HAND PLANTING VERSUS MACHINE PLANTING OF BOTTOMLAND RED OAKS ON FORMER AGRICULTURAL FIELDS IN LOUISIANA'S MISSISSIPPI ALLUVIAL PLAIN: SIXTH-YEAR RESULTS

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Abstract-Interest in restoring bottomland hardwoods on abandoned agricultural fields has gained considerably over the past 15 years, due primarily to federal cost-share programs such as the Conservation Reserve Program and the Wetlands Reserve Program. While a variety of artificial regeneration techniques are available to afforest these lands, none have met with consistently successful results, especially in the Mississippi Alluvial Plain. Therefore, a study was initiated to compare a variety of regeneration techniques for afforesting previously farmed bottomland hardwood sites. In this paper we report the results from hand planted versus machine planted 1-O bare-root bottomland red oak seedlings. Four sites in the MAP in Louisiana were planted with either 1 or 2 species in a randomized complete block design. Sites and species planted included Bayou Macon Wildlife Management Area [WMA; Nuttall oak (*Quercus nuttallii* Palmer) and willow oak (*Q. phellos* L.)], Lake Ophelia National Wildlife Refuge (NWR; Nut-tall oak), Ouachita WMA (willow oak), and the Tensas NWR [Nuttall oak and water oak (*Q. nigra* L.)]. Results after 6 growing seasons indicated little difference in density, survival, planting success, and stocking between planting methods. Densities ranged from 280 Nuttall oak seedlings per acre machine planted at the Tensas NWR to 67 willow oak seedlings per acre machine planted at the Bayou Macon WMA. Nuttall oak also tended to have higher survival (81 percent) compared to willow oak (56 percent) and water oak (38 percent). When volunteer oak and ash were included, all site-species-planting method combinations met the minimum criteria for successful afforestation, but all combinations failed to meet minimum stocking levels necessary for quality sawtimber production.

INTRODUCTION

Interest in restoring bottomland hardwood forests on former agricultural land (afforestation) has increased considerably over the past 15 years (Allen and Kennedy 1989, Schweitzer and Stanturf 1997, Gardiner and others In press). This interest on private lands has coincided with the advent of several government cost-share programs that provide financial assistance to establish trees on these lands; chief among these programs are the Conservation Reserve Program and the Wetlands Reserve Program (WRP) (Cubbage and Gunter 1987, Kennedy 1990). Interest in restoring bottomland hardwood forests on public lands is due to the recognized importance of these forests for their various wildlife habitat functions and values (Richardson 1994). Nearly 100,000 acres of former agricultural land had been afforested in the Mississippi Alluvial Plain (MAP) of Arkansas, Louisiana, and Mississippi by 1995 with potentially another 110,000 acres by 2005 (Stanturf and others 1998).

Common afforestation techniques involve either planting seedlings or sowing seed, particularly oak (*Quercus* spp.) acorns (Stanturf and others 1998, Gardiner and others In press). Much debate has existed concerning which technique is superior to ensure greatest success of afforestation efforts. Sowing seed is often touted as an easier and cheaper afforestation technique than planting seedlings (Bullard and others 1992). Direct seeding also has a larger planting window compared to planting seedlings (Johnson 1983). Likewise, advantages to planting seedlings include an easier evaluation of the planting operation, and potentially greater survival and growth (Ozalp and others 1998). Because past experience with direct seeding has not been as successful as desired, several state agencies require that seedlings be used to qualify for government cost-share programs (Mr. Larry Nance, Arkansas Forestry Commission, Little Rock, AR, pers. comm.).

The question that arises once a decision has been made to plant seedlings is whether to hand plant or machine plant. A common recommendation is to machine plant if possible because machine planting can substantially speed up the planting job in soils other than heavy clays (Allen and Kennedy 1989). It is commonly cited that one person can hand plant between 600-800 hardwood seedlings per day if conditions are good (Allen and Kennedy 1989, Kennedy 1990, Kennedy 1993) while an experienced crew of two or three people can machine plant 4,000-l 0,000 hardwood seedlings per day (Kennedy 1990, Kennedy 1993, Stanturf and others 1998). Many of the comments regarding hand planting or machine planting oak seedlings on bottomland sites are based on personal

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observations or results with planting pine (*Pinus* spp.) species on upland sites (Ezell 1987, Long 1991). Little work has focused on direct comparisons of hand versus machine planting hardwood seedlings on bottomland sites (Russell 1997, Russell and others 1998). The objective of this research was to compare hand versus machine planting of several bottomland red oak species on former agricultural fields at different locations in the MAP in Louisiana. Sixth-year post-planting results are presented.

MATERIALS AND METHODS

Locations

The study was conducted on abandoned agricultural fields at 4 locations in Louisiana's MAP. Though none of these sites receive direct flooding from a major river system (i.e., the Mississippi River or the Red River), each site floods from localized weather events and backwater of minor rivers and bayous. Each site is described separately below.

The Bayou Macon Wildlife Management Area (WMA) is located in East Carroll Parish in northeast LA. The study site is located about 2.5 miles east of Bayou Macon, north of East Carroll Parish Highway 3330. The forest was cleared in the 1960s and planted to agricultural crops. The area was purchased in 1991 by the Louisiana Department of Wildlife and Fisheries (LDWF) and converted into a state wildlife management area. Soils are Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) based on a detailed survey by National Resource Conservation Service (NRCS) personnel (NRCS soil survey field notes for each site are on file with the School of Forestry, Wildlife, and Fisheries (SFWF), Louisiana State University (LSU), Baton Rouge, LA) with an estimated site index, based age 50 years, of 90 for Nuttall oak (Q. *nuttallii* Palmer) (Baker and Broadfoot 1979).

The Lake Ophelia National Wildlife Refuge (NWR) is located in Avoyelles Parish in east-central LA. The study site is located 2-4 miles, depending on replication, from the Red River and is protected from river flooding by the main-line levee system. The forest on this site was cleared in the 1960s and planted to agricultural crops. The area was purchased by the U.S. Department of Interior Fish and Wildlife Service (FWS) and converted to a federal national wildlife refuge. Soils are of the Tensas/Sharkey complex (Tensas silty clay - fine, smectitic, thermic Aeric Epiaqualfs) with the former soil occupying ridges and the latter occupying lower elevation areas. Nuttall oak site index was estimated to be 90 (Baker and Broadfoot 1979).

The Ouachita WMA is located in Ouachita Parish in north-east LA. The study site is located about six miles southeast of Monroe, LA south of Highway 15 near the Bayou LaFourche River. The forest on this site was cleared in the 1960s or 1970s and planted to agricultural crops. The area was purchased in 1984 by the LDWF and converted to a state wildlife management area. Soils are a mixture of Portland silty clay (very-fine, mixed, nonacid, thermic Vertic Haplaquepts) and Hebert silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs). Inspection of the soil prior to study establishment indicated that the Herbert silt loam is shallow (8-9 inches) and turns powdery when dry. This soil is underlain by the Portland clay. Nuttall oak site' index was estimated to be 85 (Baker and Broadfoot 1979).

The Tensas NWR is located in Madison Parish in northeast LA. The study site is located about seven miles south of Interstate 20, three miles northeast of the refuge headquarters, and about one mile east of the Tensas River. The forest on this site was cleared in 1970s and planted to agricultural crops. The area was eventually purchased by the FWS and con-verted to a federal wildlife refuge. Soils are of the Tensas/Sharkey complex as previously described. Nuttall oak site index was estimated to be 90 (Baker and Broadfoot 1979).

Planting Methods/Design

As part of a larger afforestation study, 14 combinations of direct seeding and planting seedling treatments were utilized (see McCoy and others (2002) in this conference proceed-ings for a complete description of the direct seeding treatments). Two of these 14 combinations involved hand planting and machine planting of 1-O red oak seedlings. These two treatments are the focus of this paper.

At each study site, 1 -acre square treatment plots (209 feet on each side) were laid out for each treatment. Each plot was surrounded by a 33-foot buffer zone to allow equipment to turn around without affecting neighboring plots. For the seedling planting treatments, each plot was tilled in the Fall 1993 prior to planting. Bare-root, 1-O planting stock purchased from the LA Department of Agriculture and Forestry's Columbia Nursery was used at each site. Three red oak species were utilized in the study: Nuttall oak and willow oak (Q. *phellos* L.) at the Bayou Macon WMA, Nuttall oak at the Lake Ophelia NWR, willow oak at the Ouachita WMA, and Nuttall oak and water oak (*Q. nigra* L.) at the Tensas NWR. Nuttall oak was the primary species used due to proven success at various afforestation sites throughout the MAP. The other species were chosen based on site conditions, and to compare with Nuttall oak if space at the site permitted. Planting was done in January or February, 1994 at each site. The target spacing was 12 feet by 12 feet or 302 seedlings for the 1 -acre plot. The general design was to plant 17-18 seedlings in each of 17 rows (289-306 seedlings per acre). Hand planting was conducted using dibble bars. Machine planting was done using a lift planter on the state wildlife management areas which made furrows 6-10 inches deep (averaged 8 inches) depending on soil moisture conditions. Machine planting on the national wildlife refuges was done using a FESCO planter. While a general plan for planting was developed, final planting operations were conducting by officials associated with each wildlife management area or national wildlife refuge. The purpose for this decentralized control was to make operations as practical and applicable as possible, but problems did occur. Weather conditions at several sites resulted in machine planting being conducted under wet conditions. Such condi-tions, combined with the heavy clay soils, resulted in clay clogging the planting machine and some seedlings not being planted optimally. Furthermore, the target spacing was not always obtained due to mechanical problems with the machine planter, site conditions, and the way planted seed-lings were counted.

Measurements and Analyses

Measurements for each of the 4 study sites were conducted during November 1999, 6 growing seasons after planting. Four 0.025acre (0.01-ha) circular plots were established 20 meters diagonally from each of the four corners for each square l-acre treatment plot. In each measurement plot, all tree seedlings and saplings (including natural reproduction) were tallied in 1 of 6 size classes by species: O-30 cm tall, 30-50 cm, 50-100 cm, 100-140 cm, 140 cm • 2.5 cm dbh, and > 2.5 cm dbh. These size classes correspond to a standard sampling protocol used by the USGS Wetlands Research Center in Lafayette, Louisiana. A pvc stake flag was placed at each measurement plot center and electronic measuring devices were used to circle the plot while tallying trees by size class.

Analyses involved determining density, survival, and success of oak species planted in each plot, and stocking values of desired species (both planted oaks and volunteer oaks and green ash). All plot-level counts were converted to per-acre values and averaged across each plot to obtained density (number of stems per acre) by size class. Size classes were then summed to obtain total number of stems by plot. Survival was calculated by dividing the density counts by the actual number of seedlings planted, while planting success was calculated by dividing the density counts by the target number of seedlings planted (302 per acre). Stocking values were determined by assigning point values to each size class following Johnson's (1980) bottomland hardwood regeneration evaluation model as updated by Hart and others (1995). Size-class counts were done using the metric system of units while the bottomland hardwood regeneration evaluation model used English units. Therefore, the following points were assigned to each size class for oak and ash, respectively: (1) O-30 cm; 0.5 points for both, (2) 30-50 cm and 50-100 cm; 2 and 6 points, and (3) 100-140 cm, 140 cm • 2.5 cm dbh, and >2.5 cm dbh; 3 and 6 points. This point assignment closely follows those developed by Hart and others (1995) using size classes based in English units. Each plot was considered stocked if it contained ≥ 12.0 points for a 0.01 -acre plot. Density counts were adjusted from the O.Ol-ha measurement plot to a O.Ol-acre plot. Analysis-of-variance using a randomized complete block design with 3 replications per site and planted species was used to compare hand planting and machine planting treatments by site. Blocking was done by elevation of the site, i.e., ridges, flats, etc. Variables analyzed included density, survival, planting success, points, and stocking. Analyses were conducted using PC-SAS and an alpha level of 0.05 was used to determine significant differences (SAS 1985).

RESULTS AND DISCUSSION

Density

Seedling density, 6 growing seasons after planting ranged from 280 per acre for machine-planted Nuttall oak on the Tensas NWR site to 67 per acre for machine-planted willow oak on the Bayou Macon WMA site (table 1). Only one significant difference was found between planting methods with hand-planted willow oak having a greater density than machine-planted willow oak (table 1). In general, Nuttall oak plantings resulted in greater densities than the other oak species, especially when planted on the same site.

WRP guidelines state that for a site to be considered successfully afforested 125 stems per acre (either planted or natural) must be present 3 years after planting. Seventy-five percent of the site-species-treatment combinations met this minimum although these densities represent 6 years after planting instead of 3 years. Of interest is that all the Nuttall oak site-planting method combinations met this criteria, while only 3 of the 6 other site-species-planting method combinations met this criteria. When volunteer oaks and green ash were included in density calculations, all sites met the 125 stems per acre WRP minimum criteria for successful afforestation.

Survival

Survival 6 years after planting ranged from 97 percent for machine planted Nuttall oak on the Tensas NWR to 26 percent for machine planted willow oak on the Bayou Macon WMA (table 1). As with density, Nuttall oak tended to perform better than either willow oak or water oak when planted on similar sites. This was especially true for the Tensas NWR site. Nuttall oak averaged 92 percent survival across treatments while water oak averaged only 38 percent.

Various factors may have influenced these survival values. First, the sampling protocol involved 4 subplots for each treatment plot. Standard error values associated with each survival value ranged from 3 for hand-planted willow oak to 16 for hand-planted Nuttall oak, both on the Bayou Macon WMA. Sampling error must be taken into account when interpreting these survival values (table 1). Second, state wildlife management areas and federal wildlife refuges were planted by personnel associated with each agency. On several sites, the number of seedlings planted was calculated by subtracting the number of seedlings left in nursery package bags from an assumed total number of seedlings in the bag prior to planting. This assumption was not always correct as seedling counts in several bags was less than indicated on the bag label. A third factor involved seedling quality. Planting records indicated that several seedlings were simply too small (less than 18 inches in height and 0.5-0.75 inches in root-collar diameter). Small seedlings planted in abandoned agricultural fields are at a disadvantage to competing vegetation due to less stored food reserves in the root system. Another seedling quality issue was mixing of species. It was noted in the records that water oak seedlings were mixed with the willow oak seedlings at the nursery; therefore, some water oak was planted in willow oak treatment plots. Water oak, being less flood tolerant than willow oak, would be expected to have higher mortality rates on several of the sites used in this study.

Success

Regeneration success evaluates the current density of seedlings and saplings compared to the target planting rate set prior to the planting operation. If the target rate is met during the planting operation then survival and success are the same measures. But rarely does operational planting meet target rates; therefore, regeneration success may be a better criteria to evaluate the longer-term results of afforestation efforts. Regeneration success closely followed survival

Table l-Sixth year density, survival, regeneration succuss, and stocking by site, species, and planting method for bottmland red oaks planted on abandoned agricultural fields in Louisiana's Mississippi Alluvial Plain Numbers in parentheses represent one standard error[a]

Site	Species	Planting Treatment	Initial Densitv	1999 Densitv	Survival	Success	Points	Stocked Plots	WRP Success
			stems/ac	stems/ac	percent	percent	unitless	percent	
Bayou Macon WMA	Nuttall oak	hand	300 (2)	226 (47)	75 (16)	75 (16)	13.0 (2.7)	42	yes
		machine	286 (10)	250 (9)	87 (4)	83 (3)	10.4 (0.9)	25	yes
	willow oak	hand	281 (2)	148 (9)	53 (3)	49 (3)	14.7 (2.8)	50	yes
		machine	269 (11)	67 (27)	26 (11)	22 (9)	7.4 (4.0)	17	no
Lake Ophelia NWR	Nuttall oak	hand	330a (0)	169 (29)	51 (9)	56 (10)	4.7 (0.6)	0	yes
		machine	306b (0)	273 (20)	89 (7)	90 (7)	10.4 (1.3)	25	yes
Ouachita WMA	willow oak	hand	297 (1)	233a (21)	78 (7)	77a (7)	6.5a (0.6)	0	yes
		machine	276 (21)	185b (17)	68 (8)	61b (6)	5.2b (0.6)	0	yes
Tensas NWR	Nuttall oak	hand	289 (0)	253 (36)	88 (12)	84 (12)	11.2 (2.2)	33	yes
		machine	289 (0)	280 (38)	97 (13)	93 (12)	10.8 (1.1)	33	yes
	water oak	hand	289 (0)	101 (16)	35 (5)	34 (5)	7.1 (2.9)	17	no
		machine	289 (0)	121 (23)	42 (8)	40 (8)	6.9 (1.4)	17	no

"Numbers followed by different letters within a site, species, planting combination are significantly different at p = 0.05

trends in this study (table 1). initial planting density usually did not reach the target density of 302 seedlings per acre (table 1). On several sites, initial density was as low as 90 percent of the target planting density. Variable initial density resulted from difficult planting conditions for machine planting on several sites and simply running out of seedlings. Regeneration success though was not well correlated with the initial density. The highest initial density, 330 hand-planted Nuttall oak on the Lake Ophelia NWR, had only 56 percent success 6 years later. Obviously, other factors are involved in the success of artificial regeneration efforts than simply how many seedlings are initially planted.

Stocking

Johnson (1980) initially developed a regeneration evaluation system for bottomland hardwoods. Points were assigned to regeneration present before a harvest (advance regeneration) based on their size and to trees based on their stump sprouting potential. Using O.Ol-acre circular plots, points would be summed for desirable species until a minimum threshold of 12 points was reached. Once 12 points was obtained then the plot was considered fully stocked with desirable species. This regeneration evaluation system was develop for natural regeneration of pre-existing bottomland hardwood stands with a management objective of growing high-quality sawlogs. The system was later modified by Hart and others (1985) and Belli and others (1999) based on additional research into the regeneration dynamics of bottomland red oaks and green ash following harvesting. While developed for pre-existing stands, this regeneration evaluation system may be applied to afforested situations because we believe that stocking principles, such as points by size class and distribution of stocked plots, are similar regardless of stand initiation conditions.

The average number of points scored by treatment ranged from 14.7 for the hand-planted willow oak on the Bayou Macon WMA to 5.2 for machine-planted willow oak on the Ouachita WMA (table 1). The latter site was the only one in which a significant difference in the number of points occurred with hand-planted plots having more points than machine-planted plots. In general, sites planted with Nuttall oak scored better than sites planted with either willow oak or water oak. Only 2 of the > 12 site-species-planting method combinations averaged points 12, the Bayou Macon WMA hand-planted Nuttall oak and willow oak treatments. Plots on this site tended to have a significant component of natural green ash that was distributed from an adjacent stand. The remaining 10 combinations scored less than the minimum necessary to be considered fully stocked although four of these combinations average > 10 points.

Hart and others (1995) warned not to average points across plots because an average score may indicate that regeneration may be adequate when in reality only a few plots had considerably greater than average points that skewed the average score higher. Hart and others (1995) recommended a more appropriate application of the regeneration evaluation system would be to determine the percentage of plots that met the minimum threshold of 12 points. Johnson and Deen (1993) recommended that 60-70 percent of the plots needed to meet the 12-point minimum for the site to be considered adequately stocked. The number of plots meeting this criteria ranged from O-50 percent across the site-species-treatment combinations (12 regeneration plots for each site-species-planting method combination for a total of 144 plots; table 1); therefore, none of the areas that were planted, regardless of planting method, would be considered successfully regenerated after 6 growing seasons if the primarily objective was quality sawtimber production.

CONCLUSIONS

Little difference was found in the density, survival, and planting success of bottomland red oak seedlings and stocking of oak and ash seedlings and saplings between hand planted and machine planted treatments 6 years after planting. But, according to notes taken during planting operations (notes on file at the SFWF, LSU) and discussions with personnel who conducted the planting operations, machine planting conditions were less than ideal. Officials with the LDWF indicated that when planting operations are under ideal conditions, i.e., soils are neither too wet or too dry, they consistently get 5-10 percent greater survival for machine planting compared to hand planting (Kenny Ribbeck and Buddy Duprey, LDWF, Baton Rouge and Pineville, LA, respectively). Others have also found greater survival of machine planted bottomland red oak species when compared to hand planting (Russell and others 1998). Results from this study indicate that various considerations, such as site conditions and costs, are necessary in determining whether to machine plant or hand plant bottomland red oak seedlings.

A second observation from this study was the success or failure of the treatments depended on the afforestation objective(s). Although 6-year results were presented, all site-species-planting method combinations met the minimum density required by the WRP program (keeping in mind that WRP success is based on third-year post-planting observations). Success was obtained with only the planted oaks and volunteer oaks and green ash. Other species were found in the measurement plots (see McCoy and others (2002) in this conference proceedings), further solidifying WRP success. Concurrently, all site-species-planting method combinations failed to meet stocking criteria for quality sawlog production, even when volunteer oak and ash were included in stocking calculations. The important point is that specific management objective(s) should be developed before afforestation activities commence.

A third observation from this study was that Nuttall oak consistently outperformed willow oak and water oak. On heavy clay soils, such as those found in the MAP, Nuttall oak is often the preferred species, due to its greater flood tolerance, on these potentially harsh sites. Results from this study confirm other observations and studies that Nuttall oak is a preferred species for afforesting abandoned agricultural fields with clay soils in the MAP (Stanturf and others 1998). It is very important that only quality hardwood seedlings are purchased from nurseries, that species are properly matched to site conditions, and that constant oversight is conducted during planting operations. Attention to these factors will increase the success of any afforestation effort on bottomland sites (Gardiner and others (In press), Stanturf and others 1998).

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