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Artificial Regeneration of Northern Red Oak and White Oak on High-Quality Sites: Effect of Root Morphology and Relevant Biological Characteristics

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Abstract

Northern red oak (*Quercus rubra*) and white oak (*Quercus alba*) are important components of high-quality mesic sites and are essential as lumber species and hard mast producers. Regeneration of these species has been difficult, and their absence in newly regenerated stands is a major concern of foresters and wildlife biologists. Several important biological traits of oak species may contribute to regeneration difficulties. These primary determinable biological traits may be shade intolerance and aging, which affects their reproductive potential. These factors, coupled with incompatibility of closely related individuals, greatly hamper natural regeneration efforts by decreasing adequate advance oak regeneration for future stands. Artificial regeneration can significantly increase the oak component because large oak seedlings that exceed the suggested size of advance oak regeneration can readily be produced in forest tree nurseries with specific nursery prescriptions. Seedlings produced in this fashion can readily be evaluated. Those from the top 50 percent, based upon first-order-lateral root numbers, have proven to be very effective in artificial regeneration of stands, in establishing plantings for seed orchards, and in establishing mast-producing areas within larger forested stands.

Keywords: Artificial regeneration, high-quality mesic site, northern red oak, nursery protocol, seedling evaluation, site maintenance, white oak.

Introduction

Much has been written about the difficulty of obtaining northern red oak (NRO) (*Quercus rubra*) regeneration on high-quality mesic sites. But, in spite of much effort, little has been accomplished to change our "luck." We believe that luck has little to do with regenerating NRO. Instead, it is the biology or ecology of the species that has been ignored in attempts to find procedures that work consistently and can be prescribed with some degree of confidence.

Perhaps one of the basic problems is that "oak" tends to be used as a generic term that connotates a commonality among all species resulting in ignoring individual species' silvicultural and ecological requirements. The silviculture of swamp chestnut oak (*Q. michauxii*), turkey oak (*Q. laevis*), and NRO is significantly different and thus, the biological requirements of the individual species must not be addressed as "oak" requirements. The single biological attribute of all oaks, however, is the near obligate requirement for full sunlight in order to survive and to produce adequate early growth that enables attainment of a dominant crown position.

We are going to restrict our discussion to NRO and white oak (WO) (*Q. alba*) because these are the two species we have studied the longest. We will not present an extensive literature review of oak because many have already been published. The most recent oak proceedings edited by Loftis and McGee (1993) contain detailed reviews on many specific subjects that may be helpful in understanding, if not alleviating, specific regeneration problems. We will briefly describe the biological factors that we found to be essential in regeneration of

NRO and WO on high-quality mesic sites. These two species have contrasting biology but also share many common attributes. In this context, we will discuss several important factors involved in NRO and WO regeneration. These factors are: 1) biological constraints; 2) nursery practices; 3) acorn availability; 4) seedling evaluation; and 5) pre and post planting site maintenance. We will present data on a few current cooperative studies between the Institute of Tree Root Biology (ITRB) and Southern Region of the USDA Forest Service.

Background

The basis for our research, as well as most oak regeneration research for the past 40 years, is the work by Sanders (1971, 1972) who demonstrated the importance of advanced oak regeneration before stands are harvested. His work was done primarily on lower quality sites (site index = $65_{\text{base } 50}$) where competition from faster growing species was minimal. Even on these sites, however, considerable time and effort were required to build up the advanced regeneration required to assure oak presence in future stands.

Johnson (1981) attempted to produce nursery grown oak seedlings of sufficient sizes to mimic Sander's advance regeneration. Various multi-year growing procedures were used to obtain adequate stem dimension that was considered comparable to Sander's recommendation. The best seedlings were then top clipped and root pruned to facilitate shelterwood underplanting. However, competition from faster growing species on better sites seriously reduced the effectiveness of his prescription. Ultimately, the procedure was recommended for use where oak site $\text{index}_{(50)}$ was 70 where faster growing competitors were not present (Johnson 1993).

Loftis (1983) attempted to develop advanced regeneration on high-quality mesic sites through natural regeneration techniques consisting of a series of partial crown releases to encourage natural oak regeneration. Periodicity of acorn production and severe competition from faster growing competitors were handicaps that reduced the effectiveness of this procedure. However, this procedure clearly established that a shelterwood system was very effective in obtaining hardwood regeneration on high-quality sites with one drawback: NRO was not being established in these stands.

Three major principles of NRO and WO regeneration emerged over the past 40 years. We recognized that: 1) advanced oak regeneration is essential; 2) altered nursery practices might produce the required stock; and 3) faster growing competitors would be a major impediment on high-quality mesic sites where obtaining oak regeneration is so critical. The major goal when research on NRO and WO began at the ITRB in the mid-1980s was to develop a reliable nursery protocol that would consistently produce seedlings of adequate size for advanced oak regeneration in cleared areas. This nursery fertility protocol became, and still remains, the keystone of our oak research (Kormanik et al. 1994a; Kormanik et al. 1994b). Its consistency in producing acceptable seedlings made it possible to conduct research in physiology, mineral nutrition, and development of 1-2 hectare mast-producing areas that will provide for future acorn production for oak regeneration efforts and hard mast production for wildlife maintenance.

Biological Constraints

One of the biggest impediments to successful NRO and WO regeneration on high-quality sites is adequate sunlight: too little sunlight and oak regeneration cannot survive, abundant sunlight and the competitors take over the stand. This is closely followed in importance by the reduction in acorn production as the tree ages. When height growth slows down after age 50, only several cm of the current years' branch tips may be available for acorn development. This fact is simply overlooked, and mature stands are maintained under the illusion that they are providing acorns for hard mast and for regeneration.

Inbreeding in natural oak stands may be a most critical problem that is rarely addressed (Cecich 1993). Acorns remain close to the trees that bore them and thus, clumping of closely related oak can be expected. It is now commonly believed that the callose plugs that precede pollen tube penetration through the styles' transmitting tissue may be indicative of pollen incompatibility. This could be brought about by selfing or pollination by closely related individuals (Cecich 1993). The problem may be common within many *Quercus* species and not unique to NRO and WO.

Several studies showed that full-sun-grown NRO seedlings have higher net photosynthesis rates (Pn) than shaded seedlings (Crunkilton et al. 1992; Kubiske and Pregitzer 1996; Sung et al. 1998). Photosynthesis rates for 1- and 2-year-old NRO and WO seedlings grown with 30 percent light were about 65 percent of the Pn for full-sun-grown seedlings (Sung et al. 1998). Two-year-old 30 percent-light-grown NRO seedlings had about half as much total biomass as the full-sun-grown seedlings. More importantly, however, is that these shaded NRO seedlings had different biomass allocation patterns than the sun seedlings. In two-year-old full-sun NRO seedlings 10, 30, 37, and 23 percent of dry weight was allocated to leaves, stem plus branches, taproots, and lateral roots, respectively (Sung et al. 1998). However, in 30-percent-light-grown NRO, 14, 43, 34, and 9 percent of biomass was found in these corresponding seedling components. The 14-percent reduction in lateral roots is important because it eliminates a significant portion of the feeder root complex. Similar effects of shade on biomass allocation patterns were observed in WO (Sung et al. 1998).

In addition to the reduction in feeder root development, understory oaks must adapt to full sun when the overstory canopy is removed. With increasing light intensity, choloroplasts engage a xanthophyll cycle-mediated photoprotection mechanism to safely dissipate the excessive absorbed light energy as heat. However, leaves from shade-grown plants have smaller xanthophyll cycle pools and lower photoprotection index values as compared to sun leaves (Faria et al. 1996, Logan et al. 1996). Sung et al.1997 reported that Pn for NRO planted under hardwoods (less than 5 percent full sun) or pine (less than 40 percent full sun) was 5 and 30 percent of the Pn from oaks planted in clearcut areas. Similar results were found for WO. Oaks under hardwoods had very small photoprotection index (0.1), whereas oaks in the clearcuts had a photoprotection index of 0.8 (Sung et al.1997). Thus, release of oaks from the understory can result in at least 1-year delay in maximum photosynthesis because shade-grown oak chlorophyll probably would not have been protected from sun bleaching once the overstory canopy was removed. With little ability to protect the leaves from sudden increase in light intensity, and with small percentage lateral root biomass, it might take these released oaks several years to adapt to full sun and begin rapid growth. However, in the presence of faster growing competing species, these oaks will soon be shaded.

Acorn Production

Obtaining adequate acorns for nursery research can be a frustrating endeavor. Adverse environmental and edaphic conditions, predation, and various insects, are known to destroy more than 95 percent of the acorns in a heavy mast year and entire crops during poorer mast years. White oak acorns rapidly germinate after abscission. The radicles penetrate into the soil, and thus, it is not unusual to obtain large cohorts of seedlings following a bumper mast crop. These seedlings usually die within 2-5 years. Seldom, if ever, are such massive cohorts of NRO observed because the long stratification period required for germination often results in desiccation and reduced viability. Spring controlled burning in NRO stands in the spring after a heavy fall mast crop generally reveals abundant acorns but essentially none that germinated. This is due to severe desiccation since their maturation and abscission. It is evident that acorn-producing areas are critical, and proper collection and storage of acorns are essential if artificial regeneration is to be a viable alternative to natural regeneration.

Nursery Protocol

The development of a reliable nursery management protocol was considered essential even before problems encountered with acorn availability were considered. The basic nursery fertility protocol was developed in the mid-1980s for sweetgum (*Liquidambar styraciflua)* and with some modifications, still remains the keystone of our oak regeneration effort. Its consistency in producing reliable seedling crops has permitted the development of a biologically based seedling evaluation protocol. The protocol has resulted in the establishment of 1-2 hectares of oak mast-producing areas and other stand regeneration prescriptions. It has also proven successful in producing quality oak seedlings from 10 oak species and many other hardwoods (Kormanik et al. 1994a, 1994b).

Table 1—First-order lateral roots family means broad sense heritability estimates for *Quercus rubra* and *Q. alba* in several studies

Study	Heritability	Standard Error
Q. rubra		
1	0.898	0.153
2	0.870	0.114
3	0.843	0.235
Q. alba		
1	0.843	0.138
2	0.918	0.073
3	0.843	0.235
4	0.949	0.026
5	0.893	0.116

Although NRO and WO respond similarly to the standard fertility protocol, WO must be watered lightly almost daily during early spring in order to obtain 80 cm or more heights. During this time, seedlings are undergoing a lengthy period of extensive feeder root development without stem elongation. If feeder root development is not encouraged, one can expect the substandard WO seedlings that are characteristically being produced by forest tree nurseries. In contrast, the same early watering regime for NRO will result in too much early height growth and excessively large seedlings. These contrasting responses to watering regimes necessitate sowing these species in nursery beds under separate irrigation lines. Acorn sowing for both species should be completed very soon after collection. If drought persists throughout the winter, occasional light irrigation will be required to prevent NRO acorns from desiccation and to prevent damage to the developing taproot of WO.

Acorns are sown to obtain a bed density of 60-70/m^2 and seedling morphological development is controlled by NH_4NO_3 applications and irrigation. For outplanting, we prefer NRO and WO to have a minimum root collar diameter (RCD) of 8 mm, height (HGT) of 0.80-1.2 m, and the first-order lateral root (FOLR) number should be at or above the average for that group. The nursery soil is analyzed before each growing season, and all fields are brought up to specifications. We are, thus, developing a data base for nutritional requirements of individual oak species that are characteristically produced in the Georgia Forestry Commissions' (GFC) nurseries.

Seedling Evaluation

Seedling quality consistency at our experimental nursery near Athens and the two GFC state forest nurseries has permitted the development of a seedling evaluation system. The evaluation system is based on FOLR numbers and also specifies the minimum RCD and HGT for both species. First-order-lateral-root morphology is a highly heritable trait and is ideal for comparing progeny of half-sibling seed lots and comparing progeny from different mother trees (table 1). Although heritability estimates only apply strictly to the experiments from which they were obtained, consistently high values from repeated tests tend to substantiate the importance of a specific trait (Wright 1976).

Seedling RCD and HGTs have been the standard criteria for evaluating seedling quality. However, simple modification of bed density, fertility regime, or irrigation schedules may affect these seedling parameters, and thus, render their use questionable. First-order-lateral-root development remains consistent for a given seedling bed density even under different growing conditions and fertility regimes.

Tables 2 and 3 contain typical nursery data for NRO and WO, respectively, progeny produced by GFC using our protocol. Note the wide range in specific growth parameters is found that if an individual seedling exceeds the mean FOLR for its half-sibling group, then it will most likely also exceed the RCD and HGT means for that group. In evaluating progeny from hundreds of mother trees, seldom do more than 50 percent of the seedlings meet or exceed our outplanting standards. The seedlings from the lowest 30 percent of the crop seldom have more than a single FOLR and usually are less than 1/3 of the HGT and RCD of the better 50 percent of the crop. Evaluating and discarding the poorest 30 percent of seedlings are rapid procedures effectively done at the nursery during lifting and packing.

Sowing by mother tree seedlots permits early evaluation of the competitive ability of specific progeny groups (tables 2 and 3). Characteristically, sibling lots that perform poorly in the nursery environment develop poorly after outplanting. Mother trees from future collections whose individuals produce few FOLR and are generally substandard in both RCD and HGT are discontinued, e.g., mother tree 2-23-850 in table 2. Conversely, potentially

Table 2—Morphological and growth characteristics of 1-0 northern red oak (*Quercus rubra*) seedlings grown in 1995

	FOLR Number		Seedling less than mean[a]	RCD (mm)		HGT (cm)	
Family	*Mean*	*Range*	*%*	*Mean*	*Range*	*Mean*	*Range*
1-14-915	6.4	0-26	58	9.8	3.9-18.7	125	22-223
2-10-540	5.7	0-23	54	8.4	3.7-15.8	135	40-262
2-19-630	4.6	0-25	57	9.0	2.9-17.1	131	43-238
2-23-850	2.3	0-25	72	6.2	1.0-16.9	73	8-207
2-29-565	5.2	0-24	58	9.8	3.2-19.2	134	18-260
2-6-735	4.0	0-16	63	9.1	3.4-17.6	117	28-211
3-3-526	4.9	0-19	54	9.1	3.3-15.7	114	33-243
4-2-902	3.6	0-15	63	8.4	3.6-15.2	124	46-223
4-4-882	4.0	0-19	57	8.8	3.9-16.4	126	47-243
4-14-2459	5.9	1-20	52	10.5	3.4-18.9	125	22-253
4-27-100	4.2	0-19	56	9.3	2.9-17.9	141	33-243
6-14-200	5.0	0-20	58	8.5	3.0-15.69	121	41-232

[a] The percentage of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

Table 3—Morphological and growth characteristics of 1-0 white oak (*Quercus alba*) seedlings grown in 2000

	FOLR Number		Seedling less than mean[a]	RCD (mm)		HGT (cm)	
Family	*Mean*	*Range*	*%*	*Mean*	*Range*	*Mean*	*Range*
ASO-5	6.7	0-28	53	9.3	2.7-18.6	86	14-198
ASO-16	5.8	0-27	56	10.3	2.0-19.0	89	12-180
ASO-18	4.8	0-28	56	9.8	2.6-19.8	98	22-183
ASO-42	5.2	0-42	55	9.2	2.1-22.4	90	8-188
SRS-585	3.6	0-26	56	8.2	2.3-16.8	82	21-158
SRS-588	4.2	0-24	57	8.5	2.7-15.6	81	11-153
SRS-592	4.7	0-29	57	8.7	1.6-17.8	88	7-161
SRS-593	4.0	0-25	56	8.4	1.1-15.1	77	7-161
SRS-596	4.2	0-23	65	6.8	1.1-15.3	47	6-139
SRS-597	4.4	0-26	56	8.8	2.7-14.9	93	23-159
SRS-598	2.6	0-17	57	8.2	2.2-15.2	84	20-178
SRS-599	5.2	0-29	57	8.4	1.6-16.0	83	7-163
SRS-601	3.3	0-17	51	8.9	2.5-14.3	77	15-135
SRS-602	3.3	0-14	53	8.6	2.4-15.5	71	12-145
SRS-603	5.0	0-29	57	8.7	1.2-15.4	85	10-152
SRS-606	3.6	0-28	59	8.1	2.3-15.6	87	14-141
SRS-607	3.6	0-29	56	8.9	2.0-16.3	75	6-144
SRS-608	3.4	0-17	57	9.9	2.6-16.2	92	19-153

[a] The percentage of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

Table 4–Morphological and growth characteristics of 1-0 white oak (*Quercus alba*) seedlings from grafted mother trees

	FOLR Number		Seedling less than mean[a]	RCD (mm)		HGT (cm)	
Family	*Mean*	*Range*	*%*	*Mean*	*Range*	*Mean*	*Range*
KYWO 11	3.4	0-17	63	7.5	2.0-13.8	46	12-128
KYWO 31	3.0	0-19	66	8.4	3.0-15.3	35	8-104
NAWO-01	2.5	0-16	67	7.2	3.2-13.6	28	8-87
NAWO 23	4.1	0-22	62	8.2	2.9-15.2	48	8-142
NAWO-24	3.8	0-21	60	7.9	2.8-15.0	39	14-147
NAWO-28	2.1	0-18	72	6.5	2.5-11.6	24	6-68
NAWO-29	2.3	0-18	67	6.5	1.0-15.3	25	8-100
SAWO 3	3.9	0-27	61	8.7	3.6-18.0	39	12-110
SAWO 7	3.6	0-23	61	9.0	2.7-17.4	48	12-134
SAWO 12	2.8	0-16	58	7.4	2.4-13.0	36	11-112
SAWO 14	4.6	0-32	64	8.6	2.7-18.4	46	12-151
SAWO 28	6.2	0-36	64	8.4	2.2-19.3	45	12-171

[a] The percentage of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

better progeny groups can be identified after a single nursery growing season. In the 2000 nursery season, we identified individual NRO selections that had less than 15-20 percent substandard seedlings. This is encouraging that inclusion of such potent genetic material in seed orchards should be effective in improving the number of plantable seedlings from each nursery crop.

Establishing NRO and WO individuals in seed orchards from the very best individuals with the highest FOLR numbers has resulted in acorn production by age five. At age seven, individual WO have produced sufficient acorns for nursery testing and establishment of seed orchards by the GFC.

While seedling seed orchards have been very effective for both NRO and WO, grafted white oak seed orchards maintained by the USDA Forest Service at the Beech Creek Seed Orchard near Murphy, N.C., have not been satisfactory in terms of progeny development in the nursery (table 4). Progeny from this grafted seed orchard have been tested for 5 years, and germination normally varies from 5-50 percent. Transplanting these progeny even under ideal seed orchard conditions has not resulted in acceptable growth in most areas. The reason for this poor performance of acorns from grafted material is unclear. Investigation into this is needed since grafting specific individuals with outstanding attributes could be a valuable tree improvement tool.

Pre and Post Site Maintenance

The shelterwood method of naturally regenerating hardwoods on high-quality mesic sites works well except for lack of regeneration in the valuable oak component. Left unattended, these two oak species cannot compete against the faster growing competitor species (Loftis 1983). Unfortunately, neither will artificially regenerated NRO or WO compete under these same circumstances. They need abundant sunlight and minimal root competition to be competitive. However, a clearcut followed by an effective burn, if necessary, usually is sufficient to maintain these large artificially regenerated oak seedlings for 3-5 years. In all cases, however, stumps should be treated with a silvicide to prevent sprouting because no individual seedlings, regardless of their origin or phenotypic characteristics, can successfully compete with stump sprouts of yellow poplar (*Lilodendron tulipfera*), red maple (*Acer rubrum*) or Carolina silverbell (*Halesia carolina*) present on a high-quality mesic site. With adequate pre-planting vegetation control, the oak seedlings should be able to compete against individuals of seed origin for 3-5 years, but will usually need additional release between ages 7-15.

Initial post planting maintenance is primarily concerned with stump sprouts, but by year two blackberries (*Rubus* spp.) and grape (*Vitae* spp.) on specific sites can become a severe problem, especially when both occur simultaneously. To establish seedling seed orchards, we prefer that no thinning be attempted until acorn production is initiated between ages 5-10. Acorn production under such conditions has been achieved at ages 4-7 for both NRO and WO. However, under forest conditions, age of acorn initiation is unknown but will depend heavily upon crown competition and early fertilization.

Current Trends of ITRB Research

The nursery protocol and its potential benefits used in producing oak planting stock have been published elsewhere and need not be repeated here (Kormanik et al. 1994a, 1994b). Close examination of data in tables 1-3 reveals why a sound biologically based grading system is an essential first step in developing an effective artificial regeneration initiative. If a seedling cannot compete effectively in an ideal nursery setting, it is unlikely to be competitive in the field under significantly greater stressful conditions. This data can also serve as a wake-up call to the difficulty in obtaining advance regeneration through traditional management procedures where a high percentage of seedlings may be inherently poor competitors. Preliminary data suggest that late germinating acorns produce a disproportionally large share of these substandard seedlings.

Our initial NRO artificial regeneration study is 11 years old, and the results comparing seedling performance in a clearcut and in a shelterwood has been presented at the 11th Biennial Southern Silviculture Research Conference (Kormanik et al., in press). No pre or post planting maintenance was performed beyond the initial treatment, except at age 7 when a circle (0.9 m radius) was cleared around each tree to release the dominant individuals in the clearcut. At the same time, the overstory was removed from the shelterwood. Three years after shelterwood removal, the 11-year-old NRO seedlings had a mean HGT growth of approximately 0.60 m since outplanting. The mean HGT for the best seedlings was 1.6 m and many were overtopped by more rapidly growing competitors. Comparable individuals established in the clearcut had mean HGTs of 3.5 m and some of the dominant ones had HGTs of 5-6 m.

A NRO mast evaluation trial was installed in a small clearcut established in a hurricane-damaged stand below the scenic Brasstown Bald Visitor Center on the Chattahoochee National Forest near Blairsville, GA. Progeny from 25 mother trees represented by 1250 half-sib progeny showed considerable growth differences. Unlike the 11-year-old study, this regeneration study was maintained regularly and the competition was effectively controlled through the third year, when the crowns began controlling competition. Initial mean HGT and RCD for these trees were 0.87 cm and 9.9 mm, respectively. Mortality over the 5 years has been 21 percent due almost entirely to vole (*Microtus* spp.) damage during years 1 and 2. At year 5, mean HGT and DBH were 2.76 m and 22.9 mm, respectively. Almost every family had individuals 3.5 - 5.5 m in HGT with excessive crown competition developing in adjacent rows. Thinning will be initiated in 2001 because of this competition. Acorns have not been observed as yet, and hopefully, maintenance of competition-free crowns will encourage early acorn production.

A second NRO mast evaluation study using 17 different half-sib progeny groups was established in 1995 on an old pasture near Morganton, NC, in cooperation with the NC Division of Forest Resources. There were 765 seedlings in this test. Initial mean HGT and RCD were 0.94 m and 12 mm with mean FOLR of 9.9. Mortality during the initial 5 years was 1.6 percent, and some of this was mechanical damage that occurred in the first year. After the fifth growing season, mean HGT and DBH were 5.3 m and 52.7 mm, respectively. Many families had individuals whose HGT exceeded 7.0 m with DBH exceeding 90 mm at age 5. Crown competition was excessive after the sixth growing season, and thinning was necessary before the seventh year growing season. An appropriate herbicide was used to control the fescue sod. In our two other large studies that were planted where herbicide use was not permitted, thousands of seedlings died the first year due to excessive competition and allelopathic effects from heavy fescue sod.

The initial WO planting established by the ITRB that consists of progeny from 30 different mother trees with 1200 seedlings has just completed its third growing season in year 2000. When this study was initiated, we did not know the importance of early season irrigation. Mean HGT and RCD of the nursery stock was 0.67 m and 9.8 mm, respectively, with mean FOLR of 9.6. After three complete growing seasons, mean HGT and DBH were 1.87 m and 10.3 mm with a mortality rate of 9 percent. Progeny from almost all families was well represented by individuals with HGT and DBH exceeding 3.0 m and 32 mm, respectively.

During year 1, herbicide usage on the site was not permitted. Only stump sprouts in direct competition with the planted seedlings were controlled by mechanical procedures. During the second and third year, stump and root sprouts continued to be serious competitors but by then, herbicide usage was permitted on the sites. This treatment was effective in maintaining the WO in a dominant position.

Conclusions

A viable component of both NRO and WO are essential on high-quality mesic sites if we are to maintain the biological diversity so critical to the long-term health of the forests and organisms that depend so heavily upon them for their existence. Partial crown removals or single tree selection appear to be counter-productive as a procedure for obtaining and maintaining these oak species as a viable component. These oaks are intolerant of shade and will continue to decline in numbers and importance in future stands on these higher quality sites if we fail to provide adequate stand conditions that will permit them to be competitive.

Metric Equivalents

1 inch = 2.54 centimeters (cm)

1 foot = 0.304 meters (m)

1 inch = 25.4 millimeters (mm)

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