GROWTH AND DEVELOPMENT OF OUTPLANTED HIGH-QUALITY NORTHERN RED OAK SEEDLINGS AND THE EFFECTS OF COMPETING HERBACEOUS PRODUCTION WITHIN FOUR OVERSTORY TREATMENTS – FIRST-YEAR RESULTS

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Abstract—Historically, oak (*Quercus* spp.) regeneration success on highly productive hardwood sites can be described as highly variable. Research has shown that establishing large advance oak regeneration prior to overstory removal is necessary to maintain oak populations in future stands. However, experience indicates that forest landowners are typically unwilling to wait the necessary time to develop natural advance oak reproduction, instead allowing markets to dictate harvest times. This fact necessitates the use of artificial oak regeneration to maintain oak as an important component of future stands. To date, the success of artificial oak regeneration has also been highly variable. To develop an improved understanding and enhanced methods of artificial oak regeneration, we examined the growth of outplanted, high-quality, locally adapted, 1-0 northern red oak (*Q. rubra* L.) seedlings and the effects of competing herbaceous vegetation after four overstory treatments (no cut, high grade, commercial clearcut, two age) at the Ames Plantation in west Tennessee. Sixty seedlings from 2 genetic families were outplanted within each of twelve 2-acre treatment units, resulting in 3 replicates of the 4 treatments. Initial height, root collar diameter, and number of first-order lateral roots were recorded for each seedling. Outplantings were monitored monthly during the growing season. This paper compares the first year seedling growth patterns (height and root collar diameter growth) and the impacts of competing herbaceous vegetation with emphasis on an exotic, Asian annual C_4 grass. The silvicultural implications of seedling development over the four treatment areas are evaluated.

INTRODUCTION

The topic of successful regeneration of oak (*Quercus* spp.) has acquired great attention and generated numerous research papers over past decades. However, the successional replacement of oak persists as a major concern in eastern deciduous forests, particularly on mesic or highly productive hardwood sites. Research suggests that oaks historically persisted on productive sites due to a disturbance regime that included repetitive low to moderate intensity fire events (Delcourt and Delcourt 1997, 1998, Johnson 1993a, Van Lear and Janet 1992), which no longer exists in eastern deciduous forests (Delcourt and Delcourt 1997, Lorimer 2001, Van Lear and Janet 1992). Presently, obtaining oak reproduction within intrinsic accumulator systems (areas with a high propensity to accumulate advance reproduction, generally poor quality sites) is not difficult (Crow 1988, Johnson 1993b, Rogers and others 1993). However, after a heavy overstory removal on highly productive sites (generally site index at base age 50 of > 70 feet), oaks are out-competed by other hardwood species and are quickly replaced or relegated to subordinate positions in the canopy (Clatterbuck and others 1999, Johnson 1993a).

Research has demonstrated the need for the presence of large advance reproduction prior to final overstory removals (Johnson 1993b, Loftis 1982, 1983, Sander 1971). However, experience has shown that many nonindustrial private forest (NIPF) landowners within the eastern deciduous forest region are unwilling to take the necessary steps to ensure adequate advance oak reproduction. Instead, short-term economics tend to drive forest land management decisions, including harvest times, resulting in highly exploitive practices that in turn negatively impact oak composition in future stands. The unwillingness of NIPF landowners to culture advance oak reproduction, coupled with common exploitive forest practices, presents a need for focus on post-harvest alternatives of increasing or developing oak regeneration. A shift toward a model that emphasizes the use of artificial regeneration appears to hold promise.

Furthermore, highly invasive exotic species are beginning to present additional obstacles when attempting to establish reproduction, both natural and artificial. *Microstegium vimineum* Trinches, an exotic, shade tolerant Asian annual C_4 grass, has invaded many hardwood sites from floodplains to mesic slopes (Barden 1987) and can potentially be a problem for private landowners, land managers, and foresters.

Over the past 10 years, a number of research projects have focused on the use of nursery grown seedlings to enhance post-harvest oak composition with varying results. Deer herbivory (Buckley and others 1998), herbaceous competition including exotic species (Dubois and others 2000), and competition by other woody species (McGee and Loftis 1986) have hindered success. Therefore, seedlings capable of hastened growth to attain a competitive advantage on highly productive sites are needed. Concomitantly, genetic families exhibiting growth advantages in seedling development should be identified. Currently, protocol exists for the

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production of "advance regeneration" in the nursery (Kormanik and others 1994a, 1994b; Schlarbaum and others 1998). Through genetic selection, use of proper seed source and the optimal nursery techniques, potentially successful high quality seedlings can be developed. This study was undertaken to investigate the growth of such high quality seedlings developed by the University of Tennessee Tree Improvement Program and outplanted within four overstory treatments. We also considered the potential impacts of *Microstegium vimineum* on seedling growth and establishment.

MATERIALS AND METHODS

Study Site

The study site is located along an intermittent stream in the headwaters region of the North Fork of the Wolf River (NFWR) on the Ames Plantation in southwest Tennessee (35°09´ N, 89°13´ W). The site encompasses approximately 100 acres of mixed bottomland and riparian hardwood forest dominated by various oak species. Two distinct landforms were identified within the study site: a minor bottom near the confluence of the stream with the NFWR and ancestral terraces of the minor stream (Hodges 1997).

The headwaters region of the NFWR is located within the Mississippi Embayment of the Gulf Coastal Plainches. The geology is dominated by the highly erodible Wilcox and Claiborne formations of Tertiary age exposed by the erosion of Quaternary and Tertiary fluvial deposits and the overlying Pleistocene loess deposits common in western Tennessee (Fenneman 1938, Safford 1869). The principal soil groups are Grenada-Loring-Memphis on the terraces and Falaya-Waverly-Collins within the minor bottom (U.S. Department of Agriculture 1964).

Average site index, base age 50 years, was estimated to be 75 for oaks, 85 for yellow-poplar (*Liriodendron tulipifera* L.), and 70 for sweetgum (*Liquidambar styraciflua* L.) on both sites. Average age for the dominant and co-dominant stems across the study site was 70 years.

Study Design

In the fall of 2001, three experimental blocks were identified based on landform and position. Significant differences in average stand basal area ($p < 0.05$) were found among the blocks. Twelve 2-acre treatment units were designated within the experimental blocks and four units located within the minor bottom (Bottom block) and eight units located within the terrace sites upstream from the minor bottom (four each within the East and West blocks). Species composition at the time of establishment was dominated by oak on the ancestral terraces and yellow-poplar and sweetgum in the Bottom block. Importance values were calculated (sum of relative dominance, relative frequency and relative density) for the common midstory and overstory species located within each block (table 1).

Table 1—Pre-harvest importance values[a] for common species of the three experimental blocks within the oak regeneration study on Ames Plantation, Fayette County, Tennessee

Species	Experimental block East	Experimental block West	Experimental block Bottom
American elm	11.41	6.74	21.91
A. sycamore			4.49
Black cherry	6.35		
Black oak			5.52
Blackgum	9.10		
Boxelder			16.98
Cherrybark oak	20.48	6.64	27.47
Dogwood	10.32	15.52	8.13
E. redcedar	11.34		
Green ash	11.26		
Mock. hickory	6.09	18.21	4.73
N. red oak		19.90	
Osage-orange			4.09
Persimmon			6.28
Post oak	42.48	44.36	
Red maple		6.24	4.08
Red mulberry	8.62	4.99	4.03
Redbud			4.08
River birch			7.27
Sassafras	9.25	10.21	
Slippery elm			4.55
S. red oak	77.60	18.30	9.85
Sweetgum	17.49	22.08	49.58
Walnut	14.27	15.85	
White oak	17.02	82.32	5.57
Winged elm			15.90
Yellow-poplar	26.92	28.64	95.49

[a] Sum of relative dominance, relative density, and relative frequency.

Four overstory treatments, including a control (no cut), with 3 replications were randomly assigned to the 12 units using a randomized complete block (RCB) design. Harvesting for all treatments was completed in the winter of 2001-02. Overstory treatments are described.

- Commercial clearcut—is defined by the removal of all stems greater than 6 inches diameter breast height (d.b.h.). This treatment is designed to represent a common practice on industrial forest land.
- High grade—is a standard diameter limit cut where all stems greater then 14 inches d.b.h. are removed. This treatment is designed to represent a common and persistent practice on NIPF lands.
- Two age—is where a residual stand basal area of 15-20 square feet per acre was targeted. Residual stems were chosen based on spacing criteria and the desire to leave stems of desirable species with an opportunity to increase in value. Desirable species included oaks, hickories (*Carya* spp.) and yellow-poplar.
- No cut—is designed to act as the study control.

Seedlings

Seedlings originating from two genetic families (families 321 and 234) in a seedling seed orchard on the Ames Plantation (Schlarbaum and others 1998) were chosen for planting following harvest. The seedlings were grown at the

Georgia Forestry Commission's Flint River Nursery under fertilization and irrigation protocols developed by Kormanik and others (1994a). The seedlings were lifted in February 2002 and were graded using procedures developed by Kormanik and others (1994a, 1994b), as modified by Clark and others (2000). The seedlings were measured for height and root collar diameter (rcd) growth, the number of first-order lateral roots (folr) *sensu* (Ruehle and Kormanik 1986), and were counted and visually classified into one of three categories (cull, good, premium). Thirty seedlings from the good and premium classes in each family were planted by shovel (20 by 20 feet) in March 2002 within each of the 12 units for a total of 720 seedlings. Mean initial rcd, initial shoot height, and number of folr for premium seedlings (n = 216) were 0.50 inches, 4.06 feet, and 21, respectively. Mean initial rcd, initial shoot height and number of folr for good seedlings (n = 504) were 0.40 inches, 3.41 feet, and 16, respectively.

The planted seedlings were monitored monthly (35-45 days) throughout the growing season for a total of four periods. Seedling condition (signs of mortality and browse pressure) was monitored for all seedlings in all four periods. Seedling mortality was defined by no presence of green tissue along the stem. Browse pressure was defined as any browse on either the terminal or lateral shoots. Shoot growth measurements were recorded for one-half of all planted material the last three periods to quantify early-, mid-, and late-season growth. Mortality and end-of-season growth data (height and rcd) were obtained in January 2003 for all seedlings after seedlings entered dormancy following the first growing season.

Herbaceous Biomass

In conjunction with the collection of growth data, herbaceous biomass production was measured in the same periods. Five randomly placed 18 square inch samples were collected within each unit for a total of 60 samples for each of 4 measurement periods. All material was clipped at ground level, categorized, dried, and weighed according to procedures in Mueller-Dombois and Ellenberg (1974).

Analysis

Differences among treatment means in seedling height growth, rcd growth, browse pressure and seedling mortality were analyzed through ANOVA and Tukey-Kramer Multiple-Comparison tests (SAS Institute Inc. 1989; NCSS 2001) with an error level of $\alpha = 0.05$ set to indicate significant differences. Three independent simple linear regression analyses were used to explore possible relationships between end-of-season seedling height growth and total herbaceous biomass production, percent *Microstegium vimineum* production and seedling browse pressure.

RESULTS

The harvest resulted in a mean basal area of 142, 20, 14, and 0 square feet per acre for the no-cut, high-grade, two-age and commercial clearcut treatments, respectively (material greater than 6 inches). Little difference in mean basal area existed between the high-grade and two-age treatments; however spacing and species composition of the residual stand differed between the two treatments due to harvest criteria. The light environment in the no-cut treatment was dark with minimal light reaching the forest floor.

No significant difference existed between genetic family, seedling quality class, or treatment for time of bud break. More than 99 percent of planted seedlings experienced bud break prior to May 4, 2002.

End of growing season mortality for all seedlings was significantly greatest for the no-cut treatment with mean percent mortality of 33 percent (n = 180, $p = 0.004$) followed by the high-grade and two-age treatments with 5 percent each. The commercial clearcut experienced no seedling mortality. Tukey-Kramer comparisons resulted in no difference between the three overstory cut treatments. No significant differences in mortality were observed between genetic families ($p > 0.05$) with mean percent mortality of 11 percent for each family.

After one growing season, height growth was significantly greater for the no-cut treatment ($p = 0.0005$). Mean growth was observed as 4.90, 5.31, 3.61, and 8.80 inches for the commercial clearcut, high-grade, two-age, and no-cut treatments, respectively (table 2). Tukey-Kramer analysis resulted in no strong differences between the three cut treatments. No significant differences in mean height growth were observed between genetic families ($p = 0.68$) with mean height growth of 5.69 and 5.61 inches for families 234 and 321 respectively. Mean growth for all Premium seedlings was greater than Good seedlings ($p < 0.001$). Mean growth for Premium and Good seedlings was 7.12 and 5.02 inches, respectively. Mean height growth differed between blocks ($p < 0.0001$) with mean height growth of 6.98, 6.42, and 3.54 inches for the East, West and Bottom blocks, respectively.

A similar pattern to that of end-of-season growth existed for early growing season growth with 81 percent of all seedlings having only one growth flush. Height growth for the no-cut treatment was significantly greater than the cut treatments ($p = 0.0008$) with mean growth of 4.88 inches, 4.51, 3.44, and 10.32 inches for the commercial clearcut, high-grade, two-age and no-cut treatments, respectively (table 2). Again, no significant differences were observed between the cut treatments. Mid-season growth was significantly different between treatments ($p = 0.009$). The commercial clearcut and high-grade treatments differed from the two-age and no-cut treatments with mean mid-season growth of 1.25, 1.35, 0.0, and –0.07 inches, respectively. Late-season growth was not different across treatments ($p = 0.53$).

Root collar diameter (rcd) growth after one growing season differed between treatments ($p = 0.03$). Mean rcd growth observed for the commercial clearcut, high-grade, two-age and no-cut treatments were 0.026, 0.013, 0.007, and –0.022 inches, respectively. Tukey-Kramer mean comparison analysis revealed significant differences between the no-cut treatment and commercial clearcut differing from one another. However, neither the no-cut nor the commercial clearcut treatment differed from the high-grade or two-age treatments at the $\alpha = 0.05$ level.

Table 2—Initial height, average height growth, and total height growth (inches) of 1-0 high-quality northern red oak (*Quercus rubra* L.) seedlings for each sampling period during the 2002-growing season for each treatment and block for the oak regeneration study on Ames Plantation, Fayette County, Tennessee

Treatment	Initial height[a]		Period of growth: Early		Mid		Late		Total growth	
Commercial										
clearcut	43.50	(180)[b]	4.88 A[d]	(89)	1.25 A	(41)	0.36	(43)	4.90 A	(180)
High grade	42.83	(180)	4.51 A	(91)	1.35 A	(30)	2.42	(33)	5.31 A	(171)
Two age	43.15	(180)	3.44 A	(92)	0.00 B	(27)	-1.10	(28)	3.61 A	(170)
No cut	43.58	(180)	10.32 B	(90)	-0.07 B	(20)	-0.08	(30)	8.80 B	(121)
	p = 0.89[c]		p < 0.0008		p < 0.01		p = 0.52		p < 0.0006	
Block										
East	43.19	(240)	6.57	(119)	1.13	(38)	0.39	(40)	6.98	(222)
West	43.41	(240)	6.14	(121)	0.65	(57)	0.23	(65)	6.44	(213)
Bottom	43.20	(240)	4.65	(122)	0.11	(23)	-3.05	(29)	3.54	(207)
	p = 0.92		p < 0.04		p = 0.85		p = 0.98		p < 0.0001	

[a] Sample dates: Initial = 2/08/02; Early = 6/10/02; Mid = 7/14/02; Late = 8/25/02; End = 1/04/03.

[b] Sample size (n), 50 percent of seedlings were randomly measured at each period during the growing season with n representing the number of actual seedlings in the sample cross-referenced directly from previous sample. Total height growth was measured at the end of the growing season for all seedlings.

[c] Mixed model ANOVA results.

[d] Mean separation by Tukey-Kramer multiple comparison tests. Means followed by the same letter are not significantly different at the $\alpha = 0.05$ level.

Total herbaceous biomass production and end-of-season height growth were significantly negatively related across treatments; however, total herbaceous biomass production was only a moderate to weak predictor of end-of-season height growth ($r^2 = 0.55$, $p = 0.006$, $r = -0.74$). Herbaceous biomass production appeared to have a strong negative relationship with total height growth ($r = -0.74$). Mean total herbaceous biomass production differed across treatments ($p = 0.003$). Mean production was greatest within the two-age treatment, measuring 6,336 pounds per acre followed by the commercial clearcut, high-grade, and no-cut treatments with 4,793, 3,391, and 567 pounds per acre, respectively.

Microstegium production within some units of the study was extremely high. Although a strongly negative relationship was found between *Microstegium vimineum* production and mean seedling height growth within individual units, percent *Microstegium* appeared to be only a moderate to weak predictor of end-of-season seedling height growth ($r^2 = 0.54$, $p = 0.006$, $r = -0.74$). Although no differences in percent *Microstegium* production were found between treatments ($p = 0.29$), mean production ranged from 45 percent of total herbaceous biomass in the two-age treatment followed by the commercial clearcut, high-grade, and no-cut treatments with 37, 24, and 23 percent, respectively. Significant differences in mean percent *M. vimineum* biomass production occurred between blocks ($p = 0.0004$) and associated variation is accounted for in the blocking design.

When examined independently of all other variables, browse pressure accounted for approximately 67 percent of the variation in total seedling height growth ($r^2 = 0.6720$) with a slope different from zero ($p = 0.011$). Total browse pressure exhibited a strong negative relationship ($r = -0.82$) with total growth. Differences in seedling browse pressure were observed among blocks ($p = 0.006$), with mean number of seedlings browsed equaling 13, 21, and 34 for the East, West and Bottom blocks, respectively. Differences were observed among treatments ($p < 0.02$) due to the decrease of browse pressure experienced by the no-cut treatment. No differences in browse pressure were observed among the three cut treatments. Herbivory was concentrated in the early part of the growing season and was not recurrent. No additional browse was observed after the May observation date.

DISCUSSION

The results indicated that using high quality, large oak seedlings to maintain oak on highly productive sites with the four harvesting treatments studied appears promising. These seedlings had greater initial height and good first growing season rates of height growth. Light availability, seedling quality, and herbaceous competition along with browse pressure appear to be important factors contributing to seedling development in this study.

One of the key benefits in using high quality seedlings was the capability of seedlings to exceed browse height more rapidly due to their greater initial height at the time of outplanting. After the first growing season, heights of many seedlings, particularly the Premium seedlings, had already surpassed the “browse line” (approx. 4.5 feet). If the extra cost incurred by culling a larger number of smaller seedlings is not prohibitive, the use of only Premium seedlings may supply additional benefits. Furthermore, planting high quality seedlings may allow a reduction in the total number planted per acre, thereby reducing the total cost. However, planting high quality seedlings with current procedures generally presents a larger initial investment. Planting fewer stems per acre (108 stems per acre on 20 by 20 foot spacing as in this study) may also reduce seedling apparency and minimize herbivory. Although browse levels were greater early in the growing season, protection appeared to be realized owing to the cessation of herbivory once the herbaceous vegetation flushed.

Most of the increase in seedling height occurred early in the growing season in conjunction with the first growth flush. Although individuals with multiple flushes were identified, these seedlings did not comprise a very large number of the population. However, the majority of the seedlings experienced only one growth flush during the first growing season. End-of-season growth differed only when comparing the no-cut treatment with all-cut treatments. The three cut treatments experienced similar growth rates. Kramer and Kozlowski (1960) found that photosynthetic rates increased with increasing light availability, yet began to level at approximately 1/3 of full sunlight. Therefore, it is not surprising that differences were not detected after one growing season. One growing season may not be adequate for the planted seedlings within the harvested units to express variable growth potential until crowns of residual overstory canopies respond to increased growing space. Additionally, a lag in response may be attributed to the allocation of resources to the root system.

Comparatively, the no-cut treatment experienced the greatest growth. However, growth was etiolated, and the seedlings appeared to succumb to the low light environment created by the intact forest canopy and dense midstory. According to McGee (1968), seedlings under dense full canopies have fewer leaves and less mass. Although no photosynthetically active radiation (PAR) measurements were taken in this study, Johnson and others (2002) found that light levels of dense canopies often fall below 2 percent of full sunlight. Multiple factors may have contributed to seedling mortality including herbivory, herbaceous competition and limited light resources. However, overstory shade is probably the major factor. This would suggest that pre-harvest enrichment planting might not be favorable if higher mortality rates are unacceptable. In contrast, the open environment created by the three cut treatments realized very little mortality in the first year.

Herbaceous competition, particularly M. *vimineum*, has a significantly negative impact on seedling growth. However, the herbaceous growth may be culpable for the cessation of herbivory. The post-harvest release of this exotic grass appeared as an “explosion” due to the species’ ability to completely overwhelm the invaded site. Although, herbaceous biomass affected seedling height performance and provided some benefit with the cessation of herbivory, M. *vimineum* will probably become the overriding herbaceous competition impacting future seedling growth.

While these results appear positive, only first-year growth has been observed and reported. Further examination and research as seedling development continues will prove informative. Differences between treatments, genetic stock and seedling quality might become more apparent as development continues. Not only herbaceous competition but competition from woody species along with a more detailed investigation of the competitive effects of M. *vimineum* should be further studied.

CONCLUSION

A model emphasizing post-harvest enrichment planting of high quality oak seedlings is a management alternative for maintaining oak as a important component on highly productive sites. High-quality oak seedlings used in this research have exhibited good growth and may aid in re-establishing oaks on this site.

Highly productive or mesic hardwood sites generally include complex species mixtures (Johnson and others 2002) and pose greater uncertainty to sustaining oak dominated forests. Johnson and others (2002) state that each step of the oak regeneration process is plagued with difficulties and unknowns. The use of high quality seedlings for post-harvest enrichment planting may aid in reducing the number of necessary steps, unknowns, and difficulties in establishing a new cohort of oaks on these sites.

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