GROWING HARDWOOD NURSERY STOCK FOR PLANTING ON FOREST SITES WITH SPECIAL REFERENCE '10 NORTHERN RED OAK

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Abstract.—Conventional nursery methods can be used to grow hardwood nursery stock that meets outplanting success criteria based on the expected grawth of dominant woody competitors. In this setting, nursery stock has the potential to compete successfully if it is large enough and of adequate physiological quality. However, plantings should be based on a biologically reasonable goal of getting 50 to 75 percent of planted trees into dominant and ccdondnant crown classes during the first two decades of stand development. Plantings also should be designed to supplement natural reproduction to minimize costs by minimizing the number of planted trees needed to attain a given stocking goal. Nursery stock requirements and a silvicultural prescription for planting northern red oak in the Missouri Ozarks are presented as an example of a system for planting hardwoods on forest sites.

Additional keywords: Ouercus rubra, regeneration, artificial, shelterwood, clearcut, undercutting

Most hardwood forests in the United States have regenerated naturally. However, interest in planting hardwoods on forested sites is increasing as land managers become aware of the uncertainties of naturally obtaining adequate stocking of acceptable or preferred species. Current stumpage prices as well as environmental concerns also may justify the large investments required.

Hardwood planting in the United States has traditionally focused on the establishment of pure plantations on old fields or similar sites that usually lack a typical forest floor and flora. On Forest sites, the primary competition usually is woody vegetation including advance reproduction of tree species. The presence of desirable natural reproduction often makes it unnecessary or undesirable to artificially create pure stands or to plant large numbers of trees per acre. Thus, there is both a biologic and an economic rationale for minimizing planting costs.

Plantable forest sites include clearcuts, small openings, shelterwoods, degraded stands, and possibly other stand conditions. Although hardwood planting research on such sites has been relatively limited, the potential of the method has been substantiated by studies on yellow-poplar (Liriodendron tulipifera L.), white ash (Fraxinus americana L.), black cherry (Prunus serotina Ehrh.), sugar maple (Acer saccharum Marsh.), red maple (A. rubrum L.), American basswood (Tilia americana L.), black walnut

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(Juolans nigra L.), northern red oak (Ouercus rubra L.), white oak (Q. alba L.), and yellow birch (Betula alleghaniensis Britton) (Carvell 1966, Francis and Bivens 1985, Gottschalk and Marquis 1982, Hannah and Turner 1981, Hilt 1977, Johnson et al. 1986, Johnson and Rogers 1985, Krajicek 1975, McGee 1977, Myers et et. 1989, Russell 1979, Stroempl 1971, Tworkoski et al. 1986). However, to compete successfully, hardwoods planted on forest sites rust grow as fast as dominant and codominant competitors. This is a tall order, especially for some species such as oaks, which are slow to establish and demonstrate their growth potential. Even when herbicides are used to control competition, the competition may "rebound" faster than the newly planted nursery stock can grow. This raises the question: Can hardwood nursery stock measure up to this performance requirement?

FIELD PERFORMANCE REQUIREMENIS

Defining Success Criteria

Because hardwoods planted on forest sites grow in competition with other woody vegetation, their success should be evaluated in relation to the growth of dominant competitors. Thus, to become a valuable future crop tree, a planted tree must attain a position of dominance or codominance early in the life of the stand and then maintain that position. Unlike plantations established on old fields, the success of trees planted on forest sites cannot be judged only by survival. Instead, quantitative success criteria are needed for defining the competitive status of planted trees as they develop in juxtaposition with other woody vegetation.

A useful criterion for judging the competitive position of planted trees is the mean height of dominant competitors or some percentage of that height. For example, Johnson and Rogers (1985) used 80 percent of the mean height of dominant northern red oak sprouts (i.e., a "relative height" of 80 percent) as the minimum height a planted tree must attain to compete successfully in clearcuts in southern Wisconsin. Because red oak stump sprouts were among the dominant vegetation on those sites, they provided a useful and predictable standard for assessing the competitive status of planted trees. For some ecosystems, predictive equations are available for estimating the heights of dominant stump sprouts in clearcuts (Johnson 1975). Because the growth of competitors increases as site quality increases, success criteria for planted hardwoods should be adjusted accordingly (Fig. 1).

Good sites also may require more intensive weed control than poor sites. In fact, it may be impractical to plant certain species on exceptionally good sites if their height growth is inherently *slaw (e.g.,* white oak). For sawtimber production, it usually is not economically practical to plant hardwoods on sites with a site index of less than 65 (base age 50). However, where there is interest in planting hardwoods for wildlife habitat and mast production, poorer sites are sometimes considered for planting. Whatever the objective, species must be matched with site (Carmean 1979).

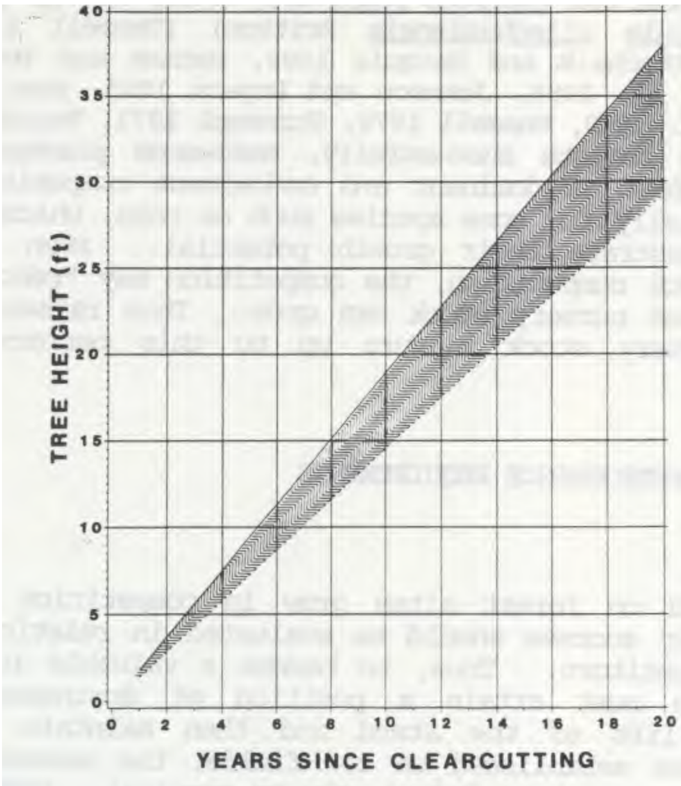

Figure 1. The minimum height that must be attained by a planted tree to be dominant or codoninant in southern Wisconsin clearcuts. The lowest values, represented by the lower edge of the shaded area, are minimum tree heights on the poorest sites; uppermost values (upper edge) are minimum tree heights on the best sites (from Johnson 1976).

Many of the hardwoods favored for planting are very sensitive to site quality. For example, responses of six hardwoods to site quality were observed 16 years after planting in clearcuts in southern Wisconsin (Johnson and Rogers 1985). The competitive success of all six species increased with increasing site quality. The results further demonstrated the advantages of planting large 1-1 stock and the negative effect of fast-growing competitors such as stump sprouts and aspen on the competitive position of planted trees when expressed as "success" probabilities (Fig. 2).

Variability in site quality and competition within stands usually produces highly variable growth responses in hardwoods planted on forest sites. In turn, this creates problems in evaluating field performance, especially on research plots. Traditional statistical methods based on linear models (e.g., ANOVA and linear regression) may not be very helpful in identifying differences among classes of nursery stock or other treatment effects because of the large proportion of variation in growth not accounted for and the low predictive utility of the resultant models. One way to cope with this problem is to evaluate outplanting performance based on differences in the distribution of specific events (e.g., "successful" versus "unsuccessful" height growth) rather than on differences in "average" height growth. Expressed as probabilities (P), these events, which are defined by the success criterion, have practical silvicultural relevance because their reciprocals (i.e., 1/P) express how

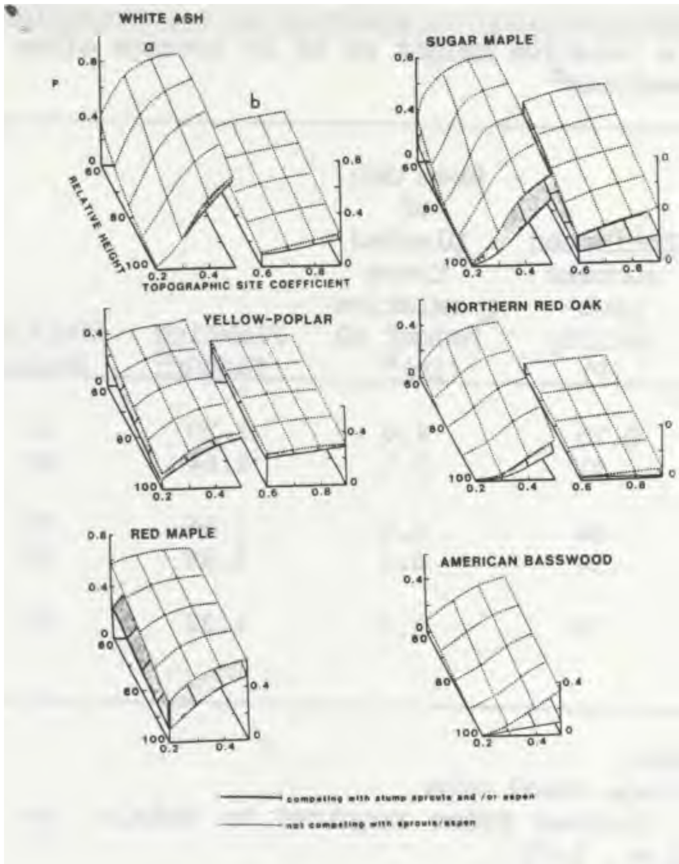

Figure 2. Success probabilities (P) for hardwoods planted in two southern Wisconsin clearcuts (a and b) in relation to relative height, site quality expressed as topographic site coefficient (TSC), and competition. P is the estimated probability that a planted tree will survive to stand age 16 and attain at least the relative height given on the diagonal axis. Clearcut (a) was planted with 1-1 stock and (b) was planted with 1-0 stock. The possible range for TSC is 0.1 to 1.0, which approximates the northern red oak site index range of 45 to 70 (base age 50) Mum Johnson and Rogers 1985).

many trees must be planted to obtain on the average, one successful tree (Johnson 1976). That relation can be extended to estimate future contributions to stocking based on growing space relations (Johnson and Rogers 1985) (Table 1). This approach also has the advantage of integrating survival and growth into one quantitative expression.

Despite a relatively long history of hardwood planting, for most ecosystems there is a shortage of good long-term data on the outplanting performance of most species, especially data that include measurements of initial seedling size and other attributes of seedling quality related to nursery culture. This is unfortunate because reliable predictions of the potential contribution of planted trees to stocking are essential to assessing the economic and biologic feasibility of planting a given species in a given ecosystem.

A Prescription for Planting Northern Red Oak

An example of a prescription for planting hardwoods on forest sites is provided by Johnson and others (1986). That prescription is based on a study of more than 3,000 planted northern red oaks including 1-0, 1-1, and container-grown stock planted in clearcuts and under shelterwoods in the Missouri Ozarks. Five years of field growth demonstrated the effects of initial seedling size, partial removal of shoots (shoot clipping), type of

Table 1. Estimated 16th-year contributions to stocking by 1-1 transplants that attain at least a relative height of 80 on average sites in southern Wisconsin clearcutsa

Species	Mean height when planted (in)	Competing with sprouts/ aspen in 16th year	Estimated success prob- ability (P)	Mean dbh of planted trees ≥ relative height 80 (in)[b]	Planting factor[c]	Stocking factor[d]
Sugar maple	10.9	No	0.75	4.0	1.33	34
		Yes	.61	3.1	1.64	66
Red maple	10.5	No	.64	4.9	1.56	32
		Yes	.54	4.1	1.85	52
White ash	27.2	No or Yes	.78	3.7	1.28	37

[a] Flom Johnson and Rogers 1985.
[b] The dbh of the tree of average basal area.
[c] The estimated number of planted trees required to obtain, on the average, one successful tree (i.e., 1/P).
[d] The estimated number of trees required to obtain, on the average, 1 percent stocking based on P and published tree area (stocking) equations.

stock, and outplanting environment (Johnson 1984).

More recent 8-year results from that study have reinforced the earlier conclusions that large 1-1 northern red oak stock with tops clipped 6 inches above the root collar can be planted most successfully under shelterwoods thinned to 60 percent stocking. Although several factors were significant in explaining variation in field performance, initial seedling size was of paramount importance in both environments (clearcuts and shelterwoods) and among all classes of stock tested (Fig. 3). These results provide a strong argument for growing large nursery stock, especially oaks, which require a relatively large root/shoot ratio and large root mass to effect the rapid shoot elongation necessary for competitive success.

The complete four-step prescription for planting northern red oak calls for: (1) controlling undesirable woody understory vegetation by applying a herbicide before planting, (2) planting under a shelterwood at 60 percent stocking, (3) using large-diameter nursery stock with clipped tops, and (4) removing the shelterwood three grading seasons after planting (Johnson et al. 1986). Based on that prescription and the use of 1-1 stock averaging 1/2 inch in diameter, 61 percent of planted trees are expected to be at least 7.9 feet tall (80 percent of the height of dominant competitors) 5 years after the shelterwood is removed. Thus it would be necessary to

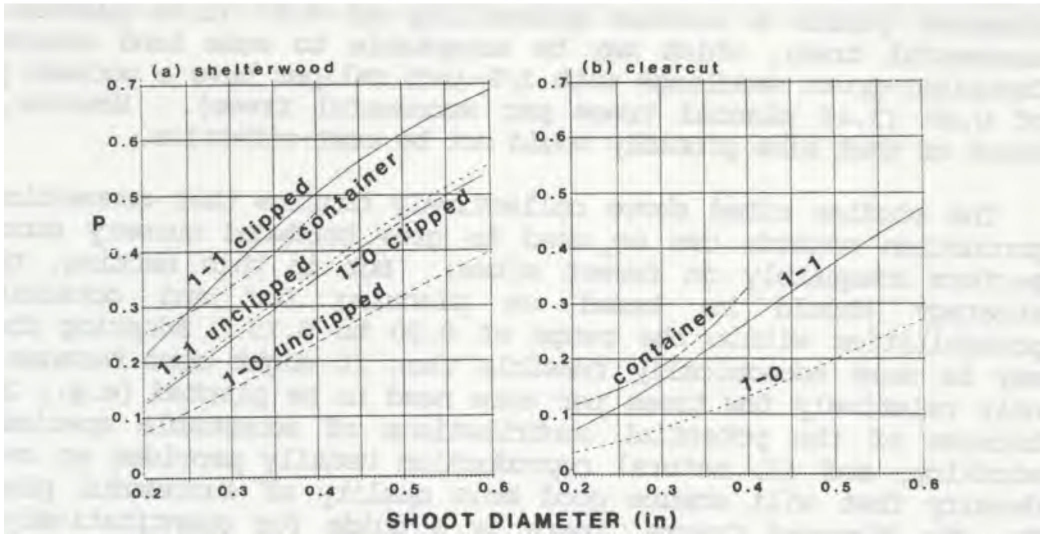

Figure 3. Estimated probabilities (P) of northern red oak nursery stock attaining dominance or codominance (relative height 80 percent) 8 years after planting in relation to initial shoot diameter 1 inch above the root collar: (a) trees planted under shelterwoods that were removed 3 years after planting; (b) trees planted in clearcuts. Nursery stock labeled "clipped" had shoots removed 6 inches above the root collar before planting. Shoot clipping had no significant effect (p>.05) on container-grown seedlings in either environment or on any class of stock planted in clearcuts. Estimates are based on logistic regression models developed fruit(data on 3,072 trees planted in the Missouri Ozarks. The study design and earlier results were reported in Johnson (1984).

plant 1.64 (the reciprocal of 0.61) 1-1 transplants to obtain one "successful" tree. Clipped 1-0 stock of the same (1/2-inch) diameter also performed relatively well with 45 percent of trees expected to successfully compete and thus requiring 2.22 planted trees to obtain one successful tree. However, in most nurseries, few 1-0 seedlings will attain 1/2-inch diameter, and average diameter is likely to be closer to 1/4 inch—thus yielding a success probability of 0.25. Recent studies have indicated that the advantages of transplanting can be obtained by undercutting 2-0 seedlings which, in turn, substantially reduces the cost of growing stock with high growth potential (Johnson 1988). Results frum other studies have also demonstrated that underplanting may be a feasible regeneration method for northern red oak *as* well as other hardwoods including white oak, white ash, American basswood, yellow-poplar, and black cherry (Carvell 1966, Francis and Bevins 1985, Gottschalk and Marquis 1982, Stroempl 1971, 1987, Tworkoski et al. 1986).

Clearcuts also can be successfully planted with northern red oak and other species including sugar maple, red maple, white ash, yellow-poplar, yellow birch, and black walnut (Hannah and Turner 1981, Johnson and Rogers

1985, Russell 1979). For northern red oak, 1-1 stock averaging 1/2 inch in diameter yields a success probability of 0.37 (2.70 planted trees per successful tree), which may be acceptable to some land owners (Fig. 3). Container-grown seedlings with 3/8-inch caliper have a succpss probability of 0.29 (3.45 planted trees per successful trees). However, container stock of that size probably would not be cost-effective.

The studies cited above collectively confirm that conventional nursery production methods can be used to grow hardwood nursery stock that can perform adequately on forest sites. But in this setting, the planting strategy should be based on planning for and obtaining success probabilities within the range of 0.50 to 0.75. Adopting that strategy may be more economically feasible than it might seen because: (1) often only relatively few trees per acre need to be planted (e.g., 200 or less) because of the potential contributions of acceptable species to future stocking, and (2) natural reproduction usually provides an overall stand density that will ensure good bole quality of successful planted trees. For the Missouri Ozarks, there is a guide for quantitatively evaluating the total oak regeneration potential, which before final harvest can be used to assess deficiencies in natural reproduction and thus planting needs (Sander et al. 1984).

GROWING NURSERY STOCK TO MEET FIELD PERFORMANCE REQUIREMENTS

Stock Size

Although many factors combine to form what has been termed nursery stock quality, probably none is more important in hardwood planting than stock size. When field performance is the primary consideration, "bigger is better." This has been substantiated for northern red oak (Foster and Farmer 1970, Olson and Hooper 1972), sweetgum (Liquidmlbar styraciflua L.) (Belanger and McAlpine 1975, Kaszkurewicz and Keister 1975, Kormanik 1986), green ash (Fraxinus pensylvanica Marsh.) and American elm (Ulmus americana L.) (George and Frank 1973), Pastern cottonwood (Populus deltoides Bartr. ex Marsh.) (Phares and White 1972), birches (Betula spp.) (Clausen 1963), black walnut (Williams 1972), sycamore (Platanus occidentalis L.) (Ike 1962), and other hardwoods (Stoeckeler 1937).

The efficient production of large nursery stock usually requires a relatively law seedbed density. For example, 4 to 6 seedlings per square foot have been recommended for northern red oak (Taft 1966). For cherrybark oak (Q. falcata var. paoodaefolia Ell.), 4 seedlings per square foot produced a significantly higher percentage of plantable 1-0 seedlings (i.e., seedlings >1/4-inch diameter) than 6, 8, or 10 seedlings per square foot (Barham 1980b). The cull percentage for 4 seedlings per square foot was 34 percent versus 56, 65, and 66 percent for 6, 8, or 10 seedlings per square foot, respectively. Undercut 2-0 white oaks responded similarly and attained maximum average diameters of 5/16 inch (7.8 mm) and a minimum proportion of cull trees (16 percent) at four trees per square foot, in contrast to 1/4-inch average diameters and 48 percent cull trees at 12 seedling per square foot (Wichman and Coggeshall 1984). However, cull percentage and seedling size can vary substantially within and among nurseries even when the same seed sources are sown at the same density

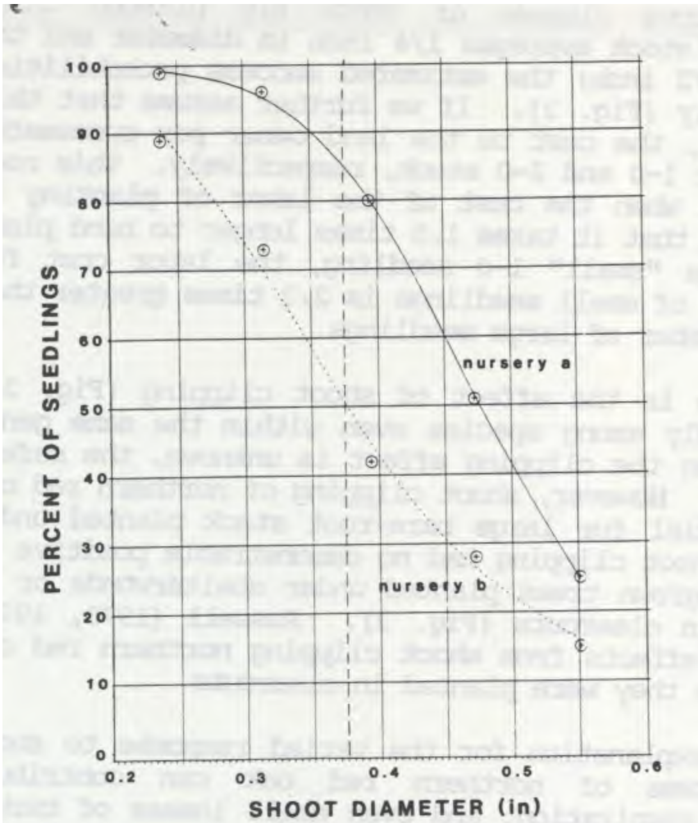

Figure 4. The percent of 2-0 northern red oak seedlings attaining at least the diameter (1 inch above the root collar) given on the horizontal axis in two Midwest nurseries. Data represent equal numbers of acorns front 10 seed sources sawn at the same time and density (4 per ft^2) at both nurseries; circles show observed values. Seedlings attaining at least 3/8-inch diameter (dotted vertical line) have the potential for acceptable performance on forest sites.

(Fig. 4). Moreover, not all hardwoods respond favorably to reduced bed density. For example, law bed densities of sweetgum did not produce larger seedlings and actually had more culls (seedlings <1/4-inch diameter) per square foot than higher bed densities (Barham 1980a).

Maintaining control of seedbed density requires information on seed quality and germination potential so that proper sawing rate can be ascertained. Methods for evaluating seed quality are available for most hardwoods including oaks (Bonner and Vozzo 1987, Teclaw and Isebrands 1986, USDA Forest Service 1974). Other nursery management practices also can influence bed density and thus seedling quality, including mulching, fertilization, irrigation, protection fruit predators, weeding, and other factors (Williams and Hanks 1976).

Although large stock is expensive to produce, it is likely to be more cost effective to plant because of its higher probability of success and the correlatively reduced numbers of trees required to meet a given stocking goal. For example, a recent analysis of the cost of producing conventional 1-0 versus undercut 2-0 northern red oak seedlings at the George 0. White State Forest Nursery in Missouri indicated that production costs are $131 per thousand and $258 per thousand, respectively. [2] Let us

[2] Personal communication, Mr. Jerry Brace, School of Natural Resources, University of Missouri, Columbia, June 2, 1989.

assume that both of the above classes of stock are planted under shelterwoods and that the 1-0 stock averages 1/4 inch in diameter and the undercut 2-0 stock averages 1/2 inch; the estimated success probabilities are 0.18 and 0.61, respectively (Fig. 3). If we further assume that this nursery stock is sold at cost, the cost to the land owner per successful tree is thus $.73 and $.42 for 1-0 and 2-0 stock, respectively. This cost difference is further widened when the cost of the labor of planting is considered. Even if we assume that it takes 1.5 times longer to hand plant a "large" 2-0 seedling than a "small" 1-0 seedling, the labor cost for planting the prescribed number of small seedlings is 2.3 times greater than for planting the prescribed number of large seedlings.

Associated with stock size is the effect of shoot clipping (Fig. 3). This effect may differ markedly among species even within the same genus (Lee et al. 1974). Thus, when the clipping effect is unknown, the safest practice would be to not clip. However, shoot clipping of northern red oak has been shoran to be beneficial for large bare-root stock planted under shelterwoods. In contrast, shoot clipping had no demonstrable positive or negative effect on container-grown trees planted under shelterwoods or on any class of stock planted in clearcuts (Fig. 3). Russell (1973, 1979) also reported no deleterious effects fruit shoot clipping northern red oak or black walnut seedlings when they were planted in clearcuts.

Although a physiological explanation for the varied response to shoot clipping is not clear, stems of northern red oak can contribute substantially to total plant respiration, and even small losses of carbon to respiration may be critical under the marginal light conditions of shelterwoods (Hanson et al. 1987). In contrast, light is probably not a limiting factor in young clearcuts (Crunkilton et al. 1988). Some studies nevertheless have indicated that shoot removals can reduce root regeneration and leaf area of northern red oak seedlings under greenhouse conditions (Johnson et al. 1984, Larson 1975).

Although shoot clipping does not reduce and may even increase production costs, it may reduce shipping costs, especially for stock with large shoots. For example, shoots account for about 40 percent of the total dry weight of 2-0 northern red oak seedlings with shoots averaging 2 feet in length.

Root Morphology

Root size and shape can be modified by nursery practices. Transplanting, undercutting, side cutting, and root wrenching have long been used to modify the root systems of bare-root seedlings. Containerization also can modify root morphology, especially if "air pruning" is facilitated by growing seedlings in containers with open bottoms and an air space beneath them (Tinus and McDonald 1979). The net morphological effect of these techniques is to increase lateral root branching and fibrosity. In turn, this has the potential to increase "plantable" root *mass,* surface area, and the number of sites from which new roots can grow. Large root size is also correlated with large carbohydrate storage capacity, another potentially important attribute of seedling quality (Farmer 1978). In oaks, the usefulness of shoot diameter near the root collar as a grading standard may largely be related to its

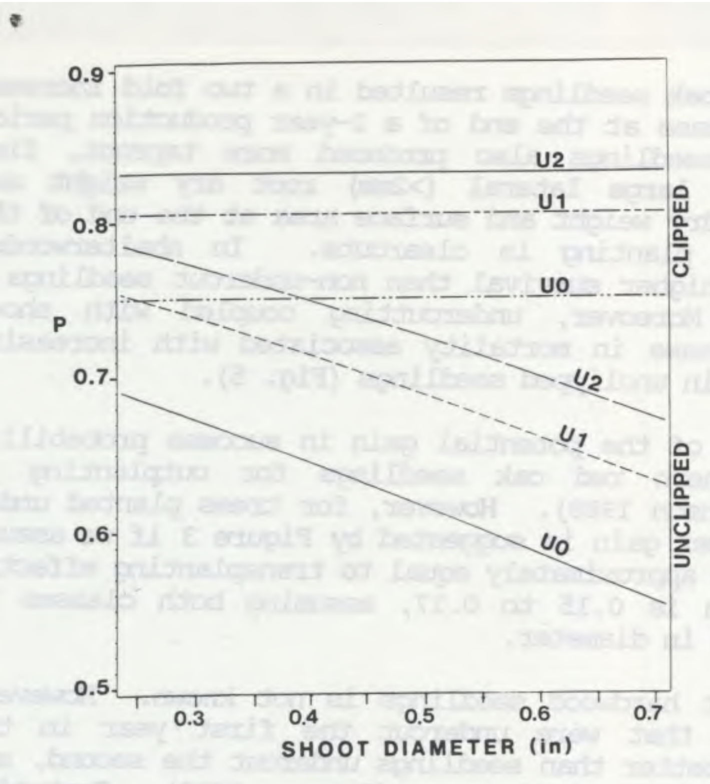

Figure 5. The probability of 4-year survival (P) for 2-0 northern red oak seedlings in relation to initial shoot diameter, undercutting (U), and shoot clipping. Trees grew under shelterwoods for 3 years and then in the open for 1 year U0 = not undercut, Ui = undercut once (first year in the nursery bed), and U2 = undercut twice (both years); shoots were clipped 8 in above the root collar (fium Johnson 1988).

In some species, root morphology can be modified by removing part of the radicle ("radicle clipping") of germinating seeds. Barden and Bowersox (1989) found that radicle clipping of pre-germinated northern red oak acorns in combination with lateral root pruning (side cutting) quadrupled the number of taproots and doubled root growth capacity (numbers of new roots) in comparison to stock originating from germinants with unclipped radicles. Those results have significant implications for growing northern red oak stock with substantially increased "plantable" root mass and thus growth potential. Barden and Bowersox proposed that radicle clipping could be accomplished by shaking germinated acorns with 1/2- to 2-inch-long radicles in a container to break the radicle tips. However, neither radicle clipping nor undercutting of black walnut seedlings improved their field performance (Williams 1972).

There is also considerable natural variation in root morphology that, like culturally induced modifications, is associated with variation in field performance. Kormanik (1986) found that sweetgum seedlings with seven or more "permanent" lateral roots [i.e., those >.04 inches (1 mm) in diameter] survived better than seedlings with fewer permanent lateral roots. Accordingly, he recommended grading seedlings based on numbers of permanent lateral roots. However, Kormanik also noted that shoot diameter was positively correlated with the number of permanent lateral roots. Species also may differ greatly in the relative distribution of carbohydrates to roots and other organs. For example, oak reproduction is very dependent on allocations to the root system and has extremely limited shoot growth potential under most field conditions until it attains relatively large shoot mass and root/shoot ratio (Johnson 1979). In contrast, species such as yellow-poplar are less dependent on root mass as a growth determinant (Kolb and Steiner 1989).

Root morphology *is* also closely related to the potential benefits from mycorrhizae (Marx and Bryan 1975). Seedlings with large numbers of lateral roots have more sites for mycorrhizal development and thus increased nutrient uptake and growth in the nursery (Dixon et al. 1984, Mitchell et al. 1984). One study demonstrated the potential for coupling mycorrhizal inoculations with growth regulators to increase the growth of container-grown oak seedlings (Baser et al. 1987). Inoculation of oaks with a suitable ectomycorrhiza also may help to solve the problem of slow growth after outplanting (Garrett et al. 1979, Larson 1988, Parker et al. 1986, Ruehle 1984).

Certain isolates of the ectomycorrhizal fungus Pisolithus tinctorius are *now* commercially available and can be used to inoculate oak nursery beds by incorporating the inoculum (vegetative mycelium mixed with peat and vermiculite) into the upper 8 inches of soil at a rate of about 0.1 quart per ft^2 of nursery bed (Marx 1979). For white oak and other fall germinating species, inoculum should be incorporated into the soil in the fall; for spring-germinating species, inoculum should be incorporated in the spring. Although excessively high availability of nutrients may discourage mycorrhizal infection of oaks (Ruehle 1980), normal nursery fertility standards should be compatible with mycorrhiza requirements. Also, other more effective endo- and ectomycorrhizae may become available to nursery managers in the future. Many other factors also can influence the quality of hardwood nursery stock (Johnson 1981, Williams and Hanks 1976).

SUMMARY AND CONCLUSIONS

Growing hardwood nursery stock for successful planting on forest sites will require the production of relatively large stock with the growth potential to keep up with associated dominant woody competitors. The capacity for planted hardwoods to attain and maintain dominance has been demonstrated for several species in various ecosystems. However, not all planted trees will compete successfully. For many species, a reasonable goal would be to establish 50 to 75 percent of planted trees in dominant or codominant crown positions during the first two decades of stand establishment. To make that goal economically practical, the number of planted trees per acre should be minimized by estimating the potential contribution of planted trees to future stocking and using that contribution to supplement the natural regeneration potential of the stand. Guidelines for making such determinations are available for northern red oak in the Missouri Ozarks. However, less information is available for other species and other regions.

Similarly, guidelines for growing hardwoods capable of acceptable field performance are now available for northern red oak, but are *less* well defined for other species. Although new methods for improving nursery stock quality will probably be developed as demand increases for hardwood planting stock for forest sites, seedling size is likely to remain of primary importance in defining seedling quality because of the large, well-documented gains obtainable from planting large stock. Factors such as root morphology and its modification in the nursery also offer opportunities for substantial gains in outplanting performance. Although the nursery practices required to obtain these gains are not new, their quantitative expression in silvicultural terms is relatively new and necessary for predicting planting success and thus for developing prescriptions for planting hardwoods on forest sites.

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