SURVIVAL AND DEVELOPMENT OF UNDERPLANTED NORTHERN RED OAK SEEDLINGS: 6-YEAR RESULTS[1]

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ABSTRACT.--A test was made of the performance of six types of northern red oak (Quercus rubra L.) nursery stock planted in the understory of a mature stand of upland hardwoods in southern Indiana. Manipulation of portions of the stand by thinning from below and chemical control of understory vegetation prior to underplanting resulted in four classes of stand condition in which seedling survival and growth were monitored. After 6 growing seasons, overall survival for all combinations of stand condition and seedling type was 50 percent and average seedling height was 60 centimeters (cm). Seedlings planted in areas receiving some type of cultural treatment achieved greater total heights, but survival was improved significantly only by the understory control treatment. Understory control alone had a greater positive effect on development of planted seedlings than did thinning alone. The combination of thinning from below to 60 percent stocking and understory control gave the best results in terms of seedling development, for all seedling types, as 56 percent of seedlings survived after 6 years with an average height of 78 cm. Nursery stock types differed little in their capacity to survive and develop. Mycorrhizae-inoculated seedlings displayed no increased survival or growth for either containerized or bare-root stock. Bare-root 1-0 stock grown in sub-irrigated nursery beds had higher survival and made comparable growth to larger 2-0 stock produced under identical nursery conditions. Containerized seedlings grew somewhat more rapidly than bare-root seedlings during the first 2 growing seasons following outplanting, but growth rates over the last 4 years were nearly the same for all six stock types, averaging about 5 cm per year. The greater costs and effort in producing, transporting, and planting oak seedlings grown in large containers are probably not justified by the small, short-term height growth advantage of containerization. Browsing by white-tailed deer throughout the 6-year study period has had a substantial impact. In the first growing season, 28 percent of all seedlings were browsed, with highest concentrations of deer activity in the brushy, unthinned/no understory control areas. As undergrowth has increased in the 6 years since treatment, so has browse incidence on planted oaks. Browse activity is now concentrated on the more vigorous seedlings growing in both thinned and understory control plots.

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INTRODUCTION

Throughout the eastern hardwood region, the amount of naturally occurring advance oak reproduction in mature upland hardwood stands chronically fails to meet adequacy standards, particularly on good sites (Sander 1979, Mills et al 1987). As a part of the continuing effort to discover workable silvicultural techniques for reproducing oak stands, a study was initiated in 1982 in southern Indiana to assess the performance of various types of northern red oak nursery stock planted in an array of culturally manipulated understory conditions.

The rationale for enrichment plantings of desirable species in the understories of mature stands prior to harvest has been explored in some detail (Arend and Scholz 1969, Johnson 1980, Johnson 1984, Johnson et al 1986). A number of factors have been identified which contribute to difficulties in attaining satisfactory growth and survival of underplanted seedlings, most of which relate to root-shoot ratio imbalances in outplanted seedlings as well as unacceptably high levels of competition for light, nutrients, and water from adjacent vegetation (Johnson 1979, Wright et al 1985). This study was designed to test a variety of combinations of cultural stand treatments and nursery stock types in an attempt to identify the most successful techniques for artificially enhancing oak reproduction.

METHODS

Study Area

The investigation was conducted at the Southern Indiana Purdue Agricultural Center located in Dubois County, Indiana which is in the unglaciated Crawford Uplands Section of the Shawnee Hills Natural Region in south-central Indiana (Homoya et al 1985). Soils in the study area are predominantly of the Gilpin series (Ultic Hapludalfs) which have silt-loam textures, are well-drained and moderately permeable, contain abundant rock fragments, and are typically 42 inches in depth to siltstone bedrock. Slopes in the study area range in steepness from 6 to 20 percent and have a southern aspect.

Oaks comprised 75 percent of the sawtimber basal area of the stand prior to thinning. White oak (Quercus alba L.) was the most common species, followed by northern red oak (Q. rubra L.), black oak (Q. velutina L.) and scarlet oak (Q. coccinea L.). Hickories (Carya spp.), white ash (Fraxinus americana L.), and sugar maple (Acer saccharum Marsh.) made up the remaining one-fourth of sawtimber stocking. White oak site index was determined to be 70 feet (Carmean 1971).

In summer of 1982, one-half of the eight-acre study stand was thinned during the test of a mechanical system designed to harvest small, low quality trees that would normally be deadened as a part of timber stand improvement operations (Gibson et al 1983). Overall, thinned areas were reduced to an average 60 percent stocking level (Gingrich 1967). In early September, 1982, plots assigned the understory control treatment were mist-blown with a broadcast application of glyphosate (1.5 lb AE/acre) plus triclopyr (1.5 lb AE/acre) in 25 gallons water per acre. Follow-up tree injection with triclopyrl 1:1 was used to control understory vegetation greater than 3 meters (m) tall. One year following treatment, average control of understory vegetation was rated as 80 percent (Wright et al 1985).

Study Design

Four two-acre plots were randomly assigned to two treatments (thinned, unthinned), with each of these whole unit plots repeated twice. Within each thinning treatment whole unit, four half-acre subunits were assigned randomly to two secondary cultural treatments (no understory control, understory control), each repeated twice, giving four half-acre understory control plots per thinning plot, a total of 16 subunits - 4 per whole unit. Sixteen seedlings of each of six types of nursery stock (total = 96) were planted in each of the half-acre treatment plots. Individuals from all stock type treatments were assigned totally at random within in the first subunit, with the 96-tree planting pattern repeated in the other 15 subunits. For analysis purposes, these assignments were treated as if they had been re-randomized in each subunit.

Planting Stock

Six types of northern red oak nursery stock were planted on a 3 m x 3 m spacing in the center portion of each half-acre treatment plot. Sixteen seedlings of each stock type were planted for a total of 96 seedlings per treatment plot and 1536 seedlings in total for the entire area. Stock types included: 1) containerized 1-0 seedlings inoculated with the mycorrhizae-former, Pisolithus tinctorius (Pt), 2) containerized 1-0 non-inoculated stock, 3) bare-root 1-0 stock inoculated with Pt, 4) bare-root 1-0 non-inoculated stock, 5) bare-root 1-0 stock grown in sub-irrigated nursery beds, and 6) bare-root 2-0 stock grown in sub-irrigated nursery beds. In-depth descriptions of nursery procedures used in production of these six seedling types have been outlined by Wright et al (1985).

Seedlings were planted in Fall of 1982. Bare-root stock were planted using planting bars and spades, while containerized stock were

planted using standard-type post-hole diggers. Seedlings were graded by height during the planting process, with a cull-limit set at approximately 25 cm total seedling height to lend uniformity within stock types to the experiment. The 1-0 sub-irrigated stock ran smaller in height than other types, and cull-limit for these seedlings was set at 15 cm.

Measurements

Seedling survival, height, and condition (browse, die-back, vigor) were checked after each of the first two growing seasons (1983 and 1984), and after the fourth (1986) and sixth (1988) growing seasons. Numbered metal tags on wire stakes at each seedling location were invaluable in allowing accurate seedling identification during the periodic measurements.

Analysis

Six-year total height, combined 5th and 6th season height increment, and percent survival data were subjected to analysis of variance. Significant treatment mean differences were further separated with Duncan's New Multiple Range Test at P = 0.05.

RESULTS AND DISCUSSION

Survival

After six years, overall survival for all seedlings in all four stand condition classes was 50 percent. Survival differed substantially by stand condition, but to only a small extent with seedling type. Highest rates of survival were consistently associated with the understory control treatment, averaging 60 percent (64% - unthinned, 56% - thinned) with understory control and only 40 percent (48% - unthinned, 33% - thinned) without understory control (significant at $p < .01$) (table 1). For the four combinations of stand condition, survival ranged from a high of 64 percent for all seedling types planted in unthinned-understory control plots to a low of 33 percent in thinned plots with no understory weed control (table 1).

Regardless of stock type, it is clear that red oak seedlings did not survive well when under heavy competition from woody and herbaceous understory weeds. Thinning from below without controlling the understory by mist-blowing resulted in the highest rate of seedling mortality, probably because of the favorable conditions for rapid growth by both newly germinated and established undesirable species. Overall, seedlings in thinned plots had 44 percent survival compared to 56 percent survival in unthinned plots. Soil disturbance by mechanical thinning equipment likely increased the amount of understory regrowth,

Table 1.--Six-year survival and total height, and 5th and 6th year height increment by stand condition for underplanted northern red oak seedlings in southern Indiana.

Stand Condition	Survival	Six-year height	Combined 5th & 6th year increment
	%	cm	
Unthinned, no understory control	48	34	3
Unthinned, understory control	64	64	12
Thinned, no understory control	33	61	12
Thinned, understory control	56	78	18

which would account for the conspicuously low rates of survival in thinned plots with no weed control. These areas, after six years, are note-worthy for their dense stands of undesirable competitors such as blackberry (*Rubus* spp.), poison-ivy (*Toxicodendron radicans*), greenbriar (*Smilax* spp.), and sassafras (*Sassafras albidum*).

Survival was extremely uniform among nursery stock types, with the exception of the bare-root 2-0 stock which had significantly lower ($p < .01$) survival than the other five types (table 2). Otherwise, there were no differences in survival attributable to seedling production methods or to interactions of seedling type with any of the combinations of cultural treatment. Bare-root stock survived as well as containerized stock, and non-inoculated stock survived as well as seedlings with nursery additions of Pt mycorrhizae. Confounding factors may be involved in stock-type performance comparisons and differences, above and beyond nursery production practices alone. These factors include differenes in planting techniques, variation in cull limits by seedling type, seed source variations, and the variable levels of naturally occurring mycorrhizae on non-inoculated seedlings.

The bare-root 2-0 seedlings had lowest survival rates, averaging only 36 percent, while the five other types survived about equally and averaged just over 50 percent for all combinations of stand condition. The lowered survival of the 2-0 stock is probably attributable to the difficulty of planting seedlings with extremely large and

well-developed lateral root systems, particularly in shallow, rocky soils. Conventional planting bars were not adequate to make suitable-sized holes to allow for proper placement of roots in the soil. A severe summer drought in 1983 may also have induced disproportionate mortality in the 2-0 stock, as second year survival for these seedlings was significantly lower than for the other five stock types (Wright et al 1985).

Survival was highest for bare-root 1-0 stock grown in sub-irrigated nursery beds and planted in unthinned plots with understory control (75 percent), and was lowest for bare-root 2-0 stock planted in thinned plots with no understory control (17 percent). High rates of survival (> 60 percent) were associated with all seedling types when competing understory vegetation was eliminated (table 2).

Total Height

The total height of surviving seedlings after six years was strongly influenced by thinning, understory control, and seedling type.

Table 2.--Six-year survival and total height, and 5th and 6th year height increment by seedling type for six nursery stock types of northern red oak underplanted in southern Indiana.

Seedling type	Survival	Six-year height	Combined 5th & 6th year increment
	%	cm	
Containerized, Pt-inoculated	51 a[1]	68 a	12 a
Containerized, not inoculated	52 a	64 ab	9 a
Bare-root, Pt-inoculated	56 a	59 ab	8 a
Bare-root, not inoculated	50 a	61 ab	9 a
Bare-root, 1-0, sub-irrigated beds	55 a	48 c	10 a
Bare-root, 20, sub-irrigated beds	36 b	56 bc	19 a

[1]Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Highly significant differences ($p < .01$) were detected for all of these main effects variables. However, no significant interactions existed for any of the combinations of treatments.

Northern red oak seedlings averaged 70 cm total height in thinned plots compared to just 49 cm in unthinned plots. Similarly, seedlings in plots receiving the understory control treatment had a mean total height of 71 cm versus (vs) only 48 cm for seedlings in plots with no understory control. Although fewer seedlings have survived in thinned - no understory control plots, those that remain have grown as well as seedlings in plots receiving the no thin - understory control treatment. Seedlings in unthinned areas with no understory control have achieved virtually no height growth in six years. These seedlings averaged just 34 cm total height, or less than half the size of seedlings in thinned, understory control plots which averaged 78 cm in height after six growing seasons (table 1).

Nursery stock type had a significant effect ($p < .01$) on six-year total height. However, the variable of total height in 1988 was found to be strongly correlated with original (1982) seedling height. Total height of each seedling at time of planting was not measured, thus analysis of covariance with original seedling height as the covariate was not possible. Since nursery production practices inherently influence size of seedlings, it was decided that height attainment comparisons between stock types are valid for the purposes of this study, keeping in mind that some differences between types may be relics of the original differences in size of planting stock.

Table 3 shows original mean seedling heights and six-year total heights (1988) for the six types of red oak planting stock. Duncan's mean separation procedure indicated no significant differences ($p < .05$) in six-year height between inoculated vs non-inoculated types or between containerized vs bare-root stock. Differences did exist between containerized-inoculated seedlings and the two types of sub-irrigated stock. Also, the 1-0 bare-root sub-irrigated stock were significantly smaller after six years than the four types of seedlings produced without sub-irrigation, a difference very probably linked to original seedling size. Examination of mean six-year height increment by seedling type indicates that growth rate potential of the initially smaller seedlings is not necessarily inferior to that of other types. Height development is important not only for chances for survival in the understory but for higher probabilities of successfully competing in the next stand. Therefore, planting large seedlings, up to a

practical limit, should result in larger size of artificial oak advance reproduction at the time of overstory removal.

5th - 6th Year Height Increment

Two-year periodic height increment (5th and 6th growing seasons combined) was determined for each seedling surviving in 1988 by computing the difference between 1988 and 1986 total height on a seedling by seedling basis. Comparisons using this rate make clear how well surviving seedlings are presently growing, and indicate to some extent whether or not treatment effects are still being expressed five to six years following study initiation.

Over the last two years, seedlings in thinned plots have grown at more than twice the rate (15 cm vs 7 cm) of seedlings in unthinned conditions. The same relationship and magnitude of difference holds for seedlings growing in areas with understory control vs no control. Seedlings in unthinned areas with no understory control grew 3 cm during this two-year interval, as compared with 18 cm height growth for oaks in thinned-understory control stand conditions (table 1). Without question, surviving seedlings continue to make acceptable growth only in areas that originally received some combination of thinning and/or understory control treatment. No significant differences between seedling types were detected by this analysis of recent growth rate trends (table 2).

Table 3.--Mean original seedling height, six-year height, and six-year height increment by seedling type for six northern red oak nursery stock types underplanted in southern Indiana.

Seedling type	Mean height at planting	Mean six-year total height	Mean six-year height increment
	cm		
Containerized, Pt-inoculated	37	68 a[1]	31
Containerized, not inoculated	34	64 ab	30
Bare-root, Pt-inoculated	41	59 ab	18
Bare-root, not inoculated	40	61 ab	21
Bare-root, 1-0, sub-irrigated beds	20	48 c	28
Bare-root, 2-0, sub-irrigated beds	32	56 bc	24

[1]Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Deer Browse

At each measurement, incidence of browsing in the current year on the dominant shoot was tallied for each seedling. However, no quantitative measure of the effect of browsing on seedling height or survival was made. Therefore, only a qualitative discussion on the effects of browsing activity of white-tailed deer on seedling development is possible. Also, relative differences in browse activity and impact between treatments and measurement periods were compiled, and are presented here.

Browsing of oak seedlings was heaviest during the first year (1983) following planting. Of the 1,536 seedlings planted, 433 (28 percent) were browsed, with nearly half of this activity (47 percent) occurring in unthinned plots with no understory control. Not surprisingly, deer apparently spent more time in these thicker, brushy sections of the study area, and browse incidence on planted oaks showed this effect. Conversely, in this same year, seedlings planted in more open stand conditions (thinned with understory control) were browsed at the rate of only 14 percent.

After six years, the situation is quite different. Browse activity by deer is now concentrated on the more vigorous, palatable seedlings in areas that originally received understory control treatment. Also, browse incidence on surviving red oak seedlings in 1988 was only 12 percent (92/770). Increased amounts and diversity of desirable browse species, as well as greatly lowered numbers (density) of study seedlings, has lessened the pressure and effect of feeding deer on surviving underplanted red oaks.

The effects of browsing activity on the survival and development of planted seedlings are important to this discussion. In addition to improving growth and survival by reducing competition for light, water, and nutrients to underplanted oaks, the cultural treatments -- in particular, understory control -- also reduced incidence of deer browsing during the critical first year. It appears that had deer not been a factor in this study, there may not have been such dramatic differences in development between seedlings in treated and untreated areas.

SUMMARY AND CONCLUSIONS

Underplanted northern red oak seedlings survived and developed best in conditions created by controlling competing understory vegetation. Growth was increased but survival was decreased by the addition of a thin-from-below treatment. Thinning or partial cutting to create shelterwood conditions causes soil disturbance and increased light levels at the forest floor, which in turn result in increased growth of competing vegetation. Without follow-up understory weed control, underplanted seedlings will perform relatively poorly under such conditions.

Seedling type in this experiment did not prove to be the key to success or failure. Survival was not linked to methods of nursery stock production, although plantability was shown to be important as survival was low for 2 year old seedlings with excessively large root systems, especially when planted under adverse conditions of shallow, rocky soils. Containerized seedlings had the highest initial growth rates, but survived no better and were not significantly larger after six years than bare-root seedlings. The small advantages of containerization do not warrant the extra production, transportation, and planting costs involved. Mycorrhizae-inoculated seedlings showed no superiority over non-inoculated seedlings. Of the six stock types used in this study, large 1-0 bare-root seedlings are the most desirable type of planting stock for use in oak underplanting when practical considerations are taken into account.

Potential impacts of deer browsing on the successful establishment of planted oaks should not be overlooked, even in areas with only moderately heavy deer densities (30-40/square mile). Browse impact on planted seedlings was reduced in this study by practices which controlled understory vegetation. Thick, brushy, stand conditions tended to attract deer, thus concentrating feeding activity on seedlings planted in these areas. Seedlings in the more open areas with understory control were much less affected by browsing activity. It is recommended that in areas with high deer populations, some consideration be given to protecting desirable regeneration from damage by browsing, particularly since establishment costs of artificial advance reproduction are high.

LITERATURE CITED

Arend, J.L. and H.F. Scholz. 1969. Oak forests of the Lake States and their management. USDA Forest Service Research Paper NC-31. 36 p.

Carmean, W.H. 1971. Site index curves for black, white, scarlet, and chestnut oaks in the Central States. USDA Forest Service Research Paper NC-62. 8 p.

Gibson, H.G., P.E. Pope, D.L. Cassens, B.C. Fischer and G. M. Wright. 1983. Thinning the upland hardwood forest: A mechanized system. Proceedings Second Southern Silvicultural Research Conference, Atlanta, Ga. USDA Forest Service General Technical Report SE-24, pp. 230-239.

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. Forest Science 13: 39-53.

Homoya, M.A., D.B. Abrell, J.R. Aldrich, and T.W. Post. 1985. The natural regions of Indiana. Proceedings Indiana Academy Science 94: 245-268.

Johnson, P.S. 1980. Oak planting in mid-South upland hardwoods: Problems and prospects. Proceedings Mid-South Upland Hardwood Symposium for the Practicing Forester and Land Manager, Harrison, Ark. pp. 74-87.

Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. Canadian Journal Forest Research 14: 536-542.

Johnson, P.S., C.D. Dale, K.R. Davidson and J.R. Law. 1986. Planting northern red oak in the Missouri Ozarks. Northern Journal Applied Forestry 3: 66-68.

Johnson, R.L. 1979. Adequate oak regeneration: a problem without a solution? Proceedings Seventh Annual Hardwood Symposium, Hardwood Research Council, Cashiers, N.C. pp. 59-65.

Mills, W.L., B.C. Fischer and T.W. Reisinger. 1987. Upland hardwood silviculture: A review of the literature. Purdue University Agricultural Experiment Station Bulletin No. 527, 29 p.

Sander, I.L. 1979. Regenerating oaks with the shelterwood system. Proceedings 1979 John S. Wright Forestry Conference, Purdue University, West Lafayette, Ind. pp. 54-60.

Wright, G.M., P.E. Pope, B.C. Fischer, H.A. Holt, and W.R. Byrnes. 1985. Chemical weed control to establish natural and artificial regeneration in a mechanically thinned upland hardwood stand. Proceedings Third Biennial Southern Silvicultural Research Conference, Atlanta, Ga. USDA Forest Service General Technical Report SO-54. pp. 266-272.