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Planting Red Oak Under Oak/Yellow-Poplar Shelterwoods: A Provisional Prescription

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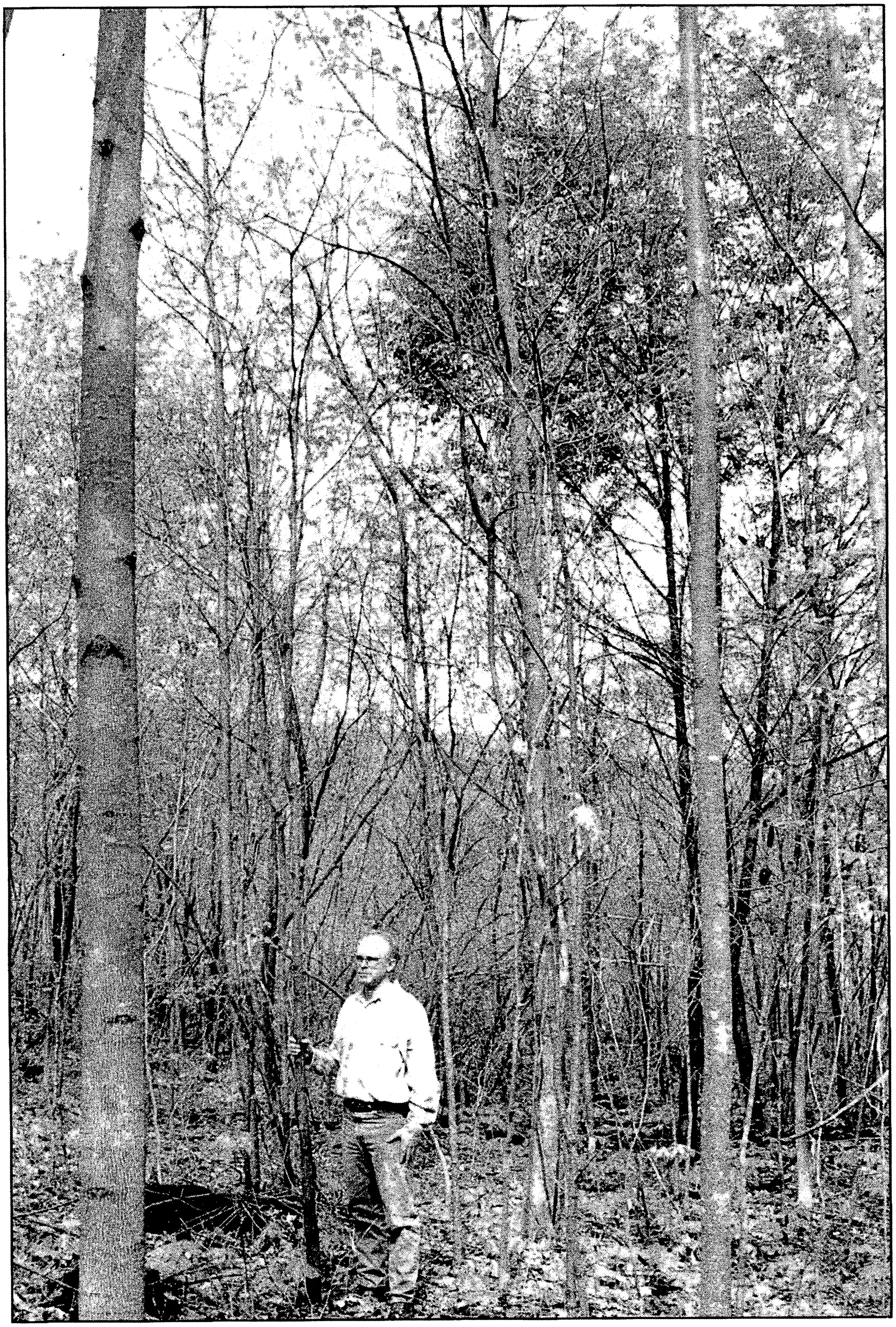

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COMBINING OAK PLANTING WITH THE SHELTERWOOD METHOD

Northern red oak (*Quercus rubra* L.) is declining in abundance across the Central Hardwood Region. Reasons for the decline are partly related to the species' slow early growth and shade intolerance. Red oak's capacity to replace itself therefore is usually severely limited on the more productive sites where high density, vertically stratified stands of mixed composition allow little light to penetrate to the forest floor. Under those conditions, the oak seedlings that become initially established are typically short-lived (Johnson 1993b). Another contributing factor is red oak's relatively demanding site requirements, which force it to co-occur with fast-growing species such as yellow-poplar (*Liriodendron tulipifera* L.). Yellow-poplar outgrows red oak, is long-lived, and regenerates aggressively from seed and sprouts after complete or moderately heavy overstory removal (Beck 1990, Beck and Della-Bianca 1981).

Although the shelterwood method has not been consistently successful in regenerating oaks (Loftis 1983, Schuler and Miller 1995), its potential nevertheless has been demonstrated in theory and practice (Dey and Parker 1996, Hannah 1987, Johnson *et al.* 1989, Loftis 1990, Schlesinger *et al.* 1993). Moreover, coupling oak planting with the shelterwood method offers a silvicultural alternative to exclusive reliance on natural regeneration (Dey and Parker 1997; Gordon *et al.* 1995; Johnson *et al.* 1986; Teclaw and Isebrands 1993; Tworkoski *et al.* 1986; Weigel and Johnson 1998a, 1998b). Successful application of the method is based on the assumption that after shelterwood removal the growth capacity of a significant proportion of the planted trees will be sufficient to keep up with or exceed the most vigorous competitors. This approach is consistent with the ability of oak reproduction to increase in root mass while growing beneath the parent stand. There, under favorable conditions, roots attain a size capable of sustaining rapid shoot growth, and thus canopy dominance, after overstory removal (Dey *et al.* 1996; Johnson 1979, 1993b; Sander 1971). However, research has shown that the success of the method depends on the pre-planting site preparation, site quality, competition, overstory density, size and type of nursery stock used, and other factors (Dey and Parker 1997; Johnson 1984; Teclaw and Isebrands 1993; Weigel and Johnson 1998a, 1998b).

This report presents a provisional prescription for planting northern red oak under shelterwoods dominated by oaks and yellow-poplar, and discusses related planting problems and opportunities. It is based on the results of combining the shelterwood method with the planting of different types of northern red oak nursery stock in southern Indiana.

APPLICATION AND PROVISIONAL PRESCRIPTION

Precaution

The following silvicultural prescription is "provisional" because it is partly based on methods of competition control not directly observed in the related research (see How the Study Was Conducted). The related study nevertheless shows that the performance of planted northern red oak on yellow-poplar sites is adequate during the first 5 years after shelterwood removal (8 years after planting) if appropriate methods are used. But after that time, mortality of planted trees due to suppression by yellow-poplar is unacceptably high in the absence of additional competition control.

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Our prescription therefore calls for competition control after shelterwood removal based on methods reported in the literature, even though the effects of those methods were not directly observed on the study area.

Prescription

The following recommendations apply to planting northern red oak where black oak (*Quercus velutina* Lam.) site index is > 65 feet at an index age of 50 years and yellow-poplar is present in the parent stand. For stands in the Central Hardwood Region where yellow-poplar is absent and black oak site index is ≤ 65 feet, we recommend applying the prescription described by Weigel and Johnson (1998b). The prescription calls for:

- Reducing overstory density to 60 percent stocking based on Gingrich's (1967) stocking chart by thinning from below (*i.e.*, concentrating removals on subcanopy trees down to 2-inches d.b.h.).
- Treating the planting site after the shelterwood cut is made with an effective herbicide applied to woody understory plants between 1/2-inch and 2-inches d.b.h. (trees and shrubs), and stumps of non-oaks removed in the shelterwood cut.
- Planting seedlings ≥ 1/2-inch in caliper that were undercut during the first year in the nursery.
- Removing the shelterwood between the third and fourth growing seasons.
- Immediately after final shelterwood removal, again treating established non-oak woody competitors and new stumps of non-oaks with an herbicide as described above.
- Between the first and sixth year after shelterwood removal, applying a competition control treatment (chemical, prescribed burning, or mechanical).

Shelterwood Cuttings and Herbicide Treatments

To create the shelterwood, we recommend thinning stands to 60 percent stocking before planting. Stand density should be reduced by removing trees from the lower crown canopy first and then removing additional trees as needed, removing undesirable species first. Gingrich's (1967) stocking chart or equation can be used to obtain the correct residual stocking. Our prescription also calls for applying an effective herbicide to woody competitors between 1/2-inch and 2-inches d.b.h. before planting. This treatment increases light at seedling height by removing or reducing the density of tall understory vegetation (Lorimer *et al.* 1994). Between the third and fourth growing seasons after planting, the shelterwood should be completely removed, including all trees 2-inches d.b.h. and larger. A second herbicide treatment should then be applied to reduce the post-shelterwood competition. For both treatments, we recommend using an herbicide such as Tordon[1] as a basal spray applied to freshly cut stems during the winter before planting and again immediately after shelterwood removal.

Planting

Nursery stock.—The prescription is based on planting seedlings that have been undercut in the nursery, top-clipped (*i.e.*, shoots cut off) 8 inches above the root collar and root-pruned 10 inches below the root collar (fig. 1). The prescription requires knowing the average shoot diameter (caliper) of seedlings measured 1 inch above the root collar. This facilitates determining the number of seedlings that must be planted to obtain, on the average, one dominant or codominant tree 5 years after shelterwood removal (8 years after planting). We call these numbers "planting factors" (PF's) (table 1). We define a planted tree as dominant or codominant if it attains at least 80 percent of the expected mean height of dominant and codominant competitors (11.2 feet) 5 years after shelterwood removal. The prescription assumes that the predominant competing tree species is yellow-poplar. Accordingly, if the objective were to obtain 100 dominant and codominant planted trees per acre 5 years after overstory removal, it would be necessary to plant PF x 100 trees per acre.

We recommend planting in the spring with seedlings that are at least 1/2-inch in caliper that were undercut the first year in the nursery and top-clipped before planting. Thus, if seedlings averaged 5/8-inch in caliper, it would be necessary to plant 240 trees to obtain 100 competitively successful trees 5 years after shelterwood removal (table 1). If seedlings averaged 7/8-inch in caliper, 190 trees would need to be planted to meet the same goal. The

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[1] *Mention of trade names does not constitute endorsement by the USDA Forest Service.*

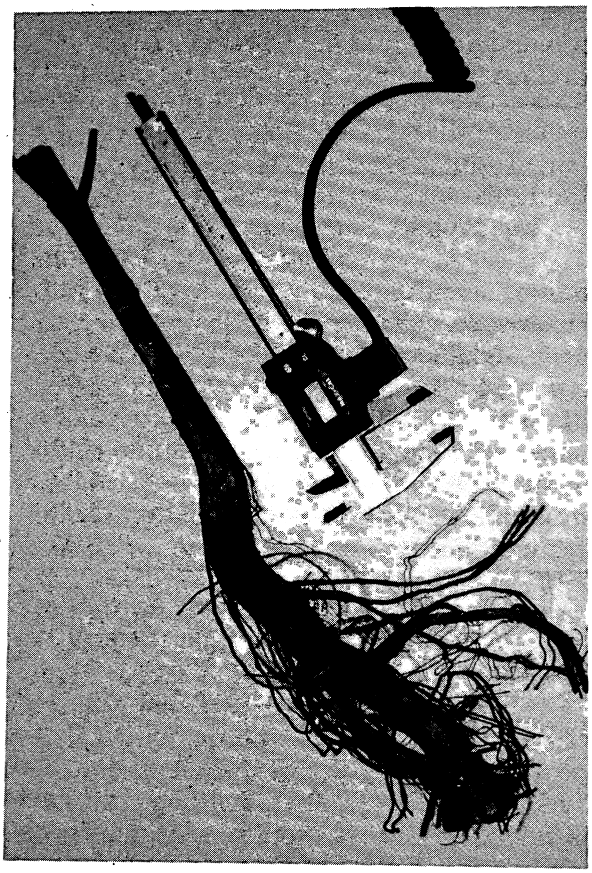

Figure 1.—*A 2-year-old northern red oak seedling prepared for planting. We recommend top-clipping shoots 8 inches above the root collar and pruning the taproot and lateral roots 10 inches below the root collar. Lateral roots should be appressed to the taproot and pruned at the taproot pruning point. After planting, new roots are produced at or near pruning points on the taproot and larger lateral roots.*

appropriate planting factor for any lot of seedlings can be determined by randomly selecting about 30 seedlings for measurement from among those to be planted. The planting factors presented in table 1 may not be applicable to stands where black oak site index exceeds 75 or is less than 65 feet. Even within that range, the planting factors presented may not be applicable where competition differs appreciably from the study site.

Planting costs.—Based on our cost estimates and observed range of seedling calipers, it would be most cost-effective to plant 7/8-inch seedlings that have been undercut and top-clipped (table 2). Obtaining 100 dominant or codominant trees of that initial size would cost $258 if undercut and top-clipped seedlings were planted. For 1/4-inch seedlings of the same treatment the cost would be $426. These estimates do not include competition control, administrative, and other costs not accounted for in table 2. For seedlings that are neither undercut nor top-clipped, the estimated cost of obtaining 100 dominant or codominant trees increases to $408 for 7/8-inch seedlings and $806 for 1/4-inch seedlings.

Although our nursery stock and planting costs have been estimated by "expert opinion," they remain to be verified operationally. Because these costs are likely to vary greatly from one locale to another and/or over time, the primary value of table 2 may be to illustrate how planting factors can be used to estimate costs and thereby determine the most cost-effective size and type of nursery stock. Competition control

Table 1.—*Number of planted seedlings required to produce one dominant or codominant tree 5 years after complete shelterwood removal (planting factor) by initial seedling caliper and undercutting/top-clipping treatment*

Initial seedling caliper (inch)[1]	Planting factor (PF)[2]		
	Undercut/[3] top-clipped	Undercut/[3] not top-clipped	Not undercut/ not top-clipped
1/4	5.6	7.0	10.6
3/8	3.7	4.6	6.8
1/2	2.9	3.5	5.0
5/8	2.4	2.9	4.0
3/4	2.1	2.5	3.4
7/8	1.9	2.2	3.0
1.0	1.8	2.0	2.7

[1] Average shoot diameter measured 1 inch above the root collar. Caliper is given for the approximate observed range of seedlings in the related study (see How the Study Was Conducted, p. 7).

[2] Based on 2-year-old seedlings with tops clipped 8 inches above the root collar after lifting and roots pruned to a common length of 10 inches before planting. Planting factors are based on the reciprocals of dominance probabilities (see fig. 5).

[3] Undercut the first year in the nursery.

Table 2.—*Estimated cost of obtaining one dominant or codominant planted tree 5 years after complete shelterwood removal by initial seedling caliper and undercutting/top-clipping treatment*

Seedling caliper (inch)[1]	Cost of one seedling[2]	Cost of planting one seedling[3]	Cost of seedling + planting	Cost per dominant/codominant tree[4]		
				Undercut/[5] top-clipped	Undercut/[5] not top-clipped	Not undercut/ not top-clipped
1/4	$0.20	$0.56	$0.76	$4.26	$5.32	$8.06
3/8	0.30	0.58	0.88	3.26	4.05	5.98
1/2	0.40	0.60	1.00	2.90	3.50	5.00
5/8	0.50	0.62	1.12	2.69	3.25	4.48
3/4	0.60	0.64	1.24	2.60	3.10	4.22
7/8	0.70	0.66	1.36	2.58	2.99	4.08
1.0	0.80	0.68	1.48	2.66	2.96	4.00

[1] Average shoot diameter measured 1 inch above the root collar.

[2] Based on 2-year-old seedlings with tops clipped 8 inches above the root collar after lifting and roots pruned to a common length of 10 inches after lifting. Our cost estimates assume there is no net cost of undercutting or shoot clipping. We assume that the modest cost of these operations is offset by subsequently reduced baling and cold storage costs associated with reduced seedling weight and volume.

[3] Does not include site preparation costs.

[4] Cost per dominant or codominant tree = (seedling + planting cost) x planting factor (from table 1).

[5] Undercut the first year in the nursery.

and administrative and other costs will add to the costs shown in table 2.

Setting a Stocking Goal.—The required number of planted trees will depend on how many oaks are desired in the future stand. Assuming that natural reproduction of acceptable species will comprise a significant and valuable part of the future stand, a cost-effective regeneration goal might be to plant the number of oaks that will account for a specified fraction of future stocking such as 25 to 50 percent of the crop trees at the end of a rotation. At the end of an 80-year rotation on a good site (black oak site index 75) in the Central Hardwood Region, we could expect to have about 48 crop trees per acre in stands that are thinned every 10 years (*e.g.*, from stand age 30 to 70) to 60 percent stocking (Gingrich 1971). Thus, 12 to 24 trees per acre occupying dominant and codominant crown positions at stand age 80 would comprise about one-fourth to one-half of the final crop trees. Of course, only a proportion of planted oaks that are competitively successful 5 years after shelterwood removal will become final crop trees. To determine the number of planted trees expected to persist in dominant and codominant crown classes, we would need to know the probability of "retaining" a planted tree in those crown classes over the course of a rotation. This probability should take into account losses from natural mortality and suppression as well as losses from the removal of poorly formed or slow-growing planted trees in periodic thinnings.

To illustrate calculating a planting goal, we have assumed that planted oaks are retained in dominant and codominant crown classes at an annual exponential rate of 0.99.[2] Based on projecting this rate from stand age 5 to 80, 47 percent (0.99^{75} x 100) of dominant or codominant trees at stand age 5 would be expected to remain in those crown classes over the rotation. Thus, after accounting for losses of planted trees through the fifth year after shelterwood removal, and assuming planted trees average 5/8-inch in caliper (planting factor = 2.4, table 1), we would need to plant 12/0.47 x 2.4 or 61 trees per acre to meet a minimum future stocking goal of 12 crop trees per acre. Twice that many, or 122 trees per acre, would need to be planted to attain the goal of 24 crop trees per acre. Such approximations can be used to establish reasonable planting goals for maintaining oaks as a significant future stand component. In addition to the factors directly considered by the prescription, the ultimate contribution of planted trees to future stocking will depend on maintaining the oaks in dominant and codominant crown classes through frequent thinnings that favor planted trees throughout the rotation.

Competition Control Treatments

Although the following competition control methods were not observed in the study on which the prescription is based, we believe they deserve consideration as alternative competition control methods.

Herbicide.—Apply a third herbicide treatment to control competition sometime between the second and fifth years after complete shelterwood removal. We do not recommend applying control measures the first year after shelterwood removal. During that growing season, competition is usually light to moderate and most planted trees are growing in full or nearly full light. Accordingly, we recommend deferring further competition control until after the first but not later than the dormant season following the fifth growing season after shelterwood removal.

Releasing planted oaks from suppression by freeing them only from their immediate competitors is unlikely to be effective. When dominant competitors are yellow-poplar and other fast-growing hardwoods, the relatively small canopy gaps created by the individual crop-tree release method will not provide adequate competition-free space for growth. Most planted oaks will not grow out of such gaps and into the main canopy (Lamson and Smith 1978, Trimble 1974). Effective competition control, therefore, will require area-wide control of competitors. However, to reduce competition control costs, treated areas can be reduced in area by limiting plantings to a portion of stands rather than dispersing them at low densities across entire stands.

This strategy can facilitate attaining an overall oak stocking goal while simultaneously reducing the area of herbicide application. For example, instead of planting across an entire stand to obtain a goal of 12 oak crop trees per acre, one-fourth of the stand could be planted at four times that density to obtain a projected 48 crop trees per acre by the end of a rotation. Whatever strategy is used, attaining a future stocking goal may require repeated thinnings throughout the rotation to maintain planted oaks in superior crown classes at stand densities that minimize oak mortality from competition and crowding.

Prescribed burning.—When applied during the shelterwood period, prescribed burning favors oaks in at least two ways: (1) by eliminating or reducing understory shade during the shelterwood interval, which in turn increases the survival and growth of planted seedlings; and (2) by reducing competition from the less fire-tolerant species such as yellow-poplar and maples after shelterwood removal. The method is generally consistent with the regeneration ecology of the fire-adapted oaks (Abrams 1992; Johnson 1993a, 1993b; Lorimer 1985; Van Lear 1993).

Within the context of the planting prescription, there are two possible approaches to prescribed burning: (1) limit prescribed burning to the early release period after final shelterwood removal (in place of a third chemical or mechanical competition control); or (2) use prescribed burning throughout the regeneration period, *i.e.*, before and after shelterwood removal. Burning also might eliminate the need for the first shelterwood cut by reducing the density of fire-vulnerable and light-intercepting subcanopy non-oaks (DeSelm *et al.* 1991, Barnes and Van Lear 1998). Moreover, two spring burns during the shelterwood period

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[2] Sander and others (1976) estimated an annual retainment rate of 0.99 for dominant and codominant oaks in the Ozark Highlands of Missouri during the first two decades after clearcutting. In New England, Hibbs (1981) concluded that about half the number of northern red oaks present at stand age 25 would be crop trees at the end of the recommended 95-year rotation (Hibbs and Bentley 1984). The corresponding annual exponential retainment rate is approximately 0.99 (authors' calculation). In another study in the same region (Ward and Stephens 1994), the annual exponential retainment rate for dominant northern red oaks was 0.992 from stand age 25 to 85 (authors' calculation from Ward and Stephens' reported values). However, the rate for codominant trees was much lower and probably reflected rapid self-thinning among those trees in dense stands. In contrast, we might expect frequent thinning (e.g., every 10 years) begun at an early age to increase the survival and growth rates of planted trees, and thus their crown class retainment rates. However, determining the number of final crop trees is complicated by the movement of some intermediate and codominant trees into superior crown classes (Ward and Stephens 1994). To simplify illustrating the application of a retainment rate in determining a planting goal, we selected an annual exponential retention rate of 0.99 as a plausible value for stands thinned frequently and moderately (e.g., to 60 percent stocking) to favor planted oaks.

were shown to have no deleterious effect on the survival of planted northern red oaks (Gordon *et al.* 1995). A disadvantage of prescribed burning is the risk of damage and related log degrade to the parent stand (Loomis 1973, 1974; Merritt and Pope 1991; Rouse 1986). However, damage to shelterwoods from single spring burns in South Carolina affected less than 20 percent of the oak overstory trees, and most of that occurred among the smaller (5 to 10 inch d.b.h.) trees (Barnes and Van Lear 1998). Nevertheless, if the risk to the shelterwood from fire damage is deemed unacceptable, prescribed burning can be limited to the post-shelterwood removal period.

Although the oaks as a group are relatively fire resistant, this characteristic varies significantly among species and within species by tree diameter (Harmon 1984, Hengst and Dawson 1993, Huddle and Pallardy 1995, Maslen 1989, Regelbrugge and Smith 1994). Among the upland oaks, northern red oak is among the least fire resistant (Hengst and Dawson 1993, Lorimer 1985). Even large-diameter oaks with thick heat-insulating bark on the lower bole can be killed if there is sufficient fuel to produce flames that reach into the more vulnerable tree crowns (Van Lear and Waldrop 1988). Although there is much variation among species in fire resistance, small-diameter non-oaks occupying the subcanopy are often the least resistant because of their thin bark and vulnerability to crown scorch (Harmon 1984). Prescribed burning also requires knowledge of fire behavior, the presence of a fire control crew for its safe implementation, and conformity to State burning laws. Consequently, burning may not be a viable option on many small privately owned forests. The method's potential use in regenerating oaks under shelterwoods nevertheless has been established in principle and application (Barnes and Van Lear 1998, Brose and Van Lear 1998, Clatterbuck 1998, Lorimer *et al.* 1994, Nyland *et al.* 1983, Rouse 1986).

Because a single burn, by itself, is not likely to achieve lasting competition control (Johnson 1974, Merritt and Pope 1991, Nyland *et al.* 1983), we recommend at least two burns if burning is the only competition control used. If the first burn is substituted for the first herbicide treatment, the second burn should be in the spring after final shelterwood removal. An objective of the second burn is to reduce the density of yellow-poplar seedlings that are likely to arise from the seed bank after the first burn (Barnes and Van Lear 1998, Shearin *et al.* 1972). However, to minimize the negative impact of burning on planted oaks, we recommend planting seedlings with root collars set about 1 inch below the soil surface. This precaution will help protect basal buds at or near the root collar (from which sprouts arise after partial top-kill) from lethally high fire temperatures (Korstian 1927).

Although detailed prescriptions for prescribed burning under shelterwoods are beyond the scope of this paper, we present the following suggestions adapted from the studies of others (Barnes and Van Lear 1998, Brose and Van Lear 1998, Clatterbuck 1998, Gordon *et al.* 1995, Nyland *et al.* 1983):

- If the first burn is substituted for the first herbicide treatment, initiate the burn the spring before planting. However, if the risk of damaging the shelterwood is deemed unacceptable, use chemical or mechanical control.
    - ➔ Burn in the spring, if possible, when leaves are 50 to 75 percent expanded;
    - ➔ Burn only if the relative humidity is ≤50 percent and air temperatures are above 60^0 F, wind is less than 15 mph, and when the litter layer has dried sufficiently to curl (moisture content *ca.* 10-20 percent);
    - ➔ Establish fire control strips around planted areas;
    - ➔ Set strip head-fires along the slope at 20- to 30-foot intervals moving progressively down slope (assuming stands are on sloping terrain).
- Initiate a second burn the spring after final shelterwood removal following the above guidelines.
- If combined mortality and overtopping of planted trees, by yellow-poplar and other competitors, exceeds 40 percent at any time during the 2- to 5-year period after shelterwood removal, we recommend applying a third burn following the above guidelines. However, standards for fuel loadings have not been established.

Although there is little information on the effects of prescribed burning initiated after final shelterwood removal, we might reasonably expect the advantages to be similar to those obtained by burning during the shelterwood period. Conceptually, the method is similar to the "fell and burn technique" for regenerating mixed oak and pine stands after clearcutting in the Piedmont Region of the Southeast (Phillips and Abercrombie 1987, Waldrop *et al.* 1989).

Mechanical.—Mechanical competition control offers a third option for competition control. It involves cutting natural reproduction that interferes with planted trees. In applying this method, we recommend cutting competitors in all but the suppressed crown classes in the spring when leaves are 50 to 75 percent expanded. At that time, sprouting vigor is low because plant carbohydrate reserves are at or near a seasonal low (Brose and Van Lear 1998). This method of control can be applied before and after planting in place of herbicide treatments. However, mechanical control is likely to be less effective than chemical control because cut trees resprout and are likely to overtop planted trees within a few years after treatment. When correctly applied, chemical control lasts longer because herbicides actually kill the targeted trees.

Prescription Caveats

On sites where planted red oaks will compete with yellow-poplar, the following caveats apply:

- *For a given type of nursery stock, planting large seedlings (≥1/2-inch in caliper) will be more cost effective than planting smaller seedlings;*
- *Only nursery stock capable of attaining dominance or codominance in acceptable proportion (e.g., ≥40 percent of trees planted) during the early release interval (within 5 years of complete shelterwood removal) should be planted;*
- *To avoid unacceptably high mortality after final shelterwood removal, yellow-poplar competition must be controlled even with the "best" nursery stock;*
- *Even then, the long-term outcome of planting is uncertain because results have not been observed beyond the early stage of stand development.*

HOW THE STUDY WAS CONDUCTED

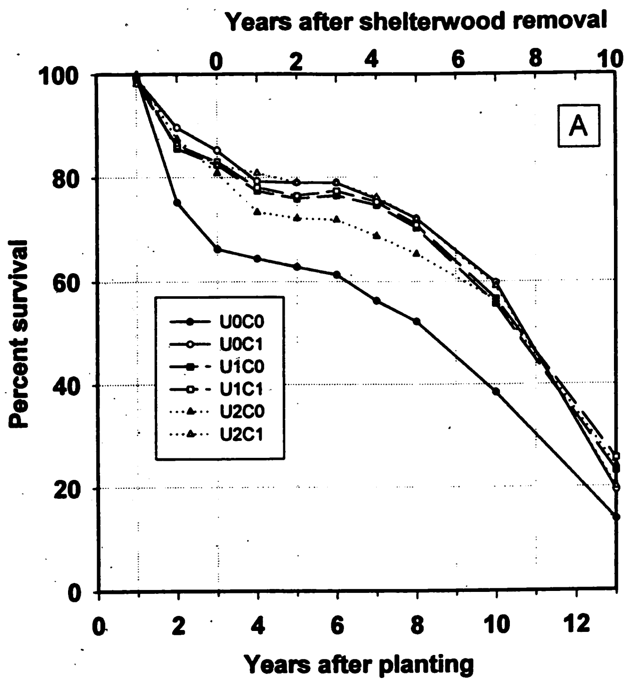
Methods

We planted 1,920 2-year-old northern red oak seedlings under a mixed oak stand thinned from below to 60 percent stocking based on Gingrich's (1967) stocking equation. Half of the seedlings were grown in the Vallonia State Forest Nursery in Indiana and half in the George O. White State Forest Nursery in Missouri. The planted trees represented 10 seed sources, 5 from Missouri and 5 from Indiana. Seedlings received one of three undercutting treatments in the nursery bed: (1) not undercut (U0), (2) undercut during the first growing season (U1), and (3) undercut the first and second growing seasons (U2). Seedlings undercut the first growing season were undercut at a depth of 6 inches during middle to late June after the completion of one or two flushes of shoot growth. Those undercut the second year were undercut at a depth of 8 inches. After spring lifting in early April 1984 and before planting, the tops of half the seedlings in each undercutting treatment were cut off ("top-clipped") 8 inches above the root collar (C1) and the other half were left intact (C0). Taproots and lateral roots of all seedlings were pruned to a common length of 10 inches. The initial caliper (stem diameter measured 1 inch above the root collar) of each seedling was measured to the nearest 0.1 inch and recorded.

In April 1984 we outplanted the seedlings at a spacing of 3.3- x 3.3-feet in a randomized block experimental design with eight replications. The planting site was dominated by mixed oaks and yellow-poplar; black oak site index at an index age of 50 years was 75 feet. All woody stems between 0.5 and 1.6 inches d.b.h. and all stumps created by the shelterwood cut were treated with an herbicide (Tordon RTU) before planting. After the third growing season the shelterwood was completely removed (trees ≥1.6 inch d.b.h.) during the winter of 1986-1987. Stumps created by the final shelterwood removal also were treated with herbicide. Planted tree heights and survival were measured and recorded annually or biennially for 13 years. The tallest woody competitor within a 3.3-foot radius of every fourth planted tree was measured 7, 8, 10, and 13 years after planting to facilitate calculation of the mean height of dominant competitors.

Study Results

Survival.—Survival of planted oaks ranged from ≥98 percent at the end of the first field growing season to 13 to 26 percent at the end of the 13th season, depending on seedling treatment (fig. 2A). In all treatments, survival plummeted after the eighth field growing season as planted trees succumbed to suppression by competitors. At the end of the study period, survival was nominally highest and lowest for treatments U1C1 and U0C0, respectively.



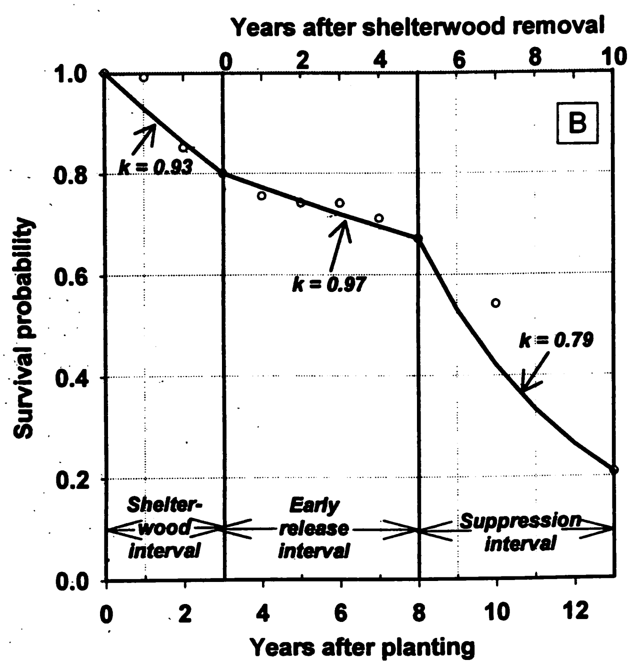


Figure 2.—*Survival of planted northern red oaks in relation to field growing season. (A) Survival by undercutting and top-clipping treatments. Seedling treatments: U0C0 = not undercut, not top-clipped; U0C1 = not undercut, top-clipped; U1C0 = undercut first year, not top-clipped; U1C1 = undercut first year, top-clipped; U2C0 = undercut both years, not top-clipped; U2C1 = undercut both years, top-clipped. (B) Observed and estimated survival probabilities for planted northern red oaks averaged across undercutting and top-clipping treatments. Probabilities are shown for three time intervals: shelterwood (0-3 years after planting), early release (3-8 years), and suppression (8-13 years). Observed probabilities are shown by circles; the curves are estimates based on the annual exponential survival rates (k) derived from the observed proportion of trees living at the beginning and end of each interval. The rate k is thus the proportion of trees expected to survive any one year during an interval.*

The shape of the survival curve averaged over all treatments indicated there were three distinct time intervals: (1) the *shelterwood interval* (0-3 years after planting); (2) the *early release interval* (3-8 years); and (3) the *suppression interval* (8-13 years) (fig. 2B). During the shelterwood interval, the annual survival rate was 0.93, which resulted in a 19.6 percent decline in survival to 80.4 percent (0.93^3) by the end of the third growing season. This moderately high survival rate was associated with the shaded environment beneath the shelterwood. Much of the mortality that did occur during the shelterwood interval may have been attributable to sub-optimal light levels, associated shoot dieback, and the death of seedlings of initially poor physiological quality. During the early release interval, the survival rate increased to 0.97. This relatively high rate was associated with full or nearly full light at seedling crown levels and low to moderate competition from other plants. During this interval, average planted tree survival declined 11.3 percent (from 80.4 to 69.1 percent). During the suppression interval, the annual survival rate was 0.79. This relatively low rate was associated with suppression of planted trees by competing species whose growth exceeded that of most planted trees (fig. 3). During this interval, average planted tree survival declined 47.9 percent (from 69.1 to 21.2 percent).

Height growth.—Mean heights of survivors varied little among treatments over the study period (fig. 3). Dieback of trees in the C0 treatments resulted in no net height growth during the first 4 years, during which planted trees were under the shelterwood for 3 years. In contrast, C1 trees averaged 10 to 20 inches in net height growth during the same period. During the 10 years after shelterwood removal, planted trees in the best treatments grew over 12 feet in height. However, this growth was not sufficient to maintain the average heights of surviving planted trees at or above 80 percent of the average heights of dominant competitors (22.7 feet in 1996). Most trees that tall or taller were yellow-poplars in dominant and codominant crown classes (fig. 4). If that height were used as the success criterion, then none of the undercutting/top-clipping treatments produced, on the average, successful results.

Dominance probabilities.—To evaluate the joint effects of seedling growth and survival on

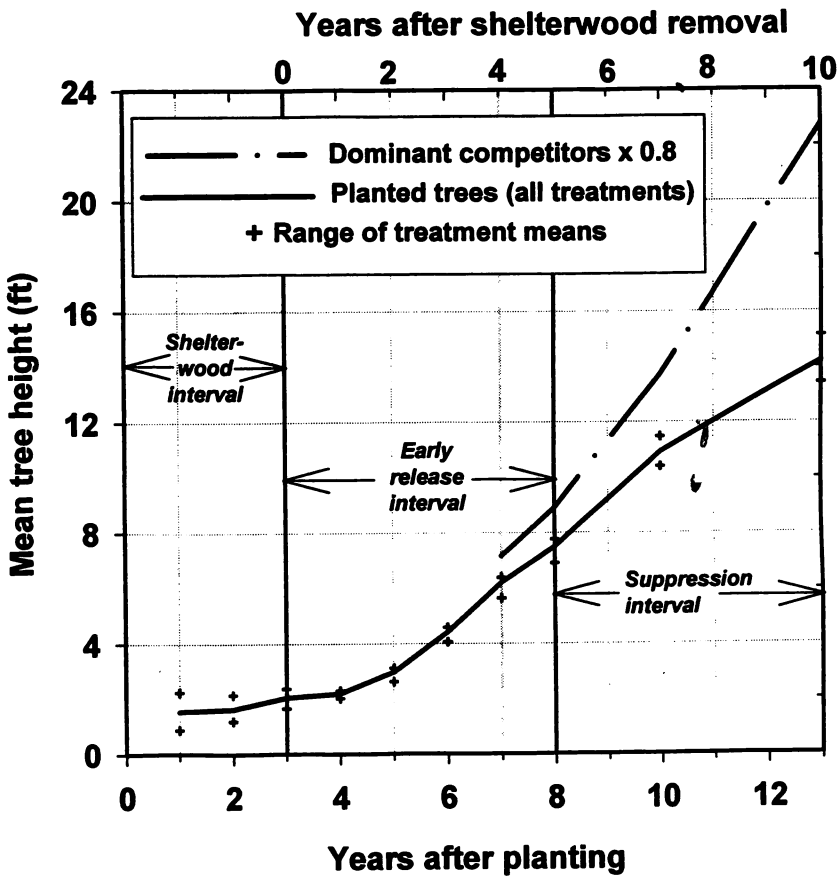


Figure 3.—*Mean heights of surviving planted northern red oaks averaged across all treatments compared to 80 percent of the mean heights of dominant competitors during the study period. Ranges for treatment means are shown by cross hair (+) symbols for each year of measurement.*

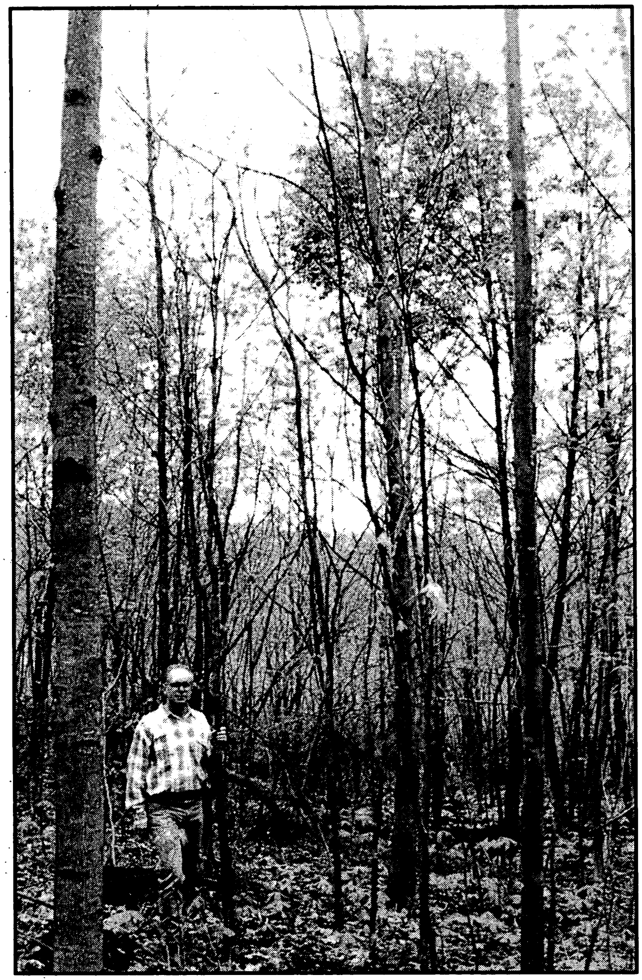


Figure 4.—*A planted northern red oak (held in hand) in an intermediate crown class 10 years after shelterwood removal. By that time, most planted trees had died or were overtopped by yellow-poplars such as the two large trees in the foreground and the one in the background.*

planting success, we used logistic regression analysis to express the likelihood that a planted tree will be competitively successful in the future. To do this, we estimated the probability that a seedling of a given treatment and initial caliper will equal or exceed 80 percent of the mean height of dominant competitors a given number of years after shelterwood removal. We call the resulting values *dominance probabilities*. These probabilities thus integrate survival and growth into a single expression of planting success that can be related to seedling treatment and initial size effects. We used initial seedling caliper as a predictor of planting success because it is correlated with seedling root mass and thus rapid height growth after shelterwood removal (Dey and Parker 1997, Kaczmarek and Pope 1993).

The resulting dominance probabilities showed that, within each treatment group, the likelihood of an individual planted tree attaining dominance increases rapidly with increasing initial seedling caliper. Dominance probabilities 4 years after shelterwood removal ranged from 0.1 for seedlings 0.25 inch in initial caliper to over 0.5 for seedlings 1 inch in caliper (fig. 5). Probabilities declined from a maximum of 0.58 for 1.0 inch caliper U1C1 seedlings 4 years after shelterwood removal to less than 0.10 for all seedlings 10 years after shelterwood removal. Once- and twice-undercut seedlings performed significantly better (α = 0.05) than seedlings that were not undercut; top-clipped seedlings performed significantly better than seedlings that were not top-clipped. For a given initial caliper, the largest estimated dominance probabilities therefore occurred in treatment U1C1 and the smallest probabilities occurred in treatment U0C0. The observed benefits from undercutting, top-clipping, and large initial seedling size are generally consistent with observations in Missouri (Johnson 1984; Weigel and Johnson 1998a, 1998b). However, none of the treatments or large seedling size produced successful results 10 years after shelterwood removal. Estimated dominance probabilities nevertheless reveal that 40 percent or more of undercut and top-clipped seedlings of initially large caliper (*e.g.*, $\geq$5/8 inch caliper) can be expected to be competitively successful through the fifth year after shelterwood removal (fig. 5).

Conclusions

The ultimate failure of the planted trees in the present study was largely related to the relatively high site quality and associated rapid height growth of yellow-poplar and other competitors, which dominated the study site by the sixth year after shelterwood removal. The results are consistent with those from other regions where yellow-poplar was present and site quality was high (red oak site index $\geq$75 feet) (McGee and Loftis 1986, Olson and Hooper 1972, Russell 1973). Wendel (1980) nevertheless was optimistic about planting northern red oak in West Virginia clearcuts (oak site index 60-70 feet) where 30 to 50 percent of planted

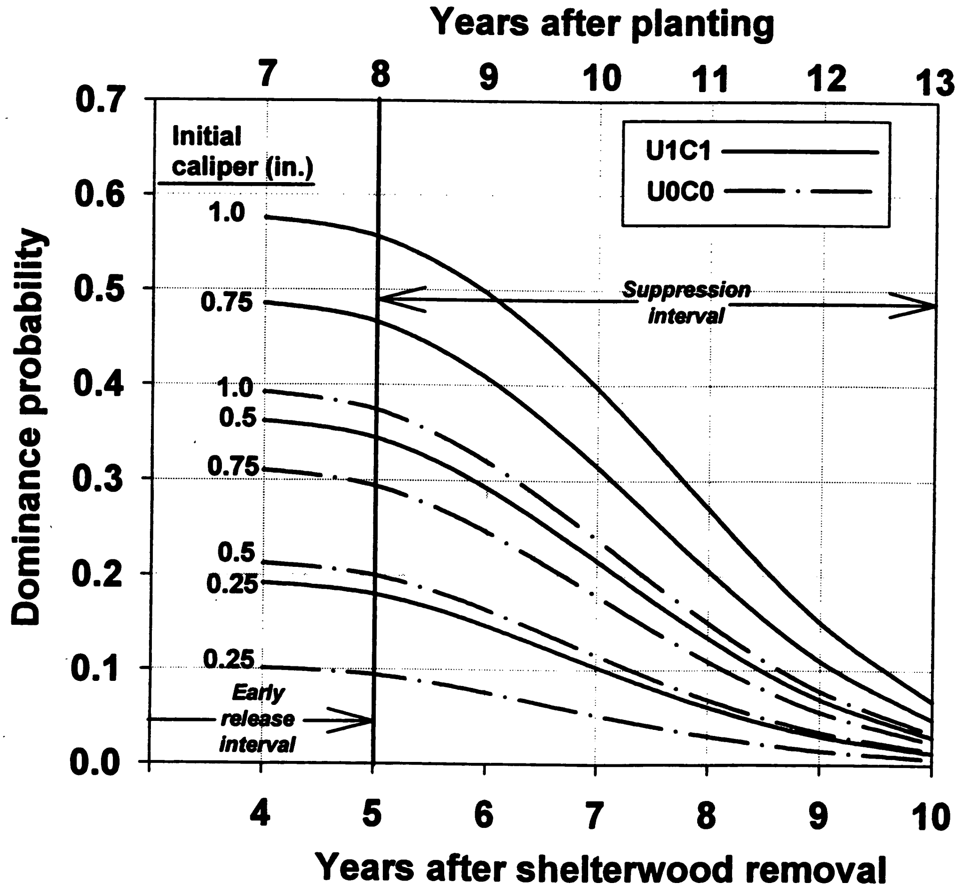


Figure 5.—*Estimated dominance probabilities for planted northern red oak in relation to initial caliper of seedling and years after shelterwood removal. Dominance probabilities are shown for the nominally "best" and "worst" undercutting (U) and shoot clipping (C) treatments. U0C0: not undercut, not top-clipped; U1C1: undercut during the first growing season in the nursery, shoots clipped 8 inches above the root collar before planting.* $P=1/\{1+e[-(-1.7829 + 1.2593 \bullet \ln CAL + 0.6659 \bullet Y - 0.0825 \bullet Y^2 + 0.4743 \bullet U1 + 0.4060 \bullet U2 + 0.2699 \bullet C)]\}$, *where P = dominance probability; CAL = seedling shoot caliper (inch); Y is number of years (growing seasons) after shelterwood removal; U1 = 0 if seedling is not undercut or undercut both years, U1 = 1 if seedling is undercut the first year; U2 = 0 if seedling is not undercut or undercut the first year, U2 = 1 if seedling is undercut both years; C = 0 if seedling is not top-clipped, C = 1 if top-clipped.*

oaks were deemed to be competing successfully with yellow-poplar and other hardwoods 5 years after planting. Those results are comparable to some seedling treatments and initial size classes observed in the present study 5 years after shelterwood removal. However, the decline of planted oaks, as demonstrated by the present study, largely occurs during the suppression interval, which for black oak site index 75 does not begin until the 6th year after shelterwood removal.

During the first 2 to 3 decades of stand development, changes in stand structure and composition are rapid and sometimes unpredictable. For example, where site quality is marginal for yellow-poplar, early dominance of stands by that species may not, by itself, reflect future stand composition. This was observed in an Ohio stand (oak site index 58 feet) that was dominated by mixed oaks and yellow-poplar 22 years after clearcutting. During the next 4 years, 93 percent of the yellow-poplars died, apparently as a result of two drought years during that time (Hilt 1985). Where yellow-poplar is absent and stands are usually not comprised of persistent dominant competitors other than oaks, research has demonstrated that oaks can be successfully planted under shelterwoods. Prescriptions for such sites have been developed for planting northern red and white oaks under shelterwoods in the Ozark Highlands of Missouri (black oak site index 60 to 70) (Johnson *et al.* 1986; Weigel and Johnson 1998a, 1998b). Thus, site quality, competition, and the quality of planted seedlings should be jointly considered in defining a strategy for planting success.

Although planted trees were not competitively successful at the end of the study period, we believe there is an established, although tentative, basis for planting northern red oak on yellow-poplar sites. However, successful planting will require controlling woody competitors, especially yellow-poplar, and planting nursery stock with the requisite growth potential (Kormanik *et al.* 1998). Thus, chemical, mechanical, or prescribed burning methods of control will need to be applied during the shelterwood and early release intervals. It also may be necessary to repeat those control measures in subsequent years. Studies by others have shown that prescribed burning can be effectively used in conjunction with the shelterwood method to increase the natural regeneration potential of oaks at the expense of the more fire-sensitive yellow-poplar, maples, and certain other non-oak competitors (Brose and Van Lear 1998, Clatterbuck 1998, Keyser *et al.* 1996, Nyland *et al.* 1983). There is no apparent reason why these methods cannot also be applied to shelterwoods underplanted with northern red oak. The present study demonstrates that a window of opportunity exists during the early release interval after shelterwood removal for preserving the advantages obtained by oak planting. The prescription presented is based on taking advantage of that opportunity by planting relatively large undercut and top-clipped seedlings coupled with effective competition control.

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Weigel, Dale R.; Johnson, Paul S.
2000. **Planting red oak under oak/yellow-poplar shelterwoods: a provisional prescription.** Gen. Tech. Rep. NC-210. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 16 p.

Presents a prescription for planting northern red oak on sites dominated by yellow-poplar using the shelterwood method.

KEY WORDS: artificial regeneration, underplanting, *Quercus rubra*, dominance probabilities.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

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