Problems and Progress in Hardwood Regeneration

R. L. McElwee and E.M. Jones [1/]

New technological procedures and increased production requirements in the past ten years have gained for our hardwood species a significant place in the total wood economy of the South, particularly for pulping. Pulpwood production of hardwoods has increased some 250% in the past ten years, causing concern for the continuing availability of both the soft and dense hardwood species.

Pulpwood. drain prior to 1960 mainly comprised. soft hardwoods, principally the gums, but present needs lean more heavily on production of dense hardwoods, primarily oaks. Needs for hardwood, logs of sawtimber and veneer size continue at levels approximately the same as in the past ten years. When these needs are added. to the future requirements for pulpwood, one does not need to be a prophet of gloom to foresee a possible shortage of hardwoods in certain species, sizes, and grades. Although shortages may not occur everywhere, or simultaneously, they will surely materialize in localized areas. Indeed, shortages are already felt in some localities.

Faced with a scarcity of hardwoods, those responsible for wood production have revamped policy and are earnestly considering what it takes to manage hardwood stands on a sustained yield basis. This represents a reversal from ten years ago when major concern focused, on elimination, not propagation, of hardwoods. Understandably, knowledge based on critical study of hardwood management and silvicultural practices is still very meager. No phase of silviculture from seed collection and regeneration to harvesting techniques has as yet been sufficiently explored to allow development of adequate silvicultural prescriptions. Industrial, public, and. private organizations are now scrambling to plug some of the widest gaps in the knowledge of hardwood culture. In sizing up where those gaps occur, regeneration looms as the first and surely a vital phase of hardwood management. To grow usable hardwoods for the future requires a reasonable measure of control over the amount and composition of regeneration. We have been asked to explore regeneration in this paper, and this is what we shall now attempt to cover, emphasizing those areas which are most important and briefly describing where we stand with respect to adequate solutions to them.

HOW BIG IS THE PROBLEM OF REGENERATION?

Some 45 million acres of forest land in the southeast have been classified as primarily hardwood sites by Putnam, Furnival, and McKnight (1960). This area excludes the Appalachian Hardwoods and those of lesser mountain chains to the west, but includes the hardwood areas of all major and minor drainages in the Atlantic and Gulf Coastal Plains, the Mississippi Delta, and lower Piedmont. A major percentage of this vast area is now understocked or consists of stands with a high proportion of unmerchantable species and cull trees. This present sad state is the result principally of past wanton high-grading practices, failure to prepare suitable seed beds, lack of an adequate seed source, grazing, and frequent recurrence of fire. The establishment of vigorous stands of the better species on these sites, i. e., regeneration of usable species and species complexes, poses perhaps the most challenging task in our efforts to assure adequate amounts of hardwood timber for all future needs.

[1/] Director and Associate Director; respectively, Hardwood Research Program, School of Forestry, North Carolina State University, Raleigh, N. C.

IS SITE IDENTIFICATION NECESSARY?

When hardwood regeneration is planned, a problem always arising is how to define and identify those sites capable of supporting satisfactory growth as distinct from those assumed to be better suited for pine. In wetter areas of the Coastal Plain and especially along stream bottoms in both the Coastal Plain and Piedmont, areas often are summarily classified as hardwood sites simply because of their current lack of pine stands or pine regeneration, regardless of the quality of existing hardwood stands. This classification, however, is too coarse for efficient allocation of soil resources. Normally a transition area exists between the pine and hardwood site. Soils and site differences between the alluvial bottom and the terrace or Piedmont hillside are often subtle, and our knowledge is not sufficiently advanced to select the most productive species to regenerate and the kinds of soils and sites that should be "off-limits" to them.

Site quality can be measured by (a) the occurrence and response of vegetation, or (b) some attribute of the environment. The vegetational response method is exemplified by the frequently flooded bottomland sites on which tupelo gum (*Nyssa biflora*) is found to make its best growth as shown experimentally by Klawitter (1964) and others, or the moist well-drained hardwood coves and, bottoms in which yellow-poplar is found to reach dominance as reported by Smalley (1964).

Species-site plantings provide a direct method of site assessment but have the handicap of time lapse before definitive results can be gleaned. In its simplest form, adjacent rows are planted across contours. Initially, height-growth and later, volume and, quality can be compared among species or species combinations to see if soil, topography, aspect, or watertable appear to influence growth differentially, and whether any useful order in differential response can be detected.

Development of site indices for hardwood species has been attempted in several ways,all with the common objective of formulating rapid but reliable methods of field determination of hardwood site potential. Broadfoot and Krinard (1959) developed three methods for site index determination for sweetgum in the Mississippi Delta. In one, site index is shown to vary inversely with the clay content of the soil at a depth of 36-48 inches and directly with amount of exchangeable potassium in the same zone up to 550 lbs/acre, the limit of their study. In another method, site index is shown to be higher on medium textured soils than on those of fine or coarse texture. Good internal drainage and absence of hardpan further enhance the site potential within each soil texture class. In a third method, site indices for sweetgum are shown to be related to soil series and phase within the Delta; obviously this method requires a type map for series and phase identification. Similarly, Phillips and Markley (1963) in the New Jersey Coastal Plain have developed site indices based on soil series, which are further subdivided by subsoil texture and drainage class.

In yellow-poplar, a study by Smalley (1964) shows that height growth increases with available water and soil depth. Both survival and growth of yellow-poplar were shown by Schomaker (1957) to decrease with elevations up the slope. At comparable elevations above the bottom, height and survival were better on north than on south-facing slopes, as Einspahr and McComb (1951) found for oaks in Iowa. Also for yellow-poplar, McAlpine (1960) found flooding during the growing season extremely deleterious in Georgia. The same author (McAlpine 1961) with in *vitro* tests of seedlings found flooding during the dormant season not harmful, but after three days flooding during the growing season mortality was high. Hocker (1953) found yellow-poplar to be sensitive to depth of the A-horizon on soils derived from acid crystalline rocks in the lower Piedmont. His equation was:

$$SI = 74.88 + 0.730 \text{ (Depth of A-horizon in inches)}.$$

Applequist's (1959) studies for tupelo show that site conditions characterized by poor drainage and long periods of wetness were conducive to best tupelo growth. Similar trends were indicated in the work of Klawitter (1964).

For the red oaks and cottonwood, Broadfoot (1960, 1961, 1963, 1964) has determined bestgrowth in the Mississippi Delta to be on sites which are medium textures and inherently moist with good internal drainage. Broadloot's papers and that of Beaufait (1956) include tables giving site indices for water, willow, and cherrybark oak on both Delta and upland sites. Examination of the environmental factors found to be limiting for the oak species studied points to the complexity of factors influencing growth. For instance, best water oak sites in the Delta were found to be those moist well-drained sites having little exchangeable sodium per acre while willow oak growth was enhanced by the availability of exchangeable potassium up to 300 lbs/acre, after which growth was reduced. It would seem that several factors including soil depth and texture, drainage, exchangeable cations, and topography all influence growth of hardwoods, but the relative importance of each and their interactions in general or on specific species are as yet unknown.

Few attempts have been made in the Southern hardwoods to relate site indices for several species growing together on common sites such as has been done in the Northern hardwoods by Curtis and Post (1962) or Doolittle (1958) in the Southern Appalachians. Nelson and Beaufait (1956) reported on surveys relating comparative site indices of eight hardwoods and loblolly pine in the Georgia Piedmont. Results from over 130 plots established. show none of the hardwoods investigated to have as high site index as loblolly pine below site index 90 for loblolly. Above loblolly site 90, both sweetgum and yellow-poplar have a higher site potential than loblolly. Only on the poorer sites was the index for any of the oaks superior to sweetgum and poplar, but all are inferior to pine on these lower sites. Site index per se does not tell the whole story since it does not necessarily reflect stand density. Miller (1954) and Timko (1962) showed volume differentials of from 2 to 4 times greater for pines over mixed hardwoods in the lower Piedmont.

Delimitation of hardwood sites, and the optimum species to plant or sow on given sites pose one of the major hurdles which must be overcome in order to efficiently produce hardwoods in the South. Site identification, site index, and yield information are being sought by several groups, public and private. For instance, we in our Cooperative Program have initiated a study to determine both site indices and yields for sweetgum in the many soils on which it grows in the Coastal Plain and Piedmont. Information on individual tree growth, stand structure, and physiographic soils information is being collected on some 300 plots for analysis.

SEEDING HABITS

For satisfactory progress in both natural and artificial regeneration, it is essential that periodicity of seed production, phenology of flowering, time of seed ripening, methods of dissemination, germination, etc., be unequivocally understood. Detailed information is available for some species, but only partly for others. The Woody Plant Seed Manual (1948) contains much valuable data on seed yields, time of seeding, collection, extraction and storage methods, and phenological information for many species, but about twenty years have elapsed since the data were compiled. The badly-needed updating work is now underway at the Eastern Tree Seed Laboratory in Macon (Jones, 1962). The Manual information has been recently strengthened on seeding habits by such work as that of Boyce and Kaeiser (1961) and. Taft (1962) for yellow-poplar, Minckler and McDermott (1960) and Tryon and Carvell (1962) for oaks, and by Fenton (1964) and Schmitt (1964) for sweetgum. Seeding habits also are covered in a general way in the silvical characteristics of individual species published by various U. S. Forest Service Experiment Stations. Some phenological observations and factors affecting seed yields are being obtained each year to bolster our knowledge of reproductive behavior in hardwoods. For example, in our current program we are making such observations on sweetgum, certain of the red oaks, swamp black gum and tupelo. To compile a detailed list on seeding habit and related facets of seed production at this time is beyond the scope of this paper, but we do want to stress here the great importance of such information to both silvicultural and genetic practices which are being developed for hardwoods.

SITE PREPARATION

For successful establishment of hardwoods, naturally or artificially, some type of site preparation appears necessary. For cottonwood it is clearly a must, and for other species some degree of preparation is indicated. As yet, except for cottonwood, no factual data are available on net value of increase in yield attributable to different kinds or degrees of site preparation; however, we feel that sweetgum, tupelo, swamp black gum, ash, and others require full sunlight for best germination, establishment and. growth. In seeding we know the soil must be exposed. On many sites reduction of competition from undesirable species must somehow be achieved, preferably at the time of initial establishment.

Site preparation requirements for hardwoods can be somewhat different from that for pine. In swamps, water or soil moisture may restrict the period and kind of mechanical equipment used on an orderly basis. Compaction and puddling may prove to be important. Fire at the time of stand renewal is beneficial, but its use is restricted to the drier sites and reasonably continuous fuels. Chemical methods are not sufficiently selective to use beyond an initial application, i.e., they cannot be used, for subsequent release as in pines, except perhaps Fenuron (Dybar) where yellow-poplar is to be favored.

Currently, site preparation studies are underway testing the biologic and economic feasibility of site preparation by chemical and mechanical means. With luck, in a few years we will know the feasibility of these techniques.

STAND ESTABLISHMENT

Hardwood regeneration differs from pine in that for some species cuttings can be used (i.e. cottonwood, willow, sycamore), and in natural regeneration coppice is often feasible. In planting, seed source obviously is as important to hardwoods as to conifers, though it may involve greater complicating factors such as root suckering, layering, etc. which reduce degree of independence. The task of seed collection itself can be formidable unless collection is made behind logging operations, and even then it can be laborious and costly.

Seed cleaning, processing, and presowing treatments are reasonably well established, although these are continually being modified as new techniques are firmed up. The Woody Plant Seed Manual (1948) contains still the most comprehensive coverage of recommendations for seed collection, storage, and pretreatment, but much information in it has been superseded by later investigations. Many nurserymen have devised their own collection and seed handling techniques, but few of these prescriptions find their way into print. Storage techniques for most Southern hardwoods can be found in the recommendations of Jones (1962).

Nursery practices, i.e., sowing methods and rates, pre- and post-emergence treatments, seedbed maintenance, and seedling lifting, grading, and packaging comprise another area for which nurserymen have devised their own techniques. The lack of uniformity in methods is frightening. For instance, several nurseries sow sweetgum at a density to yield 60 seedlings per square foot (Coleman, 1962); Webb (1964) however, recommends seedling densities of 15-25 per square foot. Similar recommendations of 25 per square foot for sycamore seedlings have been made by Vande Linde (1960). At N. C. State our target is about 25 per square foot. Sowing densities to achieve desirable seedling sizes are being determined. Preliminary information for seedling densities for several oaks is available from the studies of Shipman (1962), and, for yellow-poplar by Shipman (1962), Lovin (1959), and others.

PLANTING

Lower seedbed densities are necessary to produce husky, high quality seedlings which for several hardwood species have definitely shown better survival and growth performance when outplanted. Ike (1962a) found seedling height of sycamore correlated to root collar diameter and this in turn significantly correlated to first year height growth. Mean height growth the first year in the field. increased from 2.59 feet for seedlings less than .30 inch root collar diameter to 5.90 feet for seedlings greater than .50 inch at the root collar. Significant differences were also apparent in survival, although only 5% differences separated the larger from the smaller groups. Similar trends are becoming apparent in sweetgum and tupelo in studies we have installed (Terzi, 1965) and, in yellow-poplar (Lovin, 1959).

Planting techniques for hardwoods are not necessarily different than for pines, except where cuttings can be used. Some species respond to pre-planting treatments including top pruning, root pruning, or both. Talli (1962) showed top pruning of yellow-poplar to be feasible so far as form and growth are concerned. Talli also showed that after five years in the field, there was no difference in bar-planted growth or stem form of yellow-poplar as against center hole mattock planted seedlings. Pruning recommendations by species along with other planting information for several of the Southern hardwoods have been summarized by Bonner (1964).

At this juncture we can say little about spacing. Trials have been installed. utilizing spacings from the very close to wide. Spacings are expected to show differences by species, site, and final product desired. Wider spacings could be used if only pulpwood is desired, but for sawtimber rotations closer spacings with more opportunity to select for final crop trees of high quality seem preferable. Hand planting has been the method most often used but there is no reason why on firm uplands and bottomland terraces machine planting can't work, especially if the equipment is modified. to handle the generally greater root mass of most hardwoods.

The satisfactory methods worked out for planting cottonwood cuttings could possibly be devised for other species as well. Successful rooting procedures have been found for yellow-poplar (McAlpine, 1964) and for sweetgum (Brown and. McAlpine, 1964). Although McAlpine (1963) found. seedling sycamores to survive and grow better than rooted cuttings, and feasible methods for rooting sweetgum and yellow-poplar on a commercial basis are not yet available, the possibilities for developing successful methods have not been exhausted. Maisenhelder (1954) contends that for cottonwood, willow, and possibly sycamore and other easily-rooted species, establishment for cuttings should be cheaper than by using seedlings.

Improving hardwood establishment through use of fertilizer holds more promise than with pines. Most hardwoods are more sensitive to increased, fertility levels; and their initial height growth rates are greater, giving greater assurance of successful competition against surrounding weeds. This seedling reaction has been successfully demonstrated for yellow-poplar and sycamore in the Georgia Piedmont (Ike, 1962b) and for black locust in Maryland (McQuilkin, 1946). At the end of the fourth growing season after outplanting, yellow-poplar fertilized with diammonium phosphate on a well-drained small streambottom exceeded. height of controls in every level of fertilizer tested. Heights in plots fertilized with 500 pounds per acre exceeded height in control plots by 100 percent, the average being 8.38 feet and 4.13 feet, respectively. In plots fertilized with 1000 pounds per acre, fourth year average height was 10.21 feet with no difference in survival among treatments. In similar tests, sycamore seedlings fertilized at the rate of 1100 pounds of 10-5-5 per acre had a mean height of 6 feet at the end. of one year in the field as compared to 3.5 feet for controls (Ike, 1962c). A similar response was noted in sycamore by McAlpine (1963) using 8-8-8 at the rate of 4 ounces per seedling.

Although not constituting a fertilizer treatment, burning of heavy accumulations of logging slash was found to change the concentration of minerals (P, K, Ca, etc.) in the surface soil and to result in a spectacular increase in the growth of yellow-poplar which attained, a height of 23 feet in the ash as against 15 feet outside the burn nine years after planting (Terzi, 1965).

SEEDING

Direct seeding of hardwoods offers an alternate approach to artificial regeneration just as it does for pines. Before such techniques can be widely used, however, satisfactory methods of discouraging predators must be devised. Results of direct seeded oaks in the Piedmont and mountains of North Carolina by Sluder et. al. (1961) show this method to be effective if acorns are seeded, to a depth of one inch on mineral soil. Protection with screens was found, to be unnecessary and actually harmful in some instances. An Arasan 75-Endrin 50-W mixture on acorns was shown to be ineffective against predators, treated acorns being readily eaten by both squirrels and. mice when other foods were in short supply (Klawitter et. al. 1963). Development of an effective repellent would aid materially in oak regeneration by allowing wider use of direct seeding. With yellow-poplar, protection from predators also appears to be necessary for successful establishment (Sluder and. Rodenbach, 1964).

In seeding hardwoods, exposure of mineral soil, planting of seed at tolerable depths below the soil surface, and reduction of seed loss to birds and rodents are major problems that must be solved. They appear at this stage generally more critical than with pines. Techniques developed for pine have resulted in wide acceptance of direct seeding at reduced costs. Similar techniques, if successfully developed, will put hardwood regeneration in a very favorable light.

NATURAL REGENERATION

Natural regeneration in many instances has been achieved without intent or design, and most of the hardwood stands existing today result from operations where accident has been the silviculturist. Under these circumstances, directed natural regeneration would seem to deserve serious consideration for stand establishment. Most of our hardwoods seed prolifically either annually or periodically. With adequate seedbed preparation and complete protection against fire after a seed catch, satisfactory stands should. frequently result through natural regeneration. We can already speculate for individual species the probable value of clearcutting in strips, or with seed. trees, or use of shelterwood. where protection from insolation seems important in the initial seedling stages, but critical studies of harvest cutting methods to secure regeneration are still needed. Not only seed matured at the time of cutting but also that stored in the forest floor must be considered. There is mounting evidence that seed of tupelo, white ash, hackberry, yellow-poplar, and other hardwood. species remain viable for a year or more in the forest floor. Following removal of the overstory such seed can produce an abundant stand of natural regeneration.

Most of the existing oak stands of the Eastern United States are believed to be the result of coppice regeneration (Roth and Sleeth, 1939). Our observations lead us to believe that several other species, particularly sweetgum, frequently becomes established. through coppice regeneration where harvest cuts are followed by extremely hot burns or where overstories of pine are wiped out by fire. Coppice from root sprouts develop into satisfactory stems, but sprouts originating high on the stump are likely to be more vulnerable to entrance of decay from the deteriorating parent stump (Roth and Sleeth, 1939). Species vary as to vulnerability. Tupelo appears surprisingly immune to basal rot despite the high stumps that are invariably left. Johnson (1964) believes sweetgum sprouts of low origin may be superior to seedlings because of their more rapid initial height growth.

ANIMAL LOSSES

Hardwood. regeneration, once established, is perhaps more vulnerable than pine to losses or injury from deer, rabbits, cotton rats, mice, etc., as well as from domestic livestock. With livestock the answer is complete exclusion of grazing, but with wild. animals and. rodents no satisfactory control programs have yet been devised. Fencing against deer is too costly, and against the smaller marauders clearly impossible on a meaningful scale. In our own experience, we have observed doer to have cropped back virtually every seedling on a three-thousand acre tract annually for five years. Rabbits, mice, and other rodents locally are capable of inflicting severe losses.

Each animal apparently shows enough preference so that seedlings of certain tree species will be bypassed if more palatable specimens are present. Results with repellents have been too erratic and costly to provide a satisfactory solution to date. It would seem that relief from losses to game and rodents should be sought through other approaches than reliance on repellents. Deer herd size is subject to some control by regulating hunting; however, this approach has not yet shown sufficient promise of success. Poisons have been tried but these too often meet with failure. In hardwood establishment, development of control measures to prevent undue losses to wildlife presents a challenge which must be met to insure consistent success in forest renewal with desired species.

SUMMARY

Increased demands for Southern hardwoods by all segments of the wood using industry, but particularly the pulpwood industry, have suddenly emphasized the very genuine need to begin developing the silvicultural and management techniques necessary to provide a continuing supply of both soft and firm-textured hardwoods. This interest represents a reversal of the pulp industry policy of only a decade ago, when large expenditures were made to kill hardwoods and convert all sites to pine.

Although suitable practices for hardwood production have been under study and, development for a good many years, many gaps still exist in the information for specific areas and. regions, and for many desirable species. To insure efficient production of wood in the quantities called for, these voids in our knowledge must be plugged. Additional information needs range all the way from species- site relationships through techniques of regeneration to stand management and harvesting relationships.

This paper outlines the major hardwood. regeneration problems by both natural and artificial methods, describes the present state of knowledge on various aspects of regeneration, and considers in a general way the problems yet to be solved to provide reasonable assurance that hardwood supplies will fulfill future needs.

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