TWENTY-YEAR-OLD RESULTS FROM A BOTTOMLAND OAK SPECIES COMPARISON TRIAL IN WESTERN KENTUCKY

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Abstract.—A 20-year-old trial of five bottomland oak species (cherrybark, Nuttall, pin, water, and willow oaks) located in western Kentucky showed little difference in survival and growth but considerable difference in form characteristics. Mortality was highest between ages 1 and 3 years during plantation establishment until tree-to-tree competition began increasing between the ages of 10 and 20 years. Willow oak had the highest survival, water oak the overall best growth and cherrybark oak the best form. At age 20 the mean diameter at breast height for all species combined was 7.1 inches and their mean height was 60 feet. The relatively small tree diameters are probably the result of too many trees per acre. While suppressed trees quickly fall out of the stand, the high number of living trees per acre has perpetuated smaller crowns, a thick leaf layer, and low forest floor sunlight, resulting in very little invasion by grasses and forbs as well as virtually no acorn production. With the exception of pin oak, water oak was significantly taller than all of the other species. Water oak was also larger than all other species tested. At age 20, the various species within the study have begun to exhibit those factors that would allow determination of stand manipulation timing and scale to provide not only timber revenue but wildlife values. A discussion concerning oak species plantings examines means by which young bottomland oak stands may be manipulated to accomplish multiple goals.

INTRODUCTION

High quality bottomland oaks can provide substantial timber revenue as well as wildlife benefits. But, like other hardwoods, it is critical that the correct oak species are matched to the site. Artificial regeneration of hardwoods has primarily focused on single-species plantings (Meadows and Hodges 2004, Siry 2002). This approach is advantageous for early successional shade-intolerant species, such as eastern cottonwood (*Populus deltoides* Bartr.ex Marsh.), sycamore (*Platanus occidentalis* L.), and sweetgum (*Liquidambar styraciflua* L.), but it is much more difficult for species such as oaks that are partially shade tolerant to compete with the growth rates of those shade-intolerant species. Even when soil/site conditions are properly matched to the species, rapidly growing early successional species will survive and reach their full growth potential only when competing vegetation is held in check during the first 2 to 3 years of establishment. Early successional, shade-tolerant bottomland species also have high nutrient and water demands, which if not met will lead to slow growth or will stress the trees to the point where disease may result in significant mortality. Assuming growth rates are suitable for a positive return on investment for cottonwood, sycamore, or sweetgum, pulpwood would be the primary market as intensive bottomland hardwood monocultures focus on biomass growth and not wood quality characteristics (Robison and others 1998, Scott and others 2002, Stanturf and Portwood 1999). In contrast, oaks have slower early growth rates which are not conducive to a positive return on investment from pulpwood. However, if timber quality is high, bottomland oak plantations can be profitable if held for longer rotations. If timber quality is lacking, though, a long rotation will still yield only a limited revenue stream.

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The original objective of this study was to determine the feasibility of growing oaks in plantation culture on bottomland sites as an alternative to intensive plantation management of rapidly growing hardwood species such as cottonwood, sycamore, or sweetgum. Therefore, the key was to determine which species of oaks will not only survive and grow at an acceptable rate but will also be of the quality needed for higher rates of return. This study was originally focused on defining the financial feasibility of a pulpwood rotation for oaks, but the secondary objective was to determine a financial return from veneer or sawtimber.

METHODS AND STUDY AREA

Open-pollinated seed from seven mother trees were collected during the fall of 1985 from each of five species of red oaks: cherrybark oak (*Quercus pagoda* Raf.), Nuttall oak (*Q. texana* Buckl.), pin oak (*Q. palustris* Muenchh.) water oak (*Q. nigra* L.), and willow oak (*Q. phellos* L.). Cherrybark oak originated from west Tennessee (Ames Plantation), Nuttall oak from north-central Mississippi, pin oak from western Kentucky, water oak from the Mississippi Delta near Stoneville, MS, and willow oak from western Kentucky.

Following collection, acorns were immersed in water to facilitate removal of damaged or insect-infested seed (acorns that floated). Sound seed were drained and stored in sealed plastic bags at approximately 35 °F until sowing. The bags were opened monthly and seed were washed and re-immersed in water as an additional means of discarding nonviable seed. Prior to sowing, each seed lot was re-immersed and germinated on blotter paper in shallow metal trays. Every third day, germinated seed were sown at a rate of five seedlings per square foot at the J. P. Rhody Kentucky State Nursery, near Gilbertsville, KY. All of the seed were sown between April 14 and April 23, 1986. Nursery practices included fertilization with ammonia nitrate, foliar sprayings of chelated iron, and lateral root pruning. Chelated iron was applied following each flush of growth. Lateral root pruning designed to create a more compact root system was done three times during the growing season with colters affixed to a tractor toolbar. Seedlings were lifted on February 8, 1987. Only seedlings having root collar diameters between ½-inch and ¾-inch, with six to eight first-order lateral roots were included in the test. In addition, similar seedlings of all species were grouped by replication, thus minimizing differences within replication. Seedlings were bundled and stored by plot and replication, and stored in bags at 35 °F until planting.

The test site is located in Ballard Co., KY. Soil type is described as a Falaya-Collins silt loam, with high available moisture, moderate permeability, moderate natural fertility, medium organic matter content, and strongly acidic pH (Humphrey 1976). Periodic flooding of the test site for various lengths of time can occur during the winter and spring as the result of high water conditions on the lower Mississippi River. Stand history indicated that the area was a native bottomland hardwood stand containing various species of red oaks, eastern cottonwood, boxelder (*Acer negundo* L.), green ash (*Fraxinus pennslyvanica* Marsh.), silver maple (*A. saccharinum* L.), sugarberry (*Celtis laevigata* Willd.), shagbark hickory (*Carya ovata* (Mill) K. Koch), and sweetgum. In 1979, the natural stand was cleared and an eastern cottonwood plantation was established. The stand never received lime or fertilization, and after six years the stand did not exhibit sufficient stocking levels or growth to be economically viable. Consequently, the trees were sheared, piled, and burned. Site preparation included disking, row marking, and slitting at a spacing of 9 x 9 ft.

The experimental design is a randomized complete block consisting of six blocks and five oak species arranged in 49-tree block plots. There were only enough Nuttall oak seedlings for two complete blocks. Research personnel planted the test on March 27, 1987. Herbaceous and vine competition was controlled during the first and second year by disking. First-year maintenance was excellent. Measurements included survival and height at ages 1, 3, 5, 10, 15, and 20 years while diameter at breast height (d.b.h.) was taken at

Table 1.—Test survival for all species. Estimated trees per acre based on survival and phases that affect survival during the 20 years of the 1987 Oak Species Comparison Trial located on a bottomland site in Ballard Co., KY

	Age	Survival	Mortality	Tree/Acre
	(yrs)	(%)	(no.)	(no.)
Phase I[1]	1	98	25	527
	3	94	45	508
Phase II	5	94	1	508
	10	94	8	505
Phase III	15	90	48	484
	20	78	148	422

[1]The phases shown define specific points along a timeline during the life of this specific plantation. Phase I is the establishment phase, Phase II is the rapid-growth phase and Phase III is the intensive tree-to-tree competition phase.

ages 5, 10, 15, and 20 years. Heights were measured to the nearest tenth of a foot using poles at ages 1, 3, and 5 years. Heights at ages 10, 15, and 20 years were measured using an Impulse Laser to a tenth of a foot. Diameters were measured at ages 10, 15, and 20 years using a D-tape to the nearest tenth of an inch. Form defects such as crooked stems, forks, multiple stems and a variety of stem problems were also tallied at age 20. Survival data were transformed using arcsine transformation. Statistical analysis using GLM procedure on a plot mean basis to test for difference among species, and Duncan's Multiple Range test was used for mean comparisons ($p < 0.05$). All analyses were completed using SAS/STAT software, version 9.1 of the SAS System for Windows (SAS Institute, Inc., Cary, NC, 1999-2000). Pearson's Correlations were used to determine correlation coefficients within a specific trait across age groups using age 20 years as the desired selection age.

RESULTS

Survival

All Species. First-year survival was 98 percent, providing an excellent opportunity to determine factors affecting the number of trees per acre as age increases. By age three, mean survival dropped to 94.5 percent and remained fairly constant though age 10, where survival was nearly 94 percent (Table 1). Through age 10, the number of trees per acre was still high at approximately 500 trees per acre. Survival declined four percent between ages 10 and 15 and dropped nearly 13 percent between ages 15 and 20. Accordingly, the number of trees per acre also dropped to 422 trees as survival declined to 78.4 percent. Another aspect of Table 1 is the grouping of ages by what is termed phases. In this manner, specific ages are grouped together and identified as phases, which define the factors that play a critical role in survival and growth (Table 1).

Individual Species. Significant survival differences were noted among the various oak species after the first year, yet there was only a 3.4-percent range in survival resulting from Nuttall oak exhibited 100 percent survival while water oak was the lowest at 96.6 percent (Table 2). All of the species showed a decline in survival between ages 1 and 3 years with Nuttall and pin oak having the highest survival at 97 percent and water oak the lowest at 88 percent. Water oak survival remained significantly lower than the other species from age three to age 20 (Table 2). Survival among all species remained constant between ages 3 and 10

Table 2.—Survival of oak species at ages 1, 3, 5, 10, 15, and 20 years found in the 1987 Oak Species Comparison Trial located on a bottomland site in Ballard Co., KY

	Percent Survival ----------------Age---------------- (yrs)					
Oak Species	1	3	5	10	15	20
Willow	99ab[1]	96a	96a	96a	94a	86a
Cherrybark	98bc	96a	96a	96a	90a	77ab
Water	97c	88b	88b	86b	82b	70c
Pin	99abc	97a	97a	96a	93a	80ab
Nuttall	100a	97a	97a	97a	94a	83a

[1]Means not sharing the same letter within a column for a given age indicate significant differences at α=0.05.

Table 3.—Species means for total height at ages 1, 3, 5, 10, 15, and 20 years and diameter at ages 10, 15 and 20 years for the 1987 Oak Species Comparison Trial located on a bottomland site in Ballard Co., KY. Diameter refers to d.b.h.

	Total Height (ft) ------------ Age ------------						Diameter (in) ---- Age ----		
Oak Species	1	3	5	10	15	20	10	15	20
Willow	2.3a[1]	8.8a	13.4a	32.8a	46.9b	60.8bc	4.6a	6.0a	7.3b
Cherrybark	1.7c	5.7d	10.4d	28.4c	45.9b	60.5c	3.8b	5.6b	7.1b
Water	1.7c	7.8b	12.6b	32.8a	48.3a	63.1a	4.5a	6.1a	7.9a
Pin	1.9b	8.1b	13.7a	33.4a	48.3a	62.0ab	4.4a	5.7b	7.0b
Nuttall	1.9b	7.1c	11.9c	29.7b	43.0c	55.3d	4.0b	5.2c	6.3c

[1]Duncans Multiple Range Test where different letters within a column for a specific trait designate significant differences among means at α=0.05

years. Changes in survival between ages 10 and 15 were fairly consistent among the various oak species with cherrybark exhibited the greatest change with a 6 percent decline in survival and willow oak the least with a 2 percent decline. By age 20, survival across the five oak species was substantially lower for all species when compared to age 15 survival. Willow oak had the smallest decrease in survival at only 8 percent while cherrybark oak had the greatest decrease at nearly 14 percent.

Height and Diameter

All Species. Means for total height at ages 1, 3, 5, 10, 15, and 20 years were 1.9, 7.6, 12.5, 31.6, 47.0, and 61.1 ft, respectively. Means for d.b.h. at ages 10, 15 and 20 years were 4.3, 5.8, and 7.2 inches, respectively. Once the seedlings were established and had attained sufficient height to overtop weed competition, the observed tree growth was largely a response to the inherent site conditions in the context of the weather and climate over the study period. The growth response serves as a relative index of suitability of these five oak species to the specific soil/site conditions of the test site.

Individual Species. Oak species performance through time is shown in Table 3. Significant differences among species were noted for total height and diameter at all ages. Willow oak was significantly taller than all species at age 1 year, but by age 10 it was not significantly taller than water oak or pin oak. Although cherrybark oak and water oak total heights were not significantly different at age 1 year, they were by age

Table 4.—Height and diameter growth by species for all ages of the 1987 Oak Species Comparison Trial located on a bottomland site in Ballard Co., KY

	Height Growth (ft) ------------ Age (years) --------					d.b.h. Growth (in) --Age (years)--	
Oak Species	1-3	1-5	5-10	10-15	15-20	10-15	15-20
Willow	6.5a[1]	11.1b	19.4b	13.8c	12.9ab	1.4b	1.1b
Cherrybark	3.9d	8.6d	18.0c	16.8a	13.3a	1.6a	1.1b
Water	6.0b	10.8b	20.0a	15.2b	13.5a	1.5a	1.4a
Pin	6.1b	11.7a	19.7ab	14.7b	12.7ab	1.3c	1.0bc
Nuttall	5.2c	10.0c	17.7c	13.1c	12.3b	1.1d	0.9c

[1]Duncan's Multiple Range Test where different letters within a column for a specific trait designate significant differences among means at α=0.05

three. In fact, by age 20, water oak attained the greatest mean height of approximately 63 ft. At age 20, cherrybark oak was not significantly different from willow oak and was only significantly taller than Nuttall oak. Nuttall oak was significantly shorter than the other four oak species at ages 15 and 20 years. A range of 8 ft separated the tallest species (water oak) from the shortest species (Nuttall oak). There were numerous individual trees of water, pin, and cherrybark oak that had heights greater than 70 ft at age 20. Pin oak had the greatest number (18) of trees taller than 70 ft followed by cherrybark and water oak (16 trees each).

Differences in mean diameter among four oak species, excluding Nuttall oak, were less than 1 inch. The small diameters are probably the result of inter-tree competition due to the tight spacing and high survival rates. Cherrybark oak and water oak were the only two species exhibiting more than 10 trees greater than 10 in diameter, with a total of 15 and 19 trees, respectively.

The trend in height and diameter growth indicates a rather slow establishment period between ages 1 and 3 years, defined as Phase I (Table 1). Annual height growth peaked for all species between the ages of 5 and 10 years with water oak averaging 4 ft of height growth per year (Table 4). Although height growth of cherrybark oak started slowly, growth rates increased through time, and from age 15 on cherrybark ranked among the fastest growing species. All five oak species showed a slow but continual decline in mean growth rates from their respective peak growth rates between the ages of 5 and 10 years. However, even at the latest measurement (age 20 years), all of the oak species continued to show double-digit mean growth rates over the previous 5-year period resulting in approximately 2.5 ft of height growth per year.

Because d.b.h. measurements were taken only at ages 10, 15, and 20 years, diameter growth can be compared only over the last 10 years of the study. Average growth was greatest for all species between ages 10 and 15 years (Table 4). Diameter growth between ages 15 and 20 years was slower for all species. Except for Nuttall oak, all species averaged greater than 1-inch of diameter growth between ages 15 and 20 years.

Table 5 shows correlations for total height at ages 1, 3, 5, 10, and 15 years with age-20 total height. Correlations between age 1 year total height and age 20 total height for all oak species were very poor, with Nuttall oak exhibiting a negative correlation. As expected, correlations strengthened as age increased toward age 20. By age 10, trees exhibited a fairly strong correlation with their observed height at age 20. Although not shown, correlations between earlier diameters and age-20 diameters were similar to the correlations for height but based on a more limited time span since diameters were not measured until age 10.

Table 5.—Total height-age correlations with age-20 total height for all species in the 1987 Oak Species Comparison Trial located on a bottomland site in Ballard Co., KY

Oak Species	Age 1	Age 3	Age 5	Age 10	Age 15
Willow	0.31[1]	0.58	0.65	0.78	0.78
Cherrybark	0.26	0.57	0.68	0.78	0.75
Water	0.23	0.45	0.56	0.62	0.63
Pin	0.18	0.42	0.61	0.75	0.82
Nuttall	-0.04	0.58	0.80	0.85	0.85

[1]Pearson correlation coefficients

DISCUSSION

Survival

Survival through time provides insight into the processes affecting survival and growth. The three phases listed in Table 1 can be categorized by those factors that affect both survival and growth. For this oak trial and many other oak plantations, the first 3 years can be termed the establishment phase (i.e., Phase I) where factors such as seedling quality, site preparation, planting quality, and competition control are critical to survival. Although environmental conditions cannot be controlled, we can minimize their effect on survival by maximizing seedling quality, site preparation, planting quality, and competition control. Phase I sets the stage for the following phases and the overall performance of the plantation. If any of the above factors are neglected, the plantation will become stressed, resulting in lower survival and reduced growth. It is important to note that oak species in this trial were, in general, suited to the soil type found on this site. However, water oak and Nuttall oak are southern species not found in western Kentucky. Phase II is defined as the rapid growth stage where oak seedlings have reached heights above the competing herbaceous vegetation and started to increase in crown size. Root systems in Phase II are also large enough to accelerate growth over the establishment phase. As shown in Table 1, mortality during this stage is minimal as the trees have out-competed the herbaceous material and are now on their way to fully occupying the site. Phase III can be described as the inter-tree competition stage, where, based on growth rates, trees are competing against each other for site resources. It is during this intense tree-to-tree competition stage that mortality increases as the more thrifty trees began to gain dominance resulting in mortality of slower growing trees.

Site conditions, seedling quality and planting quality were excellent for survival and growth. Herbaceous competition clearly had only a minor impact on survival. Between ages 1 and 3 years, an additional 45 trees were lost in the test, reducing overall survival to approximately 95 percent. The majority of the mortality during this period was observed in water oak. This southern species may be more susceptible to the cooler temperatures of western Kentucky. By age 3 years, survival of water oak was significantly lower than the other four oak species, declining from 96 percent at age 1 year to 88 percent at age 3 years (Table 2). However, age-5 and age-10 survival showed very little change to that of age-3 survival, indicating that all five species were able to cope with the climatic conditions of the test site. Between ages 10 and 15 years, tree-to-tree competition began to impact the stand and mortality increased. This trend was somewhat more evident in blocks that were on a slightly better potion of the site. Even minute site differences can lead to differences in growth and survival. This finding emphasizes the need to carefully select the hardwood species for specific differences even within small acreages.

Extremely intense tree-to-tree competition was the norm between ages 15 and 20 years, where mortality increased nearly threefold from 48 trees at age 15 years to 148 at age 20 years. All oak species, with the exception of willow oak (8 percent decrease in survival), showed double-digit decreases in percent survival between the ages of 15 and 20 years. In addition there were 102 trees designated as suppressed trees during age 20 measurements. Factoring these trees into expected 5-year survival percentages indicates that survival will probably decline to below 70 percent. The number of trees on a per-acre basis for age 25 will be approximately 375 trees or less. By all indications the number of trees in the trial on a per-acre basis is higher than necessary for sawtimber objectives. However, Kennedy (1992) cited several publications that showed similar number of trees per acre for various species of bottomland oaks, such as cherrybark, water, and Nuttall oak. The data suggest that in this specific trial, removal of less desirable trees would be beneficial for additional growth to the remaining crop trees.

A potential solution would be to apply a thinning to these types of plantations. One problem associated with thinning at earlier ages is the cost, as the majority of the material would be precommercial unless whole-stem chipped. But, if landowner objectives included both timber value and wildlife benefits, early thinning might be justified. An alternative is to inject unwanted trees with herbicide, thus creating the same effect as thinning without the possibility of mechanical damage to reserved trees. In this manner, less desirable poor-quality trees would be removed, while some large, heavy-crowned trees would be left for mast production. This system could increase the value of the remaining high-quality stems by providing more growing space and opening the stand to more sunlight. Increased sunlight to the forest floor would then contribute to the production of grasses and forbs for wildlife species such as deer and turkey.

Height and Diameter Performance

The test site can be classified as an excellent hardwood site. It is located in western Kentucky on Mayfield Creek, which flows into the Mississippi River approximately 5 miles from the test site. Although these sites are subject to periodic flooding, similar sites have been cleared for agricultural production as numerous fields along the same creek are in corn and soybean production. Using the Baker-Broadfoot System (1979) of assessing site quality, it was determined that sycamore and sweetgum were the species best suited to this site. Although cottonwood and sycamore were operationally established on the site by Westvaco, it was later determined through testing that the best suited species were oaks and sweetgum.

For this study, growth of Nuttall oak growth seems the most puzzling. Based on experience, I expected an increased growth rate resulting from moving a southern species north, as observed in water oak. This type of growth gain has been noted in numerous hardwood genetic studies where movement of southern material northward results in faster growth rates (Gwaze and others 2003, Kriebel 1988, Rousseau 1987, 1989, Steiner and others 1985). In addition, the site is a typical pin oak site which seems to occupy the same niche in more northern geographic areas that Nuttall does in southern areas. The poorer performance in this study may be related to the fact that Nuttall source was from a much narrower genetic base due to the limited number of trees collected. However, this aspect may have been a positive one rather than a negative one, but in this case it does seem to be partially attributed to poor genetics.

Willow and pin oaks are frequently found on this type of site in western Kentucky whereas cherrybark oak would occur very infrequently. Cherrybark oak is typically found on western Kentucky sites that have greater nutrient capacity and increased soil aeration. I expected both willow and pin oak to perform well on this particular site but for cherrybark to suffer from poor soil drainage. Comparisons between a

Figure 1.—Difference in self-pruning ability of cherrybark oak (left) and pin oak (right) at age 20 in the 1987 Oak Species Comparison Trial located on a bottomland site in Ballard Co., Kentucky

1987 cherrybark oak progeny test planted on a loess site in western Kentucky at the same spacing and the cherrybark in this trial showed the progeny test to be approximately 6 ft taller and a half an inch greater in diameter at age 20 years (Adams and others 2007). At age 20 years, mean height and diameter for the progeny test was 66 ft and 7.6 in, respectively. In the current study, mean species height among cherrybark, pin, water and willow oak differed only slightly at age 20 with approximately 2.5 ft between the tallest (water oak) and the shortest species (cherrybark oak). This difference represents approximately a single year of height growth. Similar results were found for diameter, where again water oak and cherrybark oak represent the largest and the smallest species, respectively. This difference was 0.8 in, which on average represents approximately a 3- to 4-year separation. The anticipation was that the mean diameter at age 20 years would be approaching 10 in. In fact, only 7 and 9 percent of the trees in the cherrybark and water oak plot exhibited d.b.h greater than 10 in at age 20. The high stocking levels maintained through age 20 apparently have greatly reduced diameter growth. However, the stocking levels allowed for early capture of the site by the oaks and the ability to express inherent stem form. Increasing growing space at earlier ages may have allowed larger trees and better possibilities of a commercial thinning.

While stem quality data were collected for all species, the most dramatic differences were noted between cherrybark oak and water oak. These data provide insight into the possible revenue from quality stems. The number of defects noted between water oak and cherrybark oak is much greater than the few additional years needed for cherrybark to attain the same height and diameter. One of the most visible early differences noted was the excellent self-pruning ability of cherrybark in comparison to other species tested (Fig. 1). Even at age 20 years, pin oak and willow oak still have a large number of very low branches attached to the stem. During data collection, tree form and timber quality characteristics were also recorded and included forking, ramicorn branching, multiple tops, excessively crooked stems, double stems, and any type of bole damage. Water oak was found to have over eight times the number of defects as cherrybark oak at age 20 years. This striking difference in form quality between these two species indicates that if the site is suitable for cherrybark oak, it would be advantageous to plant this species rather than water oak.

If an intermediate thinning is needed, at what age can we be fairly confident of selecting the right trees for release? Correlations listed in Table 5 suggest that when total height at age 20 years is the desired trait, selection at ages 1 and 3 years should be avoided. However, by age 10 correlations are high enough for all species except water oak, that a manager can be fairly confident in selecting the correct crop trees for release. Allowing the stand to grow to age 10 before thinning places the desired trees in a dominant canopy position and may greatly reduce epicormic branching. Other positive aspects from an early thinning would be increased crown size, greater acorn production and increased sunlight to the forest floor, allowing the production of grasses and forbs for wildlife.

Artificial regeneration of oaks remains problematic as it encompasses site preparation, seedling quality, competition control, and other critically timed silvicultural treatments that are key to survival and rapid growth. In many circumstances the production of quality stems is critical to a greater financial return, yet typical lower numbers of seedlings per acre result in poor stem-form characteristics while higher numbers reduce growth and dictate intermediate costly steps. While this study was not designed to evaluate planting densities, I think that the higher density of 538 trees per acre, as shown in this study, provides the ability to quickly capture the site and avoid the negative effects of open grown trees when log quality is the goal. In this study, as with others, a higher number of stems per acre appears to be warranted to ensure sufficient numbers of quality trees at harvest. Currently, it has been proposed that for bottomland oak plantations there should be approximately 400 to 450 stems per acre at age 3 years (J.D. Hodges, personal communication, meeting for the Lower Mississippi River Valley Science Synthesis).

Related to the number of trees per acre needed as these types of plantations move through time is the genetic component. Currently, there is no available improved southern bottomland oak genetic material. As such, this impacts the number of trees planted on a per-acre basis as greater tree numbers provide possible alternatives in selection for log quality in our crop trees.

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