Afforestation of Marginal Agricultural Land in the Lower Mississippi River Alluvial Valley, U.S.A.

John A. Stanturf, Collie J. Schweitzer and Emile S. Gardiner

Stanturf, J.A., Schweitzer, C.J. & Gardiner, E.S. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica 32(3): 281–297.

Afforestation of marginal agricultural land in the Lower Mississippi Alluvial Valley (LMAV) relies on native species, planted mostly in single-species plantations. Hard mast species such as oak and pecan are favored for their value to wildlife, especially on public land. Successful afforestation requires an understanding of site variation within floodplains and matching species preferences and tolerances to site characteristics, in particular to inundation regimes. Soil physical conditions, root aeration, nutrient availability, and moisture availability during the growing season also must be considered in matching species to site. Afforestation methods include planting seedlings or cuttings, and direct-seeding. Both methods can be done by hand or by machine. If good quality seedlings are planted properly and well cared for before planting, the chances for successful establishment are high but complete failures do occur. Mortality and poor growth are caused by many factors: extended post-planting drought or flooding; poor planting or seeding practices; poor quality seed or seedlings; animal depredation; or herbicide drift from aerial application to nearby cropland. More species can be planted, even on continuously flooded sites. Direct-seeding, while limited to heavy-seeded species (oaks and hickories), costs less than 50 % of planting seedlings. Growth varies considerably by soil type; most bottomland hardwoods grow best on silt loam and less well on clay soils. Up to 200 000 ha of land in the LMAV subject to spring and early summer backwater flooding could be afforested over the next decade.

Keywords bottomland hardwoods, direct-seeding, *Liquidumbar styraciflua*, *Fraxinus pennsylvanica*, *Populus deltoides*, *Quercus nuttallii*, *Quercus nigra*
Authors' addresses USDA Forest Service, Southern Research Station, P.O. Box 227, Stoneville, MS 38776, USA
Fax +1 601 686 3195 **E-mail** jstantur/srs_stoneville@fs.fed.us
Accepted 2 July 1998

1 Introduction

Forested wetlands in the southern United States mostly occur in the floodplains of major rivers and their tributaries within a broad coastal plain stretching from Texas to Virginia. Occupying almost 13 million ha in the southern United States, the importance to society of these floodplain forests is well documented (Wharton et al. 1982). Nevertheless, the present extent of forested wetlands in the United States is less than one-third of their extent before European settlement. Two-thirds of the annual losses of wetlands in the conterminous United States occur in forested wetlands, primarily in the South (Wilen and Frayer 1990). Conversion to agriculture by clearing and draining has been the major cause of forested wetland loss (McWilliams and Rosson 1990). Of an estimated 8.5 to 9.5 million ha before 1780, only two million ha of forested wetlands remain in the floodplain of the lower Mississippi River (MacDonald et al. 1979, Turner et al. 198 1, The Nature Conservancy 1992). Forested wetland losses in other parts of the southern U.S. are just as striking (Tansey and Cost 1990, Hefner and Dahl 1993).

The Lower Mississippi Alluvial Valley (LMAV) once supported the largest expanse of forested wetlands in the United States. Rich alluvial soils received periodic sediment additions from the world's third largest river and supported highly productive ecosystems (Putnam et al. 1960, Harris and Gosselink 1990). Extensive areas of bottomland hardwood forests were found in the floodplains of tributaries of the Mississippi and other large rivers of the southeastern United States that drained into the Gulf of Mexico and the Atlantic Ocean. The LMAV has undergone the most widespread loss of bottomland hardwood forests in the United States. As much as 96 % of the loss of bottomland hardwood forests in the LMAV has been due to conversion to agriculture (MacDonald et al. 1979, Department of the Interior 1988).

Between the early 1800s and 1935, about one-half of the original forests were cleared. A later surge in forest clearing for agriculture took place in the 1960s and 1970s in response to a rise in soybean prices (Stemitzke 1976). When prices eventually fell, land that was marginal for agriculture because it was still subject to spring and early summer backwater flooding became idle. These are the lands that are now available for afforestation.

Over the last 25 yrs, scientists at the Southern Hardwoods Laboratory in Stoneville, Mississippi have developed most of the artificial regeneration methods used today in afforestation of bottomland hardwoods. In this paper, we provide an overview of afforestation efforts in the LMAV. Strategies vary by landowner objectives and are driven mainly by public programs supporting afforestation for water quality protection and wetlands restoration. We provide a summary of public and private programs supporting afforestation of economically marginal farmland and describe common practices of artificial regeneration, including examples of afforestation programs that have different objectives.

Afforestation primarily is occurring in the LMAV states of Louisiana, Mississippi and Ar-

Table 1. Actual and potential afforestation in the Lower Mississippi Alluvial Valley, by program and agency.

Program	Agency[2]	Area (ha)[1] 1995	Planned to 2005	Total
Wildlife refuges	USFWS	5180	10000	15180
Wetland mitigation	COE	2025	9700	11725
State agencies	MS, LA, AR	13500	40500	54000
Wetlands Reserve Program (WRP)	NRCS	53000	47750	100750
Total		73705	107950	181655

[1] Estimates furnished by participants at the Workshop on "Artificial Regeneration of Bottomland Hardwoods: Reforestation/Restoration Research Needs", held May 11-12. 1995 in Stoneville, Mississippi.
[2] USFWS=U.S. Fish and Wildlife Service; COE=U. S. Army Corps of Engineers; MS=Mississippi; LA=Louisiana; AR=Arkansas; NRCS=U. S. Natural Resources Conservation Service, formerly Soil Conservation Service.

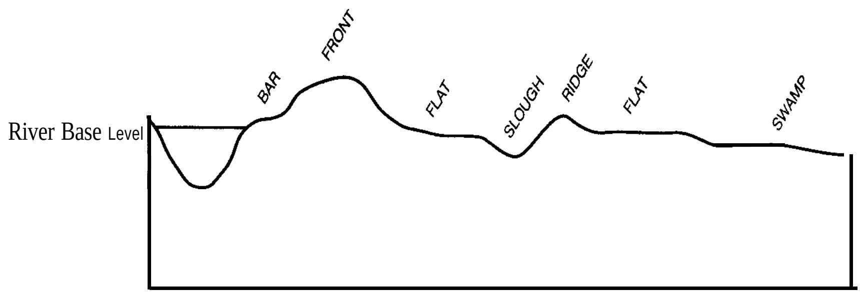

Fig. 1. Cross-section of a typical floodplain, showing the approximate relationship between site types.

kansas, although restoration is taking place throughout the South. Afforestation in the LMAV is driven primarily by acquisition of land by public agencies to enlarge federal wildlife refuges and to mitigate or offset wetland losses due to construction for flood control; by state programs; and by public policy initiatives such as the Wetlands Reserve Program (WRP) on private land. Through 1995, approximately 74 000 ha are under afforestation plans, mostly on private land (Table 1). Afforestation will increase over the next 10 years, so that 182 000 ha should be in afforestation schemes in the LMAV, primarily in the states of Mississippi, Louisiana, and Arkansas.

2 Site and Species

2.1 Species/Site Relationships

Successful afforestation of marginal farmland in the LMAV requires an understanding of site variation within floodplains and site requirements of the species to be used. Although most afforestation areas are flat, large differences in site quality exist, and many afforestation efforts have failed because these differences were ignored. Elevational changes of only a few inches can have a marked effect on the site and therefore on species occurrence and development (Hodges and Switzer 1979). Differences in hydrology, particularly drainage and soil moisture, are clearly associated with these minor elevational differences. Other factors also vary according to elevation, such as soil type, texture, structure, and pH. All these factors affect which species are suitable for the site.

2.2 Site Characteristics

The origin and development of floodplain geomorphic features were discussed by Hodges (1994) and detailed descriptions, including relative elevation, soil types, drainage class, and productivity are given in Hodges and Switzer (1979) and Hodges (1997). In summary, the fronts and ridges (former fronts) are the highest, best drained, and most productive sites within the floodplain (Fig. 1). Soils are generally sandy or silty loams. Soils on the flats are predominantly clays and the sites are poorly to somewhat poorly drained. Sloughs and swamps arise from old streambeds that are filling with sediment. The soils are usually fine-textured and drainage is poor. Standing water may be present in the swamps except in extremely dry years. Most of the land available for afforestation is on the flats; sloughs and swamps were seldom cleared, and fronts and ridges continue to support active agriculture. Because of the great spatial variability in floodplains, however, sites are often intermixed so that an area to be afforested is likely to include several site conditions.

2.3 Species Tolerances to Flooding

For successful regeneration, species preferences and tolerances must be matched to site characteristics, in particular to inundation regimes. Rel-

Table 2. Species tolerance in relation to flooding time and duration.

Continuous flooding		Periodic flooding		
January-June	January-May	January-May	January-April	January–March
Taxodium distichum L. (Baldcypress)	*Diospyros virginiana* L. (Persimmon)	*Liquidambar styraciflua* L. (Sweetgum)	*Platanus occidentalis* L. (Sycamore)	*Quercus shumardii* Buck1 (Shumard oak)
Quercus lyrata Walt. (Overcup oak)	*Fraxinus pennsylvanica* Marsh. (Green ash)	*Quercus nigra* L. (Water oak)	*Populus deltoides* Bartr. ex. Marsh. var. *deltoides* (Eastern cottonwood)	*Quercus falcata* var. *pagodifolia* Ell (Cherrybark oak)
Carya aquatica (Michx. f.) Nutt. (Water hickory)	*Quercus laurifolia* Michx. (Swamp laurel oak)	*Quercus phellos* L. (Willow oak)	*Carya illinoensis* Wangenh. (Sweet pecan)	*Quercus michauxii* Nutt. (Swamp chestnut oak)
Nyssa *aquatica* L. (Water tupelo)	*Quercus nuttallii* Palmer (Nuttall oak)		*Celtis laevigata* willd. (Sugarberry)	
	Salix nigra L. (Black willow)			

ative flood tolerance of bottomland trees is summarized in Table 2 (see McKnight et al. 198 1 for a more complete compilation). Few species can tolerate continuous flooding, especially if it extends into the growing season. Baldcypress (*Taxodium distichum* L.) and water tupelo (Nyssa *aquatica* L.) can survive extended flooding of their roots to a greater extent than other species. After leafout, seedlings can withstand limited soil inundation if their leaves are not submerged (Hook 1984). The choice of species is greater if flooding is periodic, as is true on most bottomland sites in most years.

Inundation regime is more complex, however, than whether a site floods or not, and seedlings are more susceptible than mature trees. Depth, time, and duration of flooding must be considered, and the state of the floodwater, particularly flowing versus stagnant (Hook and Scholtens 1978). Inundation regime is difficult and time-consuming to measure, and natural regimes frequently have been altered. An indicator of flooding regime is published in soil surveys, and nearby landowners often know of alterations due to drainage and other factors not reflected in soil surveys. A flood history for at least the previous five years is recommended, to select suitable species. The choice of species should be guided by the upper, rather than the lower, level of flooding. Most flood tolerant species can be planted on drier sites. but not the reverse.

2.4 Soil Characteristics

Soil physical conditions, root aeration, nutrient availability, and moisture availability during the growing season are other important factors to consider in matching species to site (Stone 1978, Baker and Broadfoot 1979). Bottomland soils of silt loam texture generally suggest a moist, well-drained site. Clay textured soils usually indicate a low-lying site that is periodically inundated. Medium-textured soils are suitable for most bottomland hardwood species, with three possible exceptions. Survival and growth of red oak species are limited by high pH (more than 7.0), although Shumard oak (Quercus *shumardii* Buckl.) does well over pH 7.5 (Kennedy 1984, Kennedy and Krinard 1985). On former cropland, plow pans can occur at 20 cm to 30 cm depth that will limit root development. Inadequate rooting will affect survival, growth, and windfirmess. Plow pans can be broken up by subsoiling before planting or direct seeding. On former agricultural land or engineered sites, mineral toxicities or nutrient deficiencies may occur, but they can be diagnosed by soil analyses and corrected. Clay soils tend to be very wet in winter and spring and very dry in mid to late summer, presenting fewer options for selecting suitable species. Green ash *(Fraxinuspennsylvanica* Marsh.) and Nuttall oak *(Quercus nuttallii* Palmer) both tolerate periodic flooding and grow better than other species when available water is low.

Broadfoot developed two methods for evaluating sites based upon soil characteristics. One approach requires knowing which soil series are present and consulting either Broadfoot (1976) or recently published soil survey reports that include woodland suitability interpretations (Francis 1985). A more complicated approach involves estimating site index, a measure of potential productivity based upon a tree's height growth over time (Baker and Broadfoot 1979). Advantages of this approach include widespread applicability throughout the southern U.S., identification of soil series is not required, and guidelines for ameliorative treatments such as fertilization are included (Baker and Broadfoot 1979). Disadvantages include the need for users to estimate soil conditions such as texture, compaction, water table depth, organic matter content, and pH (Francis 1985). On the other hand, most soil scientists and many foresters can make field estimates of these properties that produce site index estimates of sufficient accuracy for most reforestation projects. While site index is a useful guide to inherent productivity, there is no fixed rule for applying productivity measures to judge afforestation potential for wildlife and other purposes. We have suggested that a site be at least minimally acceptable for a species, as determined by Baker and Broadfoot (1979). This means growth on a site is likely to range from 54 % to 63 % of the maximum productivity level for that species (Stanturf 1993).

3 Afforestation Methods

3.1 General

Two major afforestation methods are planting seedlings or cuttings, and direct-seeding. Both methods can be done by hand or by machine. Suitability of afforesting several species with these stock types is summarized in Table 3. If good quality seedlings are planted properly and well cared for before planting, the chances for successful establishment are high (Kennedy 1984, Kennedy et al. 1987, Allen and Kennedy 1989, Allen et al. in press). Planting has the advantages that more species can be planted, and it can be done even on continuously flooded sites. Direct-seeding, while limited to heavy-seeded species such as the oaks *(Quercus* spp.) and hickories *(Carya* spp.), costs less than 50 % of the cost of seedling planting (Bullard et al. 1992). Direct-seeding has been successful in every month

Table 3. Suitable artificial regeneration methods and stock types for major bottomland hardwood species.

Species	Planting: Seedlings	Planting: Cuttings	Direct-Seeding
Carya illinoensis	x		x
Carya aquatica	x		x
Celtis laevigata	x		
Diospyros virginiana	x		
Fraxinus pennsylvanica	xx[1]	x	
Liquidambar styraciflua	xx	x	
Nyssa aquatica	x		
Platanus occidentalis	xx	x	
Populus deltoides	x	x x	
Quercus falcata var. *pagodifolia*	x		x
Q. laurifolia	x		x
Q. lyrata	x		x
Q. michauxii	x		x
Q. nigra	x		x
Q. nuttallii	x		x
Q. phellos	x		x
Q. shumardii	x		x
Salix nigra		x	
Taxodium distichum	x		

[1] xx = preferred stock type.

(Johnson 1983), and operationally it can be done for a month or longer beyond the time when planting is recommended.

3.2 Site Preparation

The best site preparation on marginal cropland is to continue farming the site until it is afforested. Normal farming operations will control woody and herbaceous weeds so that often no site preparation is needed. If a plow pan has developed, disking with a heavy disk at least twice in late summer before planting breaks up the plow pan and controls weeds. If a heavy weed cover has been allowed to develop from fallowing, disking is advisable to reduce cover for rodents. Planting or direct-seeding by machine will be aided by site preparation and generally result in greater survival.

3.3 Seedlings

Suitable bare-root hardwood seedlings are larger than the typical pine seedling planted in the southern U.S. Bare-root hardwood seedlings are usually 1-O stock. Recommended size is at least 45 cm top length with at least 1 cm root collar diameter (Kennedy 1993). Root systems should be well-developed with several lateral roots, and can be pruned to 20 cm length to make planting easier.

While bare-root seedlings are generally preferred, container stock can be planted later in the season and thus extend the planting season. This may allow sites that flood into the growing season to be planted successfully with container stock after flood waters recede, later in the season than is feasible for bare-root stock. Oak seedlings grown in pots may have higher survival on "harsher" sites such as heavy clay soils with vertic (shrink-swell) properties (Allen et al. in press). Container grown Nuttall oak seedlings survived flooding better than bare-root seedlings after out planting in one trial (Humphrey 1994). Containerized seedlings are more expensive than bare-root seedlings, heavier, and more difficult to transport and plant.

Additional research, including side-by-side comparisons of bare-root and container stock, is needed before definitive recommendations can be given. The ability to extend the planting window to include fall, late spring and early summer plantings will probably make container stock cost-effective for some public agencies (J. Kiser, Corps of Engineers-Vicksburg District, pers. comm., May 1995).

Bare-root seedlings survive best if they are planted while dormant in moist soil. These conditions are obtained in the southern U.S. from January through mid-March. Planting can begin as early as November if antecedent precipitation has recharged soil moisture (Kennedy 1979). If seedlings are kept dormant in cold storage, planting may be extended into May (Allen and Kennedy 1989). The most frequent limitations on planting are excessive cold and flooding. Subfreezing temperatures cause root death, resulting in low survival. While flood tolerant species can be planted in standing water, even hand-planting is easier if soils are moist but not flooded.

Seedlings can be hand planted using a dibble bar or shovel, or machine planted. Planting machines work well in moist sandy and loamy soils, but clay soils adhere to parts of the planter and hinder movement (Allen and Kennedy 1989). An experienced hand planter can plant up to 800 seedlings in a day under ideal conditions. An experienced two- or three-person machine planting crew can plant 4000 to 8000 seedlings per day (Allen and Kennedy 1989).

3.4 Cuttings

Planting unrooted cuttings of five species has proven successful (Table 3), and is the most common method of afforesting Eastern cottonwood (*Populus deltoides* Bartr., ex Marsh. var. *deltoides)*. One advantage of cuttings over other stock types is the ability to plant genetically superior clonal material. Presently this is important for cottonwood only, but likely to increase in importance for other species (R. Rousseau, Westvaco Corp., pers. comm., May 1995). Cottonwood cuttings are produced from wands, which are themselves produced in stool beds. Wands can be produced from root stock for three to four years, then the nursery must be re-established (McKnight 1970). Under good nursery conditions, wands will reach heights of up to 5 m in one year. Cuttings 5 1 cm long are produced from dormant wands. Cuttings should be at least 6 mm diameter at the top (small) end. Research on survival and planting techniques has shown that cuttings longer than 5 1 cm do not increase survival, but they do increase costs (McKnight 1970).

Planting options for cottonwood cuttings are similar to options for bare-root seedlings. The planting window for dormant cuttings is December through March, and cuttings can be hand- or machine-planted. Cuttings are planted about 45 cm deep, with 5 cm aboveground. Leaving only a small amount of the cutting aboveground reduces the likelihood of developing multiple-stems (McKnight 1970). Additional information on cottonwood culture is given below.

Green ash has been successfully regenerated from both horizontal and vertical cuttings (Kennedy 1977), but only from cuttings made from 1-O nursery grown seedlings. Horizontal planting of cuttings 25 cm to 36 cm long in slits 2.5 cm to 5.0 cm deep, or vertical planting of 38 cm long cuttings has been suggested as an alternative to planted seedlings (Kennedy 1977). However, where there is a danger of long periods of standing water, seedlings are better than cuttings. Seedlings were larger after one growing season than either horizontal or vertical cuttings, although all material grew the same amount.

3.5 Direct-Seeding

Direct-seeding is a widely used method of afforestation in the LMAV. Only heavy-seeded species of *Quercus* spp. and *Carya* spp. can be direct-seeded with a strong likelihood of success. Many early tests were with Nuttall oak and it continues to be the most popular species to direct-seed. At least six other red oak species (*Erythrobalanus*) and four white oak species (*Leucobalanus*) have been direct-seeded successfully (Table 3). Most attempts at direct seeding light-seeded species *(Fruxinus* spp., *Ulmus* spp., *Liquidumbar styraciflua*) have failed (Allen et al. in Press). Failures have been attributed to drought stress shortly after germination, flooding after germination, or predation by birds and rodents.

Initial trials with direct-seeding were conducted in natural stands under a complete canopy and in small openings (< 0.004 ha) created by removing single large trees. These trials generally resulted in complete failure because of rodent depredation (Johnson and Krinard 1987). Further research with larger openings has established that openings greater than one ha can be successfully regenerated by direct-seeding (Johnson and Krinard 1987). Competing vegetation may pose more of a threat to new germinants, as oaks are notoriously slow to develop aboveground. Germination and survival as high as 80 percent has been attained in research trials, but 35 percent germination is more typical for commercial sowings. Recommended rates are 1730 to 2470 sound acorns ha^{-1} on most sites. On sites that have lain fallow for a few years, are weed infested and likely to have high rodent populations, the rate should be higher: 2964 to 3705 acorns ha^{-1} (Allen et al. in press). This should produce 741 to 1235, l-year-old trees ha-‘, a number sufficient for most objectives.

Seed collection is the greatest challenge in direct-seeding (Kennedy 1993). Collections must be made between October and February, after acorns have fallen. Acorns of red oak species can be stored up to five years in cold storage (Bonner 1973, Bonner and Vozzo 1987, Bonner et al. 1994). Generally, acorns of white oak species cannot be stored longer than four months, as they naturally germinate after falling.

Direct-seeding can be conducted from November through June, depending upon site flooding frequency. While direct-seeding of Nuttall oak has been successful in every month, July through October are usually too hot and dry (Johnson and Krinard 1987, Wittwer 1991). Seeds that germinate in cold storage can still be sown and will produce suitable seedlings, even if their radicles are broken off (Bonner 1982). Seeds sown 2.5 cm to 15 cm deep will germinate and produce seedlings, although 5 cm is the recommended depth. Deeper sowing may be worthwhile when surface drying or rodent pilferage is likely. Normal spacing is rows 3 m to 3.6 m apart and acorns 1 m to 1.5 m apart within rows.

Mechanical planting and sowing are faster on clean sites with slopes less than 10 %. Modified agricultural planters have been used successfully

Table 4. Comparison of the cost of direct-seeding versus planting seedlings of oaks in the LMAV. (Source: Data are from Bullard et al. 1992 and shown in 1989 dollars).

Activity	Costs, dollars ha-' Direct-Seeding	Planting
Site preparation (bush-hogging or disking)	12.35	12.35
Seeding/Planting	86.45	86.45
Acorn/Seedling material	61.75	284.05
Total costs	$160.55	$382.85

for direct seeding, although some new equipment has been developed for acorns. Machines used for direct-seeding are modified one- and two-row grain planters. Some drop acorns automatically, others require an operator who drops acorns at specified distances. A broadcast seeder has been used in trials in Louisiana (Allen et al. in press). Aerial seeding has been shown in small trials to have potential, although more work needs to be done to optimize the delivery system and the method of burying acorns after sowing (Allen et al. in press). Typical rates of direct-seeding are 12 to 16 ha per day for a three-person crew using machines, to 2 ha per day for one person sowing by hand.

Success rates with direct-seeding have been good. Failures are usually due to poor handling of acorns, or to adverse field environments following sowing. Flooding and high water temperatures are a deadly combination for newly germinated acorns (Johnson and Krinard 1985), such as occur during May or June flooding. This may follow a dry March and April, during which acorns have successfully germinated. On sites where extended flooding is likely during the early portion of the growing season, acorns should be kept in cold storage and sown after flood waters recede (Johnson and Krinard 1987).

3.6 Direct-Seeding Versus Planting Seedlings

Advantages of planting seedlings include a wider range of species and a wider range of sites and conditions can be tolerated. While extended post-planting flooding damages most seedlings, taller planted seedlings may extend above floodwaters and survive. On the other hand, the planting window for seedlings is narrower in the South than for direct-seed.

The main advantage of direct seeding is potentially lower costs (Bullard et al. 1992, Allen et al. in press). This comes about in two ways: all the costs of growing and handling seedlings are avoided, and planting acorns is usually less time-consuming than seedlings. The major disadvantages of direct seeding are that the plants are in more vulnerable stages of development longer, so that the risk of poor survival and possible failure is greater. Bullard et al. (1992) compared the economics of direct-seeding and planting oaks on afforested sites. The significant advantage of direct-seeding was the lower cost for material (Table 4). Although direct-seeding is quicker and easier than planting seedlings, the technique is relatively new to contractors and no price differential was offered (Bullard et al. 1992). They concluded that the primary advantage of planting seedlings was that in a given year, the overall probability was greater of achieving an adequately stocked stand. Allen (1990) reached a similar conclusion from his survey of oak planting and direct-seeding on wildlife refuges.

4 Growth and Production

4.1 General

Establishment problems will be apparent within the first two years on afforestation sites. Complete failures do occur. Mortality and poor growth

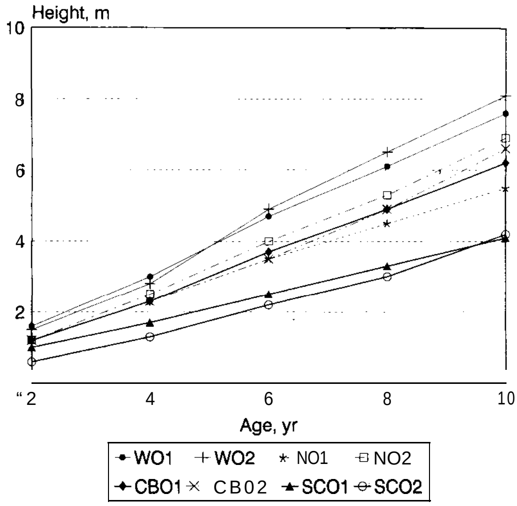

Fig. 2a. Height growth of four oak (*Quercus*) species planted at two spacings on a minor bottom site. (WO = Q. *nigra*, *NO* = *Q. nuttallii*, CBO = *Q. falcata* var. *pagodifolia*, SCO = *Q. michauxii; 1* = spacing of 2.44 m by 2.44 m and 2 = spacing of 3.66 m by 3.66 m. Source: Kennedy et al. 1988, p. 84).

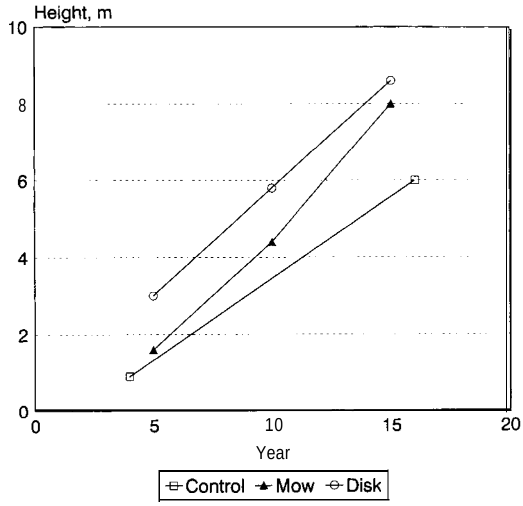

Fig. 2b. Height growth of Nuttall oak (Q. *nuttallii)* on a Sharkey Clay soil; control plots measured at age 4 and at age 16; mowed and disked plots measured at ages 5, 10 and 15 years. (Source: Krinard and Kennedy 1987a, p. 2; Krinard and Kennedy 1987b, p. 2).

are caused by many factors: extended post-planting drought or flooding; poor planting or seeding practices; poor quality seed or seedlings; animal depredation; or herbicide drift from aerial application to nearby cropland (Kennedy 1993). Sometimes the slow initial growth, especially of oaks, gives the appearance of failure because seedlings are hidden by profuse stands of tall weeds.

Early weed control, mechanical or chemical, may increase survival and speed early growth of seedlings, but benefits may not justify costs. Krinard and Kennedy (1987a) compared growth of six hardwood species on a formerly forested Sharkey clay soil (very-fine, montmorillonitic, nonacid, thermic, vertic Haplaquepts) that was mowed or disked to control weeds. Plots were treated three to five times annually the first 5 years. Mowing provided no advantage over no weed control for the first 4 years (Kennedy 1981) and there was no difference between mowed or disked treatments after 15 years (Krinard and Kennedy 1987a). Because competitors on old-field sites differ significantly, these results serve only to caution that expenditures for weed control may not be warranted.

Intensive cultivation is recommended for the first year in cottonwood plantations (McKnight 1970). High survival and best growth of sycamore was obtained with clear cultivation for 1 or 2 years, although it is possible to successfully establish sycamore plantations without weed control (Briscoe 1969). Disking often produces significantly greater growth than mowing (Aird 1962, Fitzgerald et al. 1975, Kennedy 1984).

4.2 Oak Plantings

Most species of bottomland oaks grow slowly the first several years, typically 30 cm to 60 cm in height growth annually. If seedlings are not overtopped, height growth will increase to over 1 m annually (Kennedy 1993). Four oak species (Kennedy et al. 1988) established with 1-O bareroot seedlings ranged in height from 4 m for swamp chestnut oak (Q. *michauxii* Nutt.), to 8.1 m for water oak (Q. *nigra* L.) at age 10 (Fig. 2a).

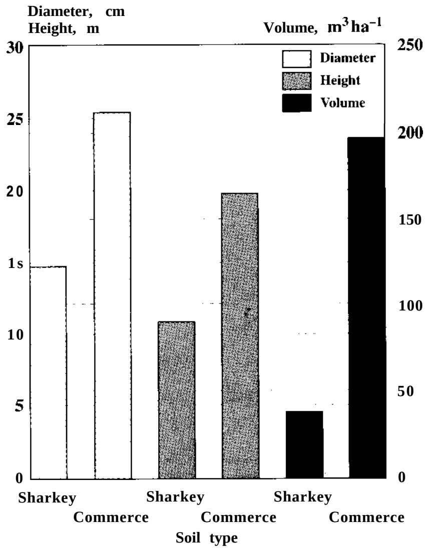

Fig. 3a. Eighteen-year average diameter, height, and volume for sweetgum *(Liquidumbar styraciflua)* grown on two soil types in Mississippi. (Source: Krinard and Johnson 198.5, p. 7).

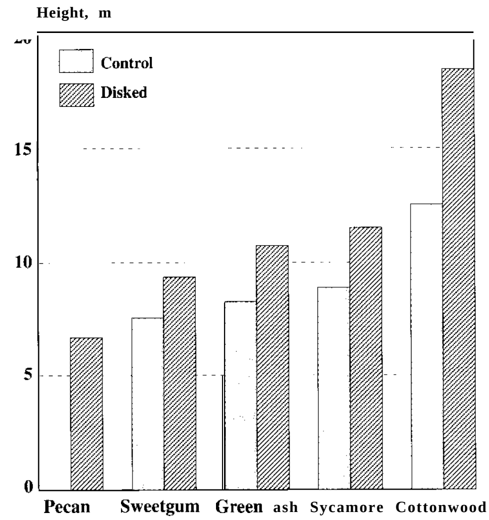

Fig. 3b. Average height of four hardwood species growing on a Sharkey Clay soil. Treatment was disking annually for the first five years. Control plots measured at age 16 and disked plots at age 15 years. Sweet pecan could not be measured reliably due to the number of water hickory *(Carya aquatica* (Michx. f.) Nutt.) sprouts present, but survival was probably low. (Source: Krinard and Kennedy 1987a, p. 2; Krinard and Kennedy 1987b, p. 2).

The site was a relatively infertile, minor bottom in Arkansas but growth was good. Swamp chestnut oak was the slowest growing in the first 6 years, probably due to the small seedlings that were available for planting (Kennedy et al. 1988).

On a Sharkey clay soil, Nuttall oak planted at 3 m x 3 m spacing and no weed control averaged 8 1 percent survival after 16 years. Height growth was only 6 m (Fig. 2b), as opposed to the better growth on the Arkansas site after only 10 years (Fig. 2a). On the Sharkey clay (Fig. 2b), mowing between the rows annually for 5 years increased height growth of Nuttall oak to 7.9 m at age 15 years (Krinard and Kennedy 1987a,b).

Nuttall oak was direct-seeded on an intensively prepared Sharkey clay soil at the Delta Experimental Forest near Stoneville, MS (Johnson 1983). Germination averaged 36 percent. Initial spacing between planting spots was 0.6 m (5380 acorns ha^{-1}). Of the trees alive at the end of the first year, 96 percent were still alive at the end of 11 years. Many of the trees were overtopped but 1360 Nuttall oak seedlings per hectare were in a free-to-grow position at age 11 years. Diameter at breast height ranged from 4 cm to 7 cm, and average height was 5.1 m.

4.3 Sweetgum Plantings

Growth varies considerably by soil type; most bottomland hardwood species grow best on medium textured soils such as Commerce silt loam (fine-silty, mixed, nonacid, thermic aeric Fluvaquents) and less wells on clay soils such as Sharkey. A comparison of two sweetgum plantations in Mississippi illustrates these differences. At the same stocking, sweetgum on the Commerce soil was 75 percent taller, and nearly five times more volume and weight (Figure 3a; Krinard and Johnson 1985, Krinard 1988). Thinning at age 12 reduced stocking in the clay soil to 4.25 m *x* 4.25 m. The stand on the silt loam soil was thinned twice. Alternate diagonal rows were removed at age 6, and half the remaining trees were removed at age 30, leaving a spacing of 6 m *x* 6 m. Remeasurement after 3 1 years shows greater basal area on fewer trees on the more productive Commerce silt loam soil (Table 5).

4.4 Green Ash Plantings

Green ash is a valuable bottomland hardwood species for timber but has not been favored in afforestation for wildlife. Krinard (1989) compared three green ash plantings of different ages planted on Sharkey (clay), Commerce (silt loam), and Tunica-Bowdre (clayey over loamy, montmorillonitic, nonacid, thermic vertic Haplaquepts and thermic fluvaquentic Hapludolls) soils. All plantings were at 3.67 m by 3.67 m spacings except the Sharkey planting was 3.05 m by 3.05 m spacing and thinned at age 10. Plantings on the Commerce and Tunica-Bowdre soils grew the fastest. Mean annual increments of average diameter and height growth were about 12.5 mm yr^{-1} and 1.22 m yr^{-1} (Table 6). Mean annual increment values for the Sharkey soil were lower, 7.6 mm yr^{-1} in diameter growth and 0.76 m yr^{-1} in height growth. Survival exceeded 80 percent on all sites. Krinard (1989) concluded that spacings wider than 3.67 m by 3.67 m were not advisable for green ash because of forking problems.

Table 5. Comparison of growth of sweetgum (*Liquidambar styraciflua*) plantations on two soil types after 31 years. (Source: J. Goelz, unpublished data on file at Southern Hardwoods Lab.).

	Density stems ha-’	Basal Area m^2 ha^{-1}	DBH (Dq) cm
Commerce Silt Loam	227	24.4	37.1
Sharkey Clay	505	15.8	19.8

4.5 Comparisons of Several Species

Relative growth rates among species planted on the same soil type and receiving similar cultural treatments illustrate adaptations to soil types. Growth on the clay soils that are available for afforestation is lower than growth on medium textured soils, thus these sites may not be suitable for timber production alone. Krinard and Kennedy (1987a) reported on five hardwood species planted on a Sharkey clay soil, disked for the first 5 years to control weeds, and selectively thinned after 5 years to double the original planting spacing. By age 15, average height was in the order sweet pecan (*Carya illinoensis* L.) < sweetgum < green ash < sycamore < cottonwood (Fig. 3b). At age 16, trees growing on control plots (no weed control, no thinning) were smaller but height growth ranking was the same (Krinard and Kennedy 1987b).

5 Afforestation Programs and Strategies

5.1 Public Programs

In 1987, the United States Fish and Wildlife Service (FWS) began an aggressive program in the LMAV to restore bottomland hardwood ecosystems (Haynes et al. 1993). This effort was not limited to existing wildlife refuges, and included reforestation of private lands and foreclosed farmland transferred to the FWS from the Farmers Home Administration, another federal agency. The FWS strategy has been to afforest the most land, at the lowest unit cost per hectare. Site

Table 6. Stand parameters of three green ash (*Fraxinus pennsylvanica* Marsh.) plantings on representative soil types in the LMAV. (Source: Krinard 1989, Table 1).

Soil Type	Age yrs	Dbh cm	Ht m	Basal Area m^2 ha-’	Cubic Volume m^3 ha-’	Trees ha-’
Sharkey	15	11.9	11.2	6.0	31.9	504
Commerce	13	16.0	15.7	13.3	101.2	635
Tunica-Bowdre	11	15.7	13.6	14.7	78.4	702

preparation is minimal; weeds on fallow sites are reduced using a bush hog or fire plow, followed by disking once or twice just before planting (Haynes et al. 1993). Spacing may be greater (7.32 m by 7.32 m), the goal is to guarantee the hard mast component. Allen (1990) reviewed operational planting and direct-seeding on ten sites on federal wildlife refuges and concluded that planting seedlings is preferred over direct-seeding if the objective is to quickly afforest old fields. A summary of afforestation efforts by agency is given in Table 1.

The Army Corps of Engineers is restoring bottomland hardwood forests to mitigate fish and wildlife habitat losses caused by water resources projects, primarily construction for flood control. One ambitious mitigation project is the Lake George property in the Yazoo River Basin in Mississippi (Corps of Engineers 1989). The site is characterized by Sharkey-Forestdale Association soils, backwater flooding in winter and spring, and poor drainage. The agency's strategy has been to treat the wettest sites first, leaving drier sites in active agriculture to lower overall project costs by revenue from leasing, and to control weeds (lower site preparation costs). Bare-root seedlings (sweet pecan, willow oak, Shumard oak, cherrybark oak (Q. *falcata* var. *pagodifolia* Ell.) are planted at 3.66 m by 3.66 m spacing, and container seedlings (water tupelo and water oak) at 4.27 m by 4.27 m spacing. Only 5 % of the area will be direct-seeded.

State government agencies such as the Louisiana Department of Wildlife and Fisheries and the Mississippi Department of Wildlife, Fisheries and Parks also have undertaken ambitious restoration projects. More than 2000 ha near Monroe, Louisiana are being restored by the Louisiana Department of Wildlife and Fisheries (Savage et al. 1989, Newling 1990). The Mississippi Department of Wildlife, Fisheries and Parks is restoring more than 400 ha near Greenwood, MS (Newling 1990). Participants at a recent workshop estimated a total of 54 000 ha are scheduled for afforestation by state agencies in Mississippi, Arkansas, and Louisiana (Stanturf, unpublished data, Table 1).

The federal Conservation Reserve Program (CRP) in 1980 began to subsidize establishing permanent vegetative cover on erodible cropland. When reauthorized by Congress as part of the 1985 Food Security Act (popularly known as the Farm Bill), the CRP included wetlands converted to cropland (Kennedy 1990). A landowner participating in CRP reserves the land for 10 years in return for reimbursement of some afforestation costs and an annual payment, per hectare. By the ninth enrollment year (1989), more than 20 000 ha of wetlands in the LMAV were placed into the CRP (The Nature Conservancy 1992). An unknown portion of this land was afforested, thus Table 1 does not include an estimate of CRP land.

The Wetland Reserve Program (WRP) was included in the 1990 Farm Bill and set a maximum sign up of 400 000 ha nationwide. A pilot program in 1992 in eight states was expanded to 20 states in 1994. Three states in the LMAV, Mississippi, Arkansas, and Louisiana, were included. More land was submitted in these three states (200 000 ha) than could be accepted because of financial limitations on the program. In 1995, Congress authorized an additional $92 million. The federal Natural Resources Conservation Service administers the program and expects a total of 100 750 ha to be afforested in the LMAV by 2005 (Table 1). In return for a permanent easement that removes the land from agricultural production, the government shares the cost of afforestation and provides a one-time payment based upon the fair market agricultural value of the land. The WRP will only reimburse afforestation costs for 741 stems ha^{-1}, which is insufficient for commercial forest management. Discussion of incorporating timber management into WRP has begun to remove some of the uncertainty surrounding future management options.

5.2 Other Private Efforts

Many private efforts that do not depend on federal cost-sharing programs have focused on hardwood plantations for producing fiber. Fitler Managed Forest near Onward, Mississippi comprises 4000 ha of eastern cottonwood plantations. Fitler is owned by Crown Vantage (formerly James River Timber Corp.) and intensively managed for pulpwood production. Intensive plantation

Table 7. Financial analysis for a private landowner of a cottonwood plantation on a lo-year pulpwood rotation. (Source: J. Portwood, Crown Vantage Corp., pers. comm., July 1995).

	Contract'	No Contract	
Yield	112[2]	112	Ton ha-'(green)
Stumpage	17.24[3]	13.24	$US Ton^{-1} (green)
Expenses	27[4]	27	$US
Capital Costs	398[5]	583	$US ha-'
Gross Income	1483	1483	$US ha^{-1}
Net Income	1058	873	$US ha-'
Internal Rate of Return	10%	4%	

1 If a landowner enters into a contract with Crown Vantage, to offer first rights on stumpage at fair market value. Crown Vantage provides cuttings at no cost. Otherwise, market price for cuttings is $US 250 for 1000 cuttings.
2 Yield on a medium-textured soil such as Tunica-Bowdre.
3 Pulpwood stumpage, inflated 26% over summer 1995 values.
4 Annual costs such as taxes, estimated as $1 ha^{-1} over an 11 -year period.
5 Cost difference between contract and no contract is the price of cuttings at planting density of 747 stems ha-'.

establishment includes two-pass disking, 3.7 m row marking, application of liquid nitrogen fertilizer (50/50 ammonium nitrate and urea, 112 kg-N ha^{-1}), hand planting of improved clonal cuttings and the application of pre-emergent herbicides. Mechanical cultivation includes as many as three two-pass diskings the first year, and insecticides and additional mechanical cultivation the second year. Total establishment costs are $583 ha^{-1}. Landowners interested in the Crown Vantage cost-sharing program may use afforestation to create wildlife habitat, in addition to fiber production. The company pays for the cuttings (about $185 ha^{-1}), and landowners agree to give first right of refusal for the timber at rotation (10 years), at market value. A financial analysis for cottonwood on former agricultural land is given in Table 7. Net income from a lo-year rotation is $873 ha^{-1}, with no contract; and $1085 ha^{-1} under contract. internal rates of return are 4 % and 10 %. All costs are estimates of what a private landowner would have to pay to contract for silvicultural operations.

5.3 Afforestation Strategies

Afforestation on marginal agricultural land in the LMAV relies on using native species, planted mostly in single-species plantations. Choice of species on a site is guided by landowner objectives, species tolerance to flooding, and soils. Hard mast producing species such as oaks and sweet pecan are favored for their value to wildlife, especially on public land. Oak plantings are widely spaced, to allow natural invasion of other species. Wind and water dispersal are relied upon to establish soft mast producers such as sweetgum, sycamore, the ashes, and the elms. While generally successful, sites that do not flood often and are more than 100 m from a seed source may not seed in with light seeded species (Allen and Kennedy 1989, Allen 1990). This strategy can best be described as extensive, or least-cost. Increasingly, it is called into question on two counts: could a more intensive approach provide a more diverse landscape more quickly, and is this approach appropriate if a landowner's objectives include timber production? While we cannot answer these questions definitively with our current knowledge of the growth and development of plantations, they can be examined within the context of specific examples, recognizing that land ownership (public or private) is an important factor in determining landowner objective.

6 Future Directions

Up to 200 000 ha of marginal agricultural land in the LMAV could be afforested over the next decade. Recent modifications to the WRP, providing for a 30-year term instead of a perpetual easement, could make the program even more attractive (Shepard 1995). Rising stumpage prices for hardwoods and changes in agricultural price supports might tip the balance in favor of private afforestation on marginal farmland, particularly if economic incentives for carbon sequestration could be captured by landowners (Shepard 1995). Experience with the Conservation Reserve Program argues that an aggressive technology transfer program will be needed to provide landowners with information on growing and marketing trees (Essek et al. 1992).

Scant provision has been made for management of afforested areas, on public and also on private land. Wildlife managers believe the extensive, low-cost strategy described above is sufficient to meet their objectives. However, managers will have few options for manipulating these understocked stands to further enhance wildlife habitat.

Private landowners who utilize WRP to afforest their marginal cropland with the intention of generating income through future timber harvesting will be disappointed, unless they are prepared to invest in denser planting. The stocking that will result from typical WRP afforestation schemes will not be sufficient to support a pulpwood thinning at age 20 or 30 (J. Goelz, U.S. Forest Service, pers. comm., May 1995). Furthermore, it is uncertain whether landowners will be allowed to harvest WRP plantings. Although an "official" interpretation of the language of the easement has not been made, public opinion in the United States is not generally supportive of harvesting and vegetation manipulation.

Concerns for restoration of wetland functions will play an increasing important role in afforestation programs. Overstory species diversity in predominantly oak plantings is expected from dispersal of light-seeded species by natural agents. Observations suggest, however, that dispersal into plantings more than a hundred meters from natural stands is ineffective (Allen 1990). Thus one response to the artificial appearance of plantings has been to plant in wavy lines, thus avoiding the regularity of straight rows.

Modifications to establish mixed species stands, with a canopy structure that approximates natural stands, have been suggested. Recommendations for establishing mixed stands have been to plant species with similar flood tolerance, soil preferences, and height growth rates. Such mixtures include cherrybark and Shumard oaks; Nuttall and overcup (Q. *lyrata* Walt.) oaks; sycamore and green ash; sweetgum ahd water oak; and cypress, green ash, overcup oak, and Nuttall oak. Most plantings following these recommendations have been block plantings or single species rows. This species clumpiness, however, does not mimic natural conditions.

Establishing understory and midstory species in afforestation programs is easy, in principle, but practical guidelines are unavailable. Methods for establishing true mixtures of shade tolerant understory and midstory species, along with intolerant overstory species, requires information on how species compete with each other during early stand development. In addition to inherent growth rates, competitive ability is greatly affected by soil properties and flooding frequency and duration.

Most afforestation work occurs in small patches, except for a few large public projects. While there has been much discussion of the effects of forest fragmentation on wildlife, particularly area-sensitive, interior dwelling neotropical migratory birds (Robbins et al. 1989), there have been few opportunities to examine the benefits of reforesting in large blocks. The Lake George Mitigation site provides an opportunity to examine this and the related question of whether travel corridors between large patches of existing natural forest is a net gain or loss for wildlife diversity.

References

Aird, P.F. 1962. Fertilization, weed control, and the growth of poplar. Forest Science 8(4): 413–428.

Allen, J.A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. Southern Journal of Applied Forestry 14(4): 206–210.

— & Kennedy, H.E., Jr. 1989. Bottomland hardwood reforestation in the Lower Mississippi Valley. Bulletin, U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Research Center Slidell, LA and U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Stoneville, MS. p. 28.

— , Kennedy, H.E., Jr, Clewell, A.F. & Keeland, B.L. In press. Bottomland hardwood restoration manual. U.S. Department of the Interior, Geological Survey, Southern Science Center, Lafayette, LA.

Baker, J.B. & Broadfoot, W.M. 1979. A practical field method of site evaluation for commercially important hardwoods. General Technical Report SO-26, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 51 p.

Bonner, F.T. 1973. Storing red oak acorns. Tree Planters' Notes 24(3): 12-13.

— 1982. The effect of damaged radicles of presprouted red oak acorns on seedling production. Tree Planters' Notes 33(4): 13-15.

— & Vozzo, J.A. 1987. Seed biology and technology of Quercus. General Technical Report SO-66, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. p. 21.

—, Vozzo, J.A., Elam, W.W. & Land, S.B., Jr. 1994. Tree seed technology training course. Student Outline. General Technical Report SO- 107, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. p. 81.

Briscoe, C.B. 1969. Establishment and early care of sycamore plantations. Research Paper SO-50, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. p. 18.

Broadfoot, W.M. 1976. Hardwood suitability for and properties of important midsouth soils. Research Paper SO-127, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 84 p.

Bullard, S., Hodges, J.D., Johnson, R.L. & Straka, T.J. 1992. Economics of direct seeding and planting for establishing oak stands on old-field sites in the South. Southern Journal of Applied Forestry 16(1): 34–40.

Corps of Engineers. 1989. Yazoo backwater area mitigation lands, Lake George property land acquisition, Yazoo Basin, Mississippi: Environmental assessment. U.S. Army Corps of Engineers, Vicksburg District, Vicksburg, MS. Processed.

Department of the Interior. 1988. The impact of federal programs on wetlands. Vol I: The Lower Mississippi Alluvial Floodplain and the Prairie Pothole Region. A report to Congress by the Secretary of the Interior, Washington, D.C. 114 p.

Essek, J.D., Kraft, S.E. & Moulton, S.J. 1992. Landowner responses to the forestry option in the Conservation Reserve Program. In: Sampson, R.N. & Hair, D. (eds.). Forests and global change. Vol 1. Opportunities for increasing forest cover. American Forests, Washington, D.C. p. 195-224.

Fitzgerald, C.H., Richards, R.F., Seldon, C.W. & May, J.T. 1975. Three year effects of herbaceous weeds in a sycamore plantation. Weed Science 23(1): 32-35.

Francis, J.K. 1985. Bottomland hardwood fertilization – the Stoneville experience. In: Proc. Third Biennial Southern Silvicultural Research Conference. USDA Forest Service, Southern Forest Experiment Station, New Orleans, LA, General Technical Report SO-54. p. 346–350.

Harris, L.D. & Gosselink, J.G. 1990. Cumulative impacts of bottomland hardwood conversion on wildlife, hydrology, and water quality. In: Gosselink, J.G., Lee, L.C. & Muir, T.A. (eds.). Ecological processes and cumulative impacts: Illustrated by bottomland hardwood wetland ecosystems. Lewis Publishers, Chelsea, MI. p. 259-322.

Haynes, R.J., Bridges, R.J., Gard, S.W., Wilkins, T.M. & Cooke, H.R., Jr. 1993. Bottomland forest reestablishment efforts of the U.S. Fish and Wildlife Service: Southeast Region. Proc. National Wetlands Engineering Workshop, St. Louis, Missouri, August 3-5, 1992. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report WRP-RE-8, Vicksburg, MS. p. 322-334.

Hefner, J.M. & Dahl, T.E. 1993. Current forested wetland systems in the Southeast Region. U.S. Fish and Wildlife Service, Southeast Region, Atlanta, GA. 76 p.

Hodges, J.D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management 90(2/3): 117-I 25.

— 1994. The southern bottomland hardwood region and brown bluffs subregion. In: Barrett, D.W. (ed.). Regional silviculture of the United States. John Wiley and Sons, New York. p. 227-269.

— & Switzer, G.L. 1979. Some aspects of the ecology of southern bottomland hardwoods. Proc. Society of American Foresters Annual Meeting, St. Louis, Missouri, 1978. Society of American Foresters, Bethesda, MD. p. 22-25.

Hook, D.D. 1984. Adaptations to flooding with freshwater. In: Kozlowski, T.T. (ed.). Flooding and plant growth. Academic Press, New York, NY. p. 265-294.

— & Scholtens, J.R. 1978. Adaptations and flood tolerance of tree species. In: Hook, D.D. & Crawford, R.M.M. (eds.). Plant life in anaerobic environments. Ann Arbor Scientific Publications, Ann Arbor, MI. p. 299-33 1.

Humphrey, M. 1994. The influence of planting date on the performance of bareroot, container- grown and direct seeded Quercus nuttallii Nuttall oak on

Sharkey soil. Unpublished MS thesis, Alcom State University, Lorman, MS. 52 p.
Johnson, R.L. 1983 . Nuttall oak direct seedings still successful after 11 years. Research Note SO-301, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 3 p.
— & Krinard, R.M. 1985. Regeneration of oaks by direct seeding. Proc. Third Symposium of Southeastern Hardwoods, U.S. Department of Agriculture, Forest Service, Southern Region, Atlanta, GA. p. 56-65.
— & Krinard, R.M. 1987. Direct seeding of southern oaks – a progress report. Proc. 15th Annual Hardwood Symposium, Memphis, Tennessee, May 10–12, 1987. Hardwood Research Council, Memphis, TN. p.10–16.
Kennedy, H.E., Jr. 1977. Planting depth and source affect survival of planted green ash cuttings. Research Note SO-224, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 3 p.
— 1979. Planting season for cottonwood can be extended. Southern Journal Applied Forestry 3(2): 54–55.
— 198 1. Foliar nutrient concentrations and hardwood growth influenced by cultural treatments. Plant and Soil 63: 307–316.
— 1984. Hardwood growth and foliar nutrient concentrations best in clean cultivation treatments. Forest Ecology and Management 8: 117–126.
— 1990. Hardwood reforestation in the South: Landowners can benefit from Conservation Reserve Program Incentives. Research Note SO-364, U.S. Department of Agriculture, Forest Service, Southem Forest Experiment Station, New Orleans, LA. 6 p.
— 1993. Artificial regeneration of bottomland oaks. In: Loftis, D.L. & McGee, C.E. (eds.). Oak regeneration: Serious problems, practical recommendations. Oak Regeneration Symposium, Knoxville, Tennessee, September 8-10, 1992. General Technical Report SE-84, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, NC. p. 241-249.
— & Krinard, R.M. 1985. Shumard oaks successfully planted on high pH soils. Research Note SO-321, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 3 p.
— , Krinard, R.M. & Schlaegel, B.E. 1988. Growth and development of four oaks through age 10 planted at five spacings in a minor stream bottom. Proc. 9th Annual Southern Forest Biomass Workshop, Biloxi, Miss, June 8-l 1, 1987. Mississippi State University, Mississippi State, MS. p. 81-91.
Krinard, R.M. 1988. Growth comparisons of planted sweetgum and sycamore. Research Note SO-351, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 5 p.
— 1989. Stand parameters of 1 l-to 15-year old green ash plantings. Research Note SO-352, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 4 p.
— & Johnson, R.L. 1985. Eighteen-year development of sweetgum (*Liquidambar styraciflua* L.) plantings on two sites. Tree Planters' Notes 36(3): 6-8.
— & Kennedy, H.E., Jr. 1987a. Fifteen-year growth of six planted hardwoods species on Sharkey clay soil. Research Note SO-336, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 4 p.
— & Kennedy, H.E., Jr. 1987b. Planted hardwood development on Sharkey clay soil without weed control through 16 years. Research Note SO-343, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 4 p.
MacDonald, P.O., Frayer, W.E. & Clauser, J.K. 1979. Documentation, chronology, and future projections of bottomland hardwood habitat losses in the lower Mississippi Alluvial Plain. Vols. 1 and 2. U.S. Fish and Wildlife Service, Washington, D.C. 34 p.
McKnight, J.S. 1970. Planting cottonwood cuttings for timber production in the South. Research Paper SO-60. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, LA. 17 p.
— , Hook, D.D., Langdon, O.G. & Johnson, R.L. 198 1. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. In: Clark, J.R. & Benforado, J. (eds.). Wetlands of bottomland hardwood forests. Elsevier Scientific, New York. p. 29-69.
McWilliams, W.H. & Rosson, J.F., Jr. 1990. Composition and vulnerability of bottomland hardwood forests of the Coastal Plain Province in the south

central United States. Forest Ecology and Management 33/34: 485–501.

Newling, C.J. 1990. Restoration of the bottomland hardwood forests in the Lower Mississippi Valley. Restoration and Management Notes 8(1): 23-28.

Putnam, J.A., Furnival, G.M. & McKnight, J.S. 1960. Management and inventory of southern hardwoods. U.S. Department of Agriculture, Forest Service, Agriculture Handbook 18 l, Washington, DC. 102 p.

Robbins, C.S., Dawson, D.K. & Dowell, B.A. 1989. Habitat area requirements of breeding forest birds of the Middle Atlantic states. Wildlife Monographs 103. 33 p.

Savage, L., Pritchett, D.W. & DePoe. 1989. Reforestation of a cleared bottomland hardwood area in northeast Louisiana. Restoration and Management Notes 7(2): 88.

Shepard, J.P. 1995. Opportunities: Reforesting marginal agricultural land. Forest Farmer 54(5): 7, 19.

Stanturf, J.A. 1993. Plantation establishment to restore bottomland hardwood wetlands: Past and future research at the Southern Hardwoods Laboratory. Proc. National Wetlands Engineering Workshop, St. Louis, Missouri, August 3-5, 1992. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report WRP-RE-8, Vicksburg, MS. p. 352-357.

Sternitzke, H.S. 1976. Impact of changing land use on Delta hardwood forests. Journal of Forestry 74: 25-27.

Stone, E.L., Jr. 1978. A critique of soil moisture-site productivity relationships. In: Balmer, W.E. (ed.). Proc. Soil Moisture...Site Productivity Symposium,. U.S. Department of Agriculture, Forest Service, Southeast Area State and Private Forestry, Atlanta, GA. p. 377-387.

Tansey, J.B. & Cost, N.D. 1990. Estimating the forested wetland resource in the southeastern United States with forest survey data. Forest Ecology and Management 33/34: 193-213.

The Nature Conservancy. 1992. Restoration of the Mississippi River Alluvial Plain as a functional ecosystem. The Nature Conservancy, Baton Rouge, LA. 53 p.

Turner, R.E., Forsythe, S.W. &Craig, N.J. 1981. Bottomland hardwood forestland resources of the southeastern United States. In: Clark, J.R. & Benforado, J. (eds.). Wetlands of bottomland hardwood forests. Elsevier Scientific, New York. p. 13-28.

Wharton, C.H., Kitchen, W.M., Pendleton, E.C. & Sipe, T.W. 1982. Ecology of bottomland hardwood swamps of the southeast: A community profile. U.S. Department of the Interior, Fish and Wildlife Service, Biological Services Program: FWS/OBS-81/37, Washington, D.C. 134 p.

Wilen, B.O. & Frayer, W.E. 1990. Status and trends of U.S. wetlands and deepwater habitats. Forest Ecology and Management 33/34: 18 1-192.

Wittwer, R.F. 1991. Direct seeding of bottomland oaks in Oklahoma. Southern Journal of Applied Forestry 15(1): 17-22.

*Total **of 60 references***