	-	-	-	-	-
421	101	99	100	103	102	-	-	-	-	-
422	-	-	-	-	-	-	-	-	-	-
423	-	-	-	-	-	-	-	-	-	-
424	110	103	100	103	102	108	106	108	108	121
425	92	96	100	103	98	-	-	-	-	-
426	-	-	-	-	-	94	91	103	96	92
427	87	93	100	101	102	-	-	-	-	-
428	93	101	100	103	102	-	-	-	-	-
429	-	-	-	-	-	103	100	108	92	88
430	-	-	-	-	-	100	95	106	109	113
431	-	-	-	-	-	77	87	101	114	111
432	114	107	100	103	104	-	-	-	-	-
433	-	-	-	-	-	101	103	100	91	87
434	-	-	-	-	-	95	93	105	104	96
435	-	-	-	-	-	94	93	104	96	103
436	-	-	-	-	-	-	-	-	-	-
437	-	-	-	-	-	-	-	-	-	-
438	-	-	-	-	-	98	102	107	109	113
439	-	-	-	-	-	115	105	102	96	100
440	-	-	-	-	-	87	87	100	104	96
441	-	-	-	-	-	-	-	-	-	-
442	-	-	-	-	-	115	108	102	115	114
443	-	-	-	-	-	112	104	92	96	100
444	-	-	-	-	-	-	-	-	-	-
445	-	-	-	-	-	-	-	-	-	-
446	-	-	-	-	-	-	-	-	-	-
447	-	-	-	-	-	-	-	-	-	-
448	-	-	-	-	-	91	98	100	104	103
449	-	-	-	-	-	-	-	-	-	-
450	108	99	100	101	102	-	-	-	-	-
451	-	-	-	-	-	-	-	-	-	-
452	-	-	-	-	-	108	100	99	85	82
453	107	107	100	96	97	-	-	-	-	-
454	-	-	-		-	-	-	-	-	-
455	-	-	-	-	-	-	-	-	-	-
456	106	101	100	105	104	-	-	-	-	-
457	87	88	100	105	104	-	-	-	-	-
458	-	-	-	-	-	100	101	97	104	95
459	103	99	100	99	100	-	-	-	-	-
460	99	100	100	99	102	-	-	-	-	-
461	-	-	-	-	-	-	-	-	-	-
462	-	-	-	-	-	-	-	-	-	-
463	-	-	-	-	-	-	-	-	-	-

Plantation	Cheoah (13)					Wayah (14)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	-	-	-	-	-	-	-	-	-	-
465	91	94	100	93	87	105	101	91	84	71
466	87	85	100	99	98	80	83	82	84	87
467	107	105	100	95	98	99	96	101	101	116
468	94	91	100	101	102	-	-	-	-	-
469	-	-	-	-	-	-	-	-	-	-
470	-	-	-	-	-	-	-	-	-	-
471	92	87	100	103	102	-	-	-	-	-
472	-	-	-	-	-	-	-	-	-	-
473	-	-	-	-	-	103	98	107	109	105
474	-	-	-	-	-	-	-	-	-	-
475	97	101	99	88	89	-	-	-	-	-
476	-	-	-	-	-	-	-	-	-	-
477	-	-	-	-	-	-	-	-	-	-
478	84	86	100	99	98	77	99	107	109	108
479	111	110	100	101	102	121	109	98	96	100
480	-	-	-	-	-	-	-	-	-	-
481	-	-	-	-	-	-	-	-	-	-
482	-	-	-	-	-	123	113	91	85	88
483	-	-	-	-	-	-	-	-	-	-
484	-	-	-	-	-	-	-	-	-	-
485	-	-	-	-	-	77	87	85	81	84
486	-	-	-	-	-	-	-	-	-	-
487	-	-	-	-	-	-	-	-	-	-
488	-	-	-	-	-	-	-	-	-	-

Plantation	Grandfather (15)					Clinch (16)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	-	-	*	-	-	-	-	-	-	-
417	-	-	*	-	-	-	-	-	-	-
418	-	-	*	-	-	102	108	100	107	108
419	-	-	*	-	-	-	-	-	-	-
420	-	-	*	-	-	-	-	-	-	-
421	-	-	*	-	-	-	-	-	-	-
422	77	81	*	101	108	-	-	-	-	-
423	103	102	*	100	106	-	-	-	-	-
424	112	110	*	96	102	100	103	100	89	83
425	92	89	*	98	104	84	86	100	104	106
426	95	91	*	85	91	-	-	-	-	-
427	-	-	*	-	-	92	91	100	102	103
428	87	91	*	98	104	-	-	-	-	-
429	-	-	*	-	-	-	-	-	-	-
430	-	-	*	-	-	-	-	-	-	-
431	97	101	*	104	111	99	96	100	108	111
432	110	112	*	97	103	118	121	100	97	91
433	94	89	*	106	113	-	-	-	-	-
434	-	-	*	-	-	-	-	-	-	-
435	79	77	*	85	91	-	-	-	-	-
436	-	-	*	-	-	85	82	100	85	88
437	-	-	*	-	-	-	-	-	-	-
438	-	-	*	-	-	99	99	100	109	110
439	-	-	*	-	-	-	-	-	-	-
440	-	-	*	-	-	-	-	-	-	-
441	105	104	*	102	109	-	-	-	-	-
442	108	105	*	102	109	-	-	-	-	-
443	105	106	*	104	111	-	-	-	-	-
444	-	-	*	-	-	97	94	100	102	103
445	96	95	*	102	109	-	-	-	-	-
446	91	94	*	106	113	-	-	-	-	-
447	83	89	*	102	109	-	-	-	-	-
448	-	-	*	-	-	-	-	-	-	-
449	-	-	*	-	-	96	94	100	93	88
450	111	110	*	102	109	112	109	100	98	103
451	-	-	*	-	-	113	112	100	104	108
452	-	-	*	-	-	103	101	100	107	106
453	-	-	*	-	-	-	-	-	-	-
454	-	-	*	-	-	-	-	-	-	-
455	115	112	*	102	109	-	-	-	-	-
456	114	110	*	100	106	-	-	-	-	-
457	-	-	*	-	-	-	-	-	-	-
458	-	-	*	-	-	-	-	-	-	-
459	-	-	*	-	-	101	95	100	109	110
460	112	113	*	102	109	102	100	100	102	103
461	-	-	*	-	-	-	-	-	-	-
462	-	-	*	-	-	-	-	-	-	-
463	-	-	*	-	-	-	-	-	-	-

Plantation	Grandfather (15)					Clinch (16)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	-	-	*	-	-	-	-	-	-	-
465	-	-	*	-	-	107	106	100	87	85
466	-	-	*	-	-	-	-	-	-	-
467	-	-	*	-	-	-	-	-	-	-
468	-	-	*	-	-	-	-	-	-	-
469	-	-	*	-	-	-	-	-	-	-
470	-	-	*	-	-	-	-	-	-	-
471	94	93	*	104	111	-	-	-	-	-
472	-	-	*	-	-	-	-	-	-	-
473	-	-	*	-	-	116	116	100	100	108
474	-	-	*	-	-	106	105	100	102	106
475	-	-	*	-	-	86	86	100	93	92
476	-	-	*	-	-	91	98	100	104	99
477	112	115	*	102	109	-	-	-	-	
478	-	-	*	-	-	-	-	-	-	-
479	105	104	*	100	106	-	-	-	-	-
480	-	-	*	-	-	-	-	-	-	-
481	97	94	*	100	106	-	-	-	-	-
482	-	-	*	-	-	-	-	-	-	-
483	-	-	*	-	-	111	107	100	100	99
484	-	-	*	-	-	-	-	-	-	
485	80	85	*	100	106	80	82	100	104	108
486	107	107	*	104	111	105	104	100	102	103
487	-	-	*	-	-	111	106	100	102	101
488	99	96	*	98	104	88	86	100	89	92

Plantation	Glenwood (17)					Deerfield (18)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
416	*	*	*	*	*	*	*	*	*	*
417	*	*	*	*	*	*	*	*	*	*
418	*	*	*	*	*	*	*	*	*	*
419	*	*	*	*	*	*	*	*	*	*
420	*	*	*	*	*	*	*	*	*	*
421	*	*	*	*	*	*	*	*	*	*
422	*	*	*	*	*	*	*	*	*	*
423	*	*	*	*	*	*	*	*	*	*
424	*	*	*	*	*	*	*	*	*	*
425	*	*	*	*	*	*	*	*	*	*
426	*	*	*	*	*	*	*	*	*	*
427	*	*	*	*	*	*	*	*	*	*
428	*	*	*	*	*	*	*	*	*	*
429	*	*	*	*	*	*	*	*	*	*
430	*	*	*	*	*	*	*	*	*	*
431	*	*	*	*	*	*	*	*	*	*
432	*	*	*	*	*	*	*	*	*	*
433	*	*	*	*	*	*	*	*	*	*
434	*	*	*	*	*	*	*	*	*	*
435	*	*	*	*	*	*	*	*	*	*
436	*	*	*	*	*	*	*	*	*	*
437	*	*	*	*	*	*	*	*	*	*
438	*	*	*	*	*	*	*	*	*	*
439	*	*	*	*	*	*	*	*	*	*
440	*	*	*	*	*	*	*	*	*	*
441	*	*	*	*	*	*	*	*	*	*
442	*	*	*	*	*	*	*	*	*	*
443	*	*	*	*	*	*	*	*	*	*
444	*	*	*	*	*	*	*	*	*	*
445	*	*	*	*	*	*	*	*	*	*
446	*	*	*	*	*	*	*	*	*	*
447	*	*	*	*	*	*	*	*	*	*
448	*	*	*	*	*	*	*	*	*	*
449	*	*	*	*	*	*	*	*	*	*
450	*	*	*	*	*	*	*	*	*	*
451	*	*	*	*	*	*	*	*	*	*
452	*	*	*	*	*	*	*	*	*	*
453	*	*	*	*	*	*	*	*	*	*
454	*	*	*	*	*	*	*	*	*	*
455	*	*	*	*	*	*	*	*	*	*
456	*	*	*	*	*	*	*	*	*	*
457	*	*	*	*	*	*	*	*	*	*
458	*	*	*	*	*	*	*	*	*	*
459	*	*	*	*	*	*	*	*	*	*
460	*	*	*	*	*	*	*	*	*	*
461	*	*	*	*	*	*	*	*	*	*
462	*	*	*	*	*	*	*	*	*	*
463	*	*	*	*	*	*	*	*	*	*

Plantation	Glenwood (17)					Deerfield (18)				
	height		survival			height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3	Year 1	Year 2	Year 3
464	*	*	*	*	*	*	*	*	*	*
465	*	*	*	*	*	*	*	*	*	*
466	*	*	*	*	*	*	*	*	*	*
467	*	*	*	*	*	*	*	*	*	*
468	*	*	*	*	*	*	*	*	*	*
469	*	*	*	*	*	*	*	*	*	*
470	*	*	*	*	*	*	*	*	*	*
471	*	*	*	*	*	*	*	*	*	*
472	*	*	*	*	*	*	*	*	*	*
473	*	*	*	*	*	*	*	*	*	*
474	*	*	*	*	*	*	*	*	*	*
475	*	*	*	*	*	*	*	*	*	*
476	*	*	*	*	*	*	*	*	*	*
477	*	*	*	*	*	*	*	*	*	*
478	*	*	*	*	*	*	*	*	*	*
479	*	*	*	*	*	*	*	*	*	*
480	*	*	*	*	*	*	*	*	*	*
481	*	*	*	*	*	*	*	*	*	*
482	*	*	*	*	*	*	*	*	*	*
483	*	*	*	*	*	*	*	*	*	*
484	*	*	*	*	*	*	*	*	*	*
485	*	*	*	*	*	*	*	*	*	*
486	*	*	*	*	*	*	*	*	*	*
487	*	*	*	*	*	*	*	*	*	*
488	*	*	*	*	*	*	*	*	*	*

Plantation	Combined data				
	height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3
416	108	108	102	96	100
417	116	117	101	109	111
418	107	107	106	110	109
419	100	101	106	104	103
420	95	96	99	100	96
421	109	102	103	102	100
422	82	85	101	96	96
423	97	91	102	101	103
424	110	103	92	98	95
425	91	89	99	101	99
426	96	89	101	93	95
427	89	87	100	99	99
428	91	94	94	99	101
429	103	96	93	96	92
430	112	104	100	99	97
431	91	90	99	109	108
432	116	110	95	100	99
433	97	96	101	101	97
434	97	93	95	99	97
435	98	92	99	95	100
436	92	83	100	88	88
437	95	92	106	111	105
438	101	101	110	111	108
439	113	102	100	99	101
440	87	86	107	100	103
441	100	98	101	105	103
442	111	104	105	110	111
443	106	101	100	101	107
444	98	91	99	96	100
445	97	94	103	101	101
446	89	87	108	99	97
447	86	89	103	98	103
448	92	94	100	101	100
449	98	96	99	96	91
450	111	103	99	101	100
451	109	104	98	102	97
452	108	100	95	104	99
453	106	98	92	95	92
454	113	105	103	120	100
455	112	111	103	105	109
456	112	107	100	100	101
457	95	92	101	100	96
458	104	99	90	93	91
459	105	95	102	102	104
460	106	103	99	101	103
461	94	94	100	110	108
462	94	94	101	107	107
463	94	89	106	114	99

Plantation	Combined data				
	height		survival		
Family	Year 2	Year 3	Year 1	Year 2	Year 3
464	90	87	101	95	100
465	105	100	92	84	81
466	87	82	95	93	97
467	106	100	100	89	100
468	93	89	100	102	107
469	95	87	103	106	109
470	94	88	96	105	99
471	95	91	101	102	97
472	89	93	100	96	101
473	113	106	105	99	101
474	108	104	103	96	97
475	92	92	95	85	83
476	104	103	101	111	100
477	103	98	94	89	88
478	83	88	100	100	99
479	113	105	100	98	100
480	100	93	95	104	101
481	93	88	100	105	111
482	120	112	102	105	111
483	113	105	101	100	105
484	104	95	99	106	99
485	80	81	105	96	99
486	107	103	99	104	101
487	112	98	94	94	95
488	92	88	100	93	92

Vita

The author was born in Atlanta, Georgia, on March 26, 1974. At age five, her family moved to Chattanooga, Tennessee where she attended elementary and middle school and graduated from Hixson High School in 1992. In the fall of same year, she entered The University of Tennessee at Knoxville. She graduated with a Bachelor's of Science in Forest Resource Management in August, 1996.

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