Comparing regeneration techniques for afforesting previously farmed bottomland hardwood sites in the Lower Mississippi Alluvial Valley, USA

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Summary

A study was implemented to test site preparation methods and artificial regeneration of three oak (*Quercus* spp.) species on four agricultural fields in the Lower Mississippi Alluvial Valley in Louisiana, USA. Six years after establishment, few consistent differences were found in oak density between sowing acorn methods (seed drill versus broadcast seeding), autumn sowing versus spring sowing, and sowing acorns versus planting oak seedlings. Results indicated that some degree of site preparation is needed to establish oak seedlings but few differences were found between site preparation treatments. These results indicate that no one prescription for oak regeneration fits all potential afforestation projects in the Lower Mississippi Alluvial Valley. Successful bottomland hardwood afforestation projects will require plans that include specific objectives, site evaluation, and a regeneration prescription prior to sowing the first seed or planting the first seedling.

Introduction

Bottomland hardwood forests are highly productive ecosystems located along the floodplains of rivers and streams throughout the central and eastern United States (Hodges, 1994). These ecosystems provide important functions including hydrologic flux and storage, biological productivity, biogeochemical cycling and storage, decomposition and wildlife habitat (Richardson, 1994). Bottomland hardwood ecosystems also provide important values to humans including timber production, hunting, fishing, flood control and storage, nutrient removal and educational and research opportunities (Richardson, 1994). In the United States, the largest extent of bottomland hardwood forests occurred in the Lower Mississippi Alluvial Valley, covering about 10

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million hectares at the time of European settlement (Hefner and Brown, 1985). Conversion of these ecosystems to other land uses, especially row-crop agriculture during the 1950s to the 1970s (Newling, 1990), reduced the extent of bottomland hardwood forests in the Lower Mississippi Alluvial Valley to about 2 million hectares by 1978 (Hefner and Brown, 1985). Much of this deforested land is subjected to late spring and early summer flooding, conditions unsuitable for sustainable annual row-crop agriculture (Newling, 1990; Stanturf *et al.*, 2001).

Recognition of the important functions and values of bottomland hardwood forests along with the monetary losses associated with flooded crops have created interest in restoring bottomland hardwood ecosystems. A key component in these restoration efforts is afforesting abandoned agricultural fields. About 77 000 ha of former agricultural fields have been afforested within the Lower Mississippi Alluvial Valley during the past 10 years (King and Keeland, 1999) with another 89 000–105 000 ha expected to be afforested by 2005 (Stanturf *et al.*, 1998; King and Keeland, 1999). Unfortunately, many difficulties have been reported in afforesting abandoned agricultural fields, chief among these is poor survival of sowed acorns and planted oak (*Quercus* spp.) seedlings (Schweitzer, 1998). Therefore, a study was initiated to compare different intensities of site preparation, acorn sowing methods, and sowing acorns versus planting oak seedlings for afforesting previously farmed bottomland hardwood sites in the Lower Mississippi Alluvial Valley. Treatments were applied at an operational scale to provide landowners and forest resource managers with information that may be applied directly to large abandoned agricultural fields.

Materials and methods

Study sites

The study was conducted on former agricultural fields at four locations in Louisiana's Lower Mississippi Alluvial Valley (Figure 1; for descriptions see Table 1). Each site was originally forested but converted to row-crop agriculture during the 1960s and 1970s. These sites were then purchased either by the Louisiana state government and converted to a wildlife management area or by the Federal government and converted to a national wildlife refuge. Though none of the sites receive direct flooding from a major river system due to constructed levees, each site floods from localized weather events and backwater of minor rivers and bayous.

Treatments

Six combinations of site preparation and direct seeding were selected in this study based on their practicality for afforestation operations and prior experience by wildlife management area and national wildlife refuge staff in afforestation efforts. Site preparation treatments were selected to represent a range of intensities and consisted of (listed in order of intensity from low intensity to high intensity) no disc, strip disc (single discing in alternating 3-m strips prior to sowing in the strips), single disc (discing the entire plot before and after sowing) and double disc (discing the entire plot two times prior to sowing). A rolling treatment was implemented on two additional disc treatments (one single disc treatment and one double disc treatment) after sowing by dragging a length of steel pipe behind the tractor to smooth the clumps of soil that discing produced and to aid in covering the acorns. At the Lake Ophelia National Wildlife Refuge site, rolling was not accomplished. Sowing methods were direct seeding with a seed drill, which was a modified soybean (*Glycine max* (L.) Merrill) cultivator called a Max-emerge seeder, and broadcast seeding with a Cyclone spreader.

Acorns were collected in forests near each study site, floated tested, and floating acorns were discarded. The apparently sound acorns were stored at 2°C until used in the study. Acorn viability prior to sowing was determined following the procedures of Bonner and Vozzo (1987). Acorn viability for all species and sowing time were similar and ranged from 71 per cent to 92 per cent.

Acorns were sowed using the seed drill at a target rate equivalent to 3000 acorns ha^{-1} (0.9 m by 3.7 m spacing), though the actual sowing rate across all sites was 3251 acorns ha^{-1} with a range of 1833–4552 acorn ha^{-1} (see Table 2 for actual sowing and planting rates). The target number of acorns sowed per hectare using the broadcast spreader was 6177. The higher target rate for the

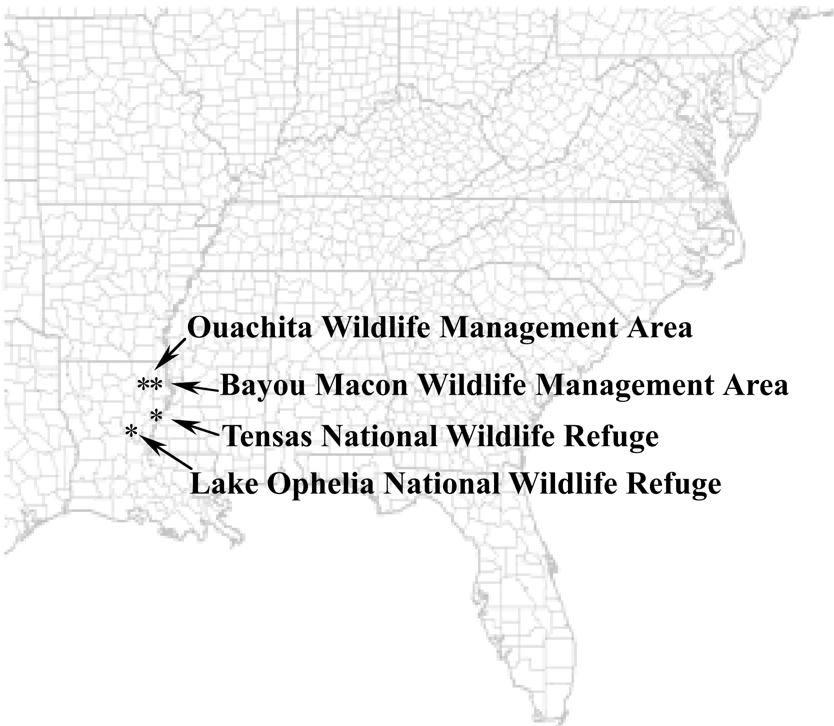

Figure 1. Location of afforestation study sites in Louisiana's Lower Mississippi Alluvial Valley.

broadcast spreader is typical for afforestation operations in the Lower Mississippi Alluvial Valley since these acorns would be exposed to soil surface conditions compared with those incorporated into soil by the seed drill. The actual sowing rate was 6435 acorns ha^{-1} with a range of 3212–14 134 acorns ha^{-1}. Variation in the actual sowing rates was due to wet soil conditions and equipment malfunctions at the time of sowing.

Acorns were sown in the autumn (October and November 1993) and spring (March to May 1994) to evaluate the season of sowing. Spring sowing occurred on the Bayou Macon Wildlife Management Area in early June 1994 due to site flooding early in the growing season. Two additional treatments involved hand planting and machine planting 1-year-old bare-root oak seedlings on a 3.7 m × 3.7 m spacing in December 1993 (winter).

Species

Three oak species were chosen based on species–site relationships for bottomland hardwood sites (Hodges, 1997). Correctly matching species to site drainage conditions is essential for establishment success. Nuttall oak (*Q. nuttallii* Palmer) was the most flood tolerant of the species tested and was used on low sites that were the last to drain in the spring. Water oak (*Q. nigra* L.) was the least tolerant of flooding and was used on relatively higher sites, i.e. ridges. Willow oak (*Q. phellos* L.) was intermediate in flooding-tolerance compared with the other species. All three species are noted for their ability to produce mast for wildlife in addition to providing quality timber (Bullard *et al*., 1992).

Design

At each site, all possible combinations of site preparation, sowing method and season, in addition to hand and machine planting seedlings, were assigned at random to 0.40-ha square experimental plots within each of three replicates in a randomized complete block design. Nuttall oak was planted at three sites (Bayou Macon

Table 1: History and description of study sites in Louisiana's Lower Mississippi Alluvial Valley

Site	Location	Soils	Year cleared	Year purchased	Ownership	Site index (m)*
Bayou Macon Wildlife Management Area	32° 18′ N, 91° 18′ W	Sharkey clay (very fine, smectitic, thermic Chromic Epiaquerts)	1960s	1991	State	27
Lake Ophelia National Wildlife Refuge	31° 14′ N, 91° 54′ W	Tensas–Sharkey complex (Tensas silty clay – fine, smectitic, thermic Aeric Epiaqualfs)	1960s	1980s	Federal	27
Ouachita Wildlife Management Area	32° 21′ N, 92° 02′ W	Portland silty clay (very fine, mixed, non-acid, thermic Vertic Haplaquepts) and Hebert silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs)	1960s or 1970s	1984	State	26
Tensas National Wildlife Refuge	32° 16′ N, 91° 24′ W	Tensas–Sharkey complex	1970s	1980s	Federal	26

* Site index, base age 50 years, for Nuttall oak is based on soil and site characteristics using the Baker/Broadfoot Method (Baker and Broadfoot, 1979).

Wildlife Management Area, Lake Ophelia National Wildlife Refuge and Tensas National Wildlife Refuge), willow oak at two sites (Bayou Macon Wildlife Management Area and Ouachita Wildlife Management Area), and water oak at one site (Tensas National Wildlife Refuge). Different species were used at different sites based on size of fields, drainage, and soil series. Plots were arranged with a 10-m buffer between plots to allow equipment to turn without influencing adjacent plots. All three blocks were installed in one field with the exception of Lake Ophelia National Wildlife Refuge where blocks were established in three separate fields due to the small size of individual fields.

Measurements and analyses

Stem counts were conducted in November and December 1999, six growing seasons after treatment installation. Four 0.01-ha circular quadrats were established 20 m toward the plot centre from each corner of each plot. All sowed or planted oak species were tallied in each quadrat and expressed as stems per ha (sph). Data were transformed using the natural log transformation to remove heteroscedasticity in the residuals. The data were then analysed using analysis of variance for a randomized complete block design for combinations of species and site. Initial seeding or planting rate was used as a co-variate in all analyses of variance. Means were compared with a protected least-square means procedure. Due to the high number of treatments (14 in total) for each site and species combination, specific contrasts were created prior to analyses. Contrasts were analysed for each species–site combination and compared season of sowing, method of sowing, type of discing site preparation, post-sowing rolling, method of planting seedlings, and sowing verses planting seedlings. Comparisons were also made between species on the Bayou Macon Wildlife Management Area and the Tensas National Wildlife Refuge and between sites utilizing the same species. Untransformed data in per hectare values are presented in all tables. Alpha values <0.1 signified significant treatment effects. This alpha value was used due to the variation commonly associated with hardwood regeneration. Further, the increased probability of a Type I error (rejecting a true null hypothesis) was considered acceptable given the low success of afforestation projects in the Lower Mississippi Alluvial Valley (Schweitzer, 1998). Alpha values <0.1 have been used elsewhere (Tang *et al.*, 1999a, b; Stevens *et al.*, 2002; Whitney *et al.*, 2002). A table is provided that shows the *P*-values for all contrasts by site and species should landowners and forest resource managers decide to use a lower probability of a Type I error.

Results

Average stem density across all species–site combinations was 678 sph. Densities ranged from >1800 sph for the autumn, double-disc treatment with seed drill sowing of Nuttall oak to <66 sph for the no discing, direct seeding of willow oak on the Bayou Macon Wildlife Management Area and Nuttall oak on the Tensas National Wildlife Refuge (Table 3). Greatest density within treatments across all sites was 1223 sph for the autumn, single disc and roll treatment, while greatest density for a given species–site combination was 1019 sph for Nuttall oak on the Bayou Macon Wildlife Management Area (Table 3).

Five of the six species–site combinations contained a significant difference within the contrast statements (Table 4). Among these species–site combinations, 12 of 126 contrast statements were significant but few trends existed. Autumn sowing resulted in greater oak seedling densities than spring sowing for two of the six species–site combinations (Table 3), although the mean density values were numerically higher for autumn sowing on the remaining four species–site combinations.

Few differences were found between sowing acorns using a seed drill compared with broadcast seeding (Table 4). Greater Nuttall oak density was found 6 years after sowing on the Bayou Macon Wildlife Management Area using broadcast seeding (1327 sph) compared with seed drilling (981 sph). Higher mean seedling densities for broadcast seeded Nuttall oak and water oak compared with seed drilling existed on the Tensas National Wildlife Refuge (Table 3), but these differences were not significant (Table 4) due to the greater initial seeding rate for broadcast seeding (Table 2).

No differences were found between single disc

Table 2: Initial acorn sowing or seedling planting per hectare by site and species combination for 14 site preparation and sowing/planting treatments in the Lower Mississippi Alluvial Valley

	Bayou Macon WMA		Lake Ophelia NWR	Ouachita WMA	Tensas NWR	
Treatments	Nuttall oak	Willow oak	Nuttall oak	Willow oak	Nuttall oak	Water oak
Autumn						
No disc, seed drill	3477 ±571	2936 ±62	3059 ±0	2884 ±269	3897 ±114	3074 ±0
Strip disc, seed drill	2916 ±494	2777 ±62	1833 ±84	2483 ±245	4013 ±114	3168 ±94
Single disc, broadcast, single disc	3212 ±0	3212 ±0	8547 ±1725	3212 ±0	6570 ±0	14 134 ±0
Single disc, broadcast, single disc, roll	4282 ±1070	3212 ±0	–	3212 ±0	6570 ±0	14 134 ±0
Double disc, seed drill	3711 ±724	2765 ±170	3375 ±316	2624 ±96	3553 ±114	2889 ±94
Double disc, seed drill, roll	3585 ±610	3286 ±420	–	2916 ±59	3553 ±114	2795 ±0
Spring						
No disc, seed drill	4208 ±264	3879 ±282	3252 ±351	4119 ±166	3284 ±0	2241 ±77
Strip disc, seed drill	3986 ±450	3311 ±198	1989 ±101	3477 ±59	3833 ±109	2550 ±133
Single disc, broadcast, single disc	4324 ±0	3583 ±0	5777 ±1097	3707 ±0	7823 ±0	13 309 ±0
Single disc, broadcast, single disc, roll	4324 ±0	3583 ±0	–	3707 ±0	7823 ±0	13 309 ±0
Double disc, seed drill	4552 ±319	3608 ±104	3479 ±178	3707 ±156	3175 ±109	2318 ±0
Double disc, seed drill, roll	3664 ±796	3615 ±84	–	4134 ±72	3284 ±0	2318 ±0
Winter						
Hand plant	741 ±5	694 ±5	815 ±0	734 ±2	714 ±0	714 ±0
Machine plant	707 ±10	665 ±27	756 ±0	684 ±49	714 ±0	714 ±0

Treatments are listed from the least intensive to the most intensive site preparation.
Values include ± 1 SD.

before and after sowing and double-discing prior to sowing (Table 4). Water oak on the Tensas National Wildlife Refuge had a higher mean seedling density following the single disc treatment compared with the double-disc treatment, being 574 sph and 140 sph, respectively, but this difference was not significant due to the greater initial seeding rate for broadcast seeding in concert with the single disc treatment (Table 4). Differences were found when comparing strip disking to no discing, especially for Nuttall oak and water oak on the Tensas National Wildlife Refuge (Table 4). No differences were found for any of the treatments involving a rolling operation in concert with discing.

We were unable to detect differences in our contrast between hand planting and machine planting 1–0 bare-root oak seedlings, being 454 sph and 482 sph, respectively. Furthermore, no differences were found in seedling density comparing sowing acorns versus planting oak seedlings (Table 4) despite the greater seeding rate compared with the planting rate (Table 2).

Nuttall oak had the highest sph among the species tested in this study with 1108 sph compared with 341 sph for willow oak on the Bayou

Table 3: Stems per hectare 6 years after regeneration of direct seeded and planted oaks by site and species combination for 14 site preparation and planting treatments in the Lower Mississippi Alluvial Valley

	Bayou Macon WMA		Lake Ophelia NWR	Ouachita WMA	Tensas NWR	
Treatments	Nuttall oak	Willow oak	Nuttall oak	Willow oak	Nuttall oak	Water oak
Autumn						
No disc, seed drill	158 ±122	50 ±14	158 ±98	616 ±112	66 ±36	183 ±44
Strip disc, seed drill	750 ±301	291 ±279	466 ±199	458 ±217	1250 ±392	583 ±154
Single disc, broadcast, single disc	1308 ±391	716 ±204	741 ±218	958 ±242	866 ±134	1591 ±349
Single disc, broadcast, single disc, roll	1775 ±112	516 ±252	–	1516 ±253	1125 ±346	1833 ±79
Double disc, seed drill	1858 ±399	541 ±159	1125 ±453	1000 ±440	1733 ±258	325 ±104
Double disc, seed drill, roll	1666 ±793	558 ±98	–	833 ±356	1083 ±320	350 ±90
Spring						
No disc, seed drill	841 ±406	491 ±479	225 ±66	675 ±284	266 ±84	83 ±30
Strip disc, seed drill	616 ±96	583 ±423	183 ±44	375 ±184	1141 ±408	525 ±104
Single disc, broadcast, single disc	816 ±316	83 ±44	225 ±62	466 ±147	816 ±292	675 ±256
Single disc, broadcast, single disc, roll	1408 ±217	200 ±62	–	450 ±137	1066 ±185	1575 ±232
Double disc, seed drill	908 ±270	133 ±72	358 ±106	450 ±173	1133 ±293	350 ±118
Double disc, seed drill, roll	1058 ±216	100 ±62	–	333 ±54	1000 ±101	366 ±82
Winter						
Hand plant	500 ±101	366 ±22	416 ±72	575 ±52	625 ±87	250 ±38
Machine plant	616 ±22	166 ±66	675 ±50	458 ±41	691 ±92	291 ±65

Treatments are listed from the least intensive to the most intensive site preparation.
Values include ± 1 SD

Macon Wildlife Management Area (P = 0.0001) and 946 sph compared with 639 sph for water oak on the Tensas National Wildlife Refuge (P = 0.0001). Between sites, planting Nuttall oak resulted in more sph on the Tensas National Wildlife Refuge (946) and Bayou Macon Wildlife Management Area (1108) compared with the Lake Ophelia National Wildlife Refuge (494; P = 0.0001). Also, a greater number of willow oak seedlings were found on the Ouachita Wildlife Management Area (624) compared with the Bayou Macon Wildlife Management Area (341; P = 0.0007).

Discussion

Site preparation

A common perception in afforestation in the Lower Mississippi Alluvial Valley is that site preparation is necessary when direct seeding oaks. This perception is founded on observations of heavy herbaceous cover that soon invades abandoned agricultural fields and the need to give newly germinated oak seedlings sufficient sunlight for successful establishment (Gardiner *et al.*, 2002). Results from competition control studies with direct seeding oaks have been mixed

Table 4: *P*-values for associated contrast statements by site and species combination for 14 site preparation and sowing/planting treatments 6 years after regeneration in the Lower Mississippi Alluvial Valley

	Bayou Macon WMA		Lake Ophelia NWR	Ouachita WMA	Tensas NWR	
Contrast	Nuttall oak	Willow oak	Nuttall oak	Willow oak	Nuttall oak	Water oak
Autumn sowing versus spring sowing	0.5819	0.0534	0.0047	0.4017	0.1935	0.5411
Seed drill versus broadcast seeding	0.0566	0.7106	0.1727	0.1414	0.5179	0.7709
Autumn	0.0480	0.3124	0.1985	0.1600	0.4086	0.7324
Spring	0.4602	0.6221	0.1990	0.6541	0.6002	0.8064
Double disc versus single disc	0.7605	0.7994	0.5603	0.3344	0.7360	0.7974
Autumn	0.9307	0.7070	0.6912	0.3701	0.7213	0.7471
Spring	0.7249	0.9955	0.4632	0.7315	0.7477	0.8449
Strip disc versus no disc	0.0689	0.1235	0.7040	0.1664	0.0001	0.0004
Autumn	0.8090	0.1426	0.8847	0.2432	0.0001	0.0076
Spring	0.3988	0.4323	0.4374	0.3201	0.0004	0.0034
Roll versus no roll	0.6608	0.4577	–	0.6291	0.5543	0.2378
Autumn	0.8090	0.6416	–	0.8901	0.9364	0.7035
Spring	0.3988	0.5542	–	0.4040	0.4536	0.1954
Autumn, double disc, roll versus no roll	0.4361	0.8374	–	0.9613	0.2902	0.7573
Autumn, single disc, roll versus no roll	0.6718	0.6387	–	0.8012	0.2436	0.8190
Spring, double disc, roll versus no roll	0.8088	0.4684	–	0.9747	0.6922	0.1800
Spring, single disc, roll versus no roll	0.1484	0.9150	–	0.2404	0.5021	0.6200
Hand versus machine planting	0.4861	0.2181	0.5977	0.7583	0.8531	0.8110
Sowing versus planting	0.8960	0.2143	0.6829	0.9395	0.6675	0.8867
Autumn	0.9463	0.2428	0.5068	0.8603	0.6540	0.8685
Spring	0.8514	0.1916	0.8958	0.9937	0.6815	0.9067
Analysis of variance	0.1059	0.1288	0.0120	0.3040	0.0001	0.0002
Initial seedling/planting rate (co-variate)	0.8258	0.2404	0.3276	0.8379	0.6498	0.9458

(Kennedy, 1990; Timmons *et al.*, 1993; Ezell and Catchot, 1998). Gardiner *et al.* (2002) indicated that site preparation is vital to afforest former agricultural fields, not only to decrease competition from herbaceous species but also to provide a desirable seedbed for seedling establishment, reduce herbivore habitat, improve nutrient availability and improve access to the site for planting operations. Allen *et al.* (2001) stated that for machine sowing acorns on heavy clay soils, the site should be double disced the autumn prior to sowing to prevent cracking of the soil along the furrow lines during dry weather. Furthermore, Patterson and Adams (2003) indicated that bedding can also increase survival and growth of direct seeded oaks on heavy clay soils found in the Lower Mississippi Alluvial Valley.

Results from the present study indicate that site preparation is necessary to increase the density of direct seeded oaks 6 years after sowing (Table 5). Discing the entire site, whether by single discing before and after sowing or double discing prior to sowing acorns, increased the number of sph by 33 per cent and 23 per cent, respectively, compared with strip discing and 65 per cent and 59 per cent, respectively, compared with no discing. Intensive discing reduces, but does not eliminate, the density of competing herbaceous vegetation thereby increasing available moisture and nutrient resources to oak seedlings. Strip discing every 3 m and sowing within the strips ranked third of the four general site preparation treatments (Table 5). Strip discing decreased the time of discing by about 150 per cent compared with the single disc before and after sowing and the double discing treatments, thereby reducing site preparation costs. No discing, while the least costly of the site preparation treatments, resulted in the lowest number of oak seedlings 6 years after sowing. Rolling was believed to aid in covering sown acorns, especially those sowed with the broadcast seeder, and could result in a greater number of established oak seedlings. Rolling with a steel bar after the second single disc treatment

Table 5: Stems per ha and rank of site preparation treatments by species and site combinations in the Lower Mississippi Alluvial Valley

Treatments	Bayou Macon WMA Nuttall oak	Bayou Macon WMA Willow oak	Lake Ophelia NWR Nuttall oak	Ouachita WMA Willow oak	Tensas NWR Nuttall oak	Tensas NWR Water oak	Treatment average	Average rank
No disc, seed drill	499 (4)	270 (4)	191 (4)	645 (3)	166 (4)	133 (4)	317 (4)	3.8
Strip disk, seed drill	683 (3)	437 (1)	324 (3)	416 (4)	1195 (2)	554 (2)	601 (3)	2.5
Single disc, broadcast seeding, single disc	1326 (2)	378 (2)	483 (2)	749 (1)	1066 (3)	1418 (1)	903 (1)	1.8
Double disc, seed drill	1372 (1)	333 (3)	741(1)	654 (2)	1237 (1)	347 (3)	780 (2)	2.0

Treatments are listed from the least intensive to the most intensive site preparation.
Ranking levels (1 = best and 4 = poorest) are in parentheses.
Autumn and spring direct seedings were combined.

following sowing or following sowing with the double disc treatment did not increase the density of oak seedlings in this study (Table 3).

A common target density for afforestation success is 317 sph of hard mast species 3 years after sowing or planting for federal government cost-share programmes such as the Wetlands Reserve Program. A second criterion for success can be developed based on an initial planting density of 747 sph. This density is based on a common spacing of 3.7 m × 3.7 m for planted oak seedlings (12 ft × 12 ft spacing), primarily for wildlife habitat but, to a lesser extent, for timber production. Assuming 80 per cent survival of seedlings planted at this spacing, then a success criteria of 597 sph is set. Using these afforestation success criteria and the results in Table 5, all three discing treatments resulted in 100 per cent success for the 317 sph minimum, while four of the six site and species combinations failed when no discing was used. Using the higher success criteria of 597 sph, four of the six site and species combinations were successful for the two intensive discing treatments (single disc before and after sowing and double discing prior to sowing). Only two and one of the species and site combinations were successful for the strip disc and no disc treatments, respectively. Therefore, some level of site preparation treatment is necessary to ensure successful establishment of oak in afforestation efforts in the Lower Mississippi Alluvial Valley although the level of site preparation needed should be based on the objectives of the afforestation project. For example, strip discing, with its associated lower costs, may be all that is needed if success is determined under Wetland Reserve Program guidelines. Also, it is possible that herbicide application in strips may substitute for strip discing and may result in similar survival at a lower cost (A. Ezell, Mississippi State University, pers. comm.). More intensive site preparation is needed if a greater density of oak seedlings are desired, especially for timber-oriented objectives.

Method and season of sowing

Distributing acorns across the area with a broadcast seeder resulted in greater densities for only one species and site combination compared with sowing directly with a seed drill. Greater density may be the result of a greater target density using the broadcast seeder compared with seed drilling. Concurrently, as part of the seed drill operation, a slit was made in the soil so that the acorn could be buried to a specified depth of 4–8 cm. The slit was then mechanically closed. During the course of the growing season as the clay soil dried, cracks developed along the slit lines and exposed newly germinated seedlings, desiccating their root systems (K. Ribbeck, Louisiana Department of Wildlife and Fisheries, pers. comm.). This difference was especially acute during autumn sowing but, in general, depended on weather patterns before and after sowing.

Autumn sowing resulted in greater oak

densities in two of the six site and species combinations (Table 4). Autumn sowing allows acorns of red oak species to stratify naturally in the soil (Allen *et al.*, 2001). Acorns used in the spring sowing were kept artificially cool and were handled more often than acorns sowed in the autumn. Autumn sowed acorns may have also germinated earlier than spring sowed acorns thereby initiating height growth at an earlier date. Earlier height growth may give these seedlings a greater advantage over competing herbaceous vegetation compared with spring sowed acorns.

Sowing versus planting

Another common perception regarding afforestation in the Lower Mississippi Alluvial Valley is that planting seedlings is a more reliable regeneration technique than direct seeding (King and Keeland, 1999; Schoenholtz *et al.*, 2001). This perception has resulted from many failures, real or perceived, that have occurred when direct seeding oaks in large abandoned agricultural fields (Johnson and Krinard, 1985b; Schweitzer, 1998). Planted seedlings are believed to have more rapid early height growth compared with seedlings from direct seeding, a key factor when competing with herbaceous vegetation (Stanturf and Kennedy, 1996). Results from this study indicate that the density of direct seeded oaks was similar to planted oaks for all species and site combinations, possibly due to the correct matching of species to soil conditions. The initial target density for direct seeding oaks (3000 ha^{-1} for seed drilling and 6177 ha^{-1} for broadcast seeding) was based on research and experience in afforesting previously farmed agricultural fields in the Lower Mississippi Alluvial Valley. This study confirms that these target densities can result in a similar number of oak seedlings per ha 6 years following sowing compared with the standard seedling planting target of 747 sph. The choice of whether to direct seed acorns or plant oak seedlings will depend on the objectives of the afforestation project, availability of seed or seedlings, site conditions, equipment and personnel availability and weather conditions.

Species and site

Nuttall oak is the preferred oak species for afforestation projects in the Lower Mississippi Alluvial Valley that contain heavy clay soils (Johnson, 1983; Allen *et al.*, 2001). Nuttall oak is the most flood tolerant of the red oak species naturally found in the Lower Mississippi Alluvial Valley. Its relatively larger acorn size gives new germinates a greater food resource to utilize following germination. This may provide Nuttall oak germinates a competitive advantage with herbaceous competition compared with other bottomland red oak species. Furthermore, Nuttall oak can delay germination until after flood waters, that occasionally extend into the early and middle parts of the growing season, have receded. Results from this study confirm that Nuttall oak is a preferred oak species for the heavy clay soils typical of the study areas (Johnson, 1981; Johnson and Krinard, 1985a). Nuttall oak had considerably greater densities than willow oak on the Bayou Macon Wildlife Management Area and water oak on the Tensas National Wildlife Refuge. Both of these sites contained heavy clay soils (Table 1).

Conclusions

Site preparation is necessary to increase the density of sown acorns or planted oak seedlings in afforestation of former agricultural fields in the Lower Mississippi Alluvial Valley. Intensive site preparation treatments, such as single discing before and after sowing acorns and double discing prior to sowing acorns, resulted in greater densities of oak seedlings compared with less-intensive site preparation treatments. Strip discing resulted in satisfactory oak seedling density under Wetland Reserve Program stocking guidelines, while no discing resulted in unsatisfactory establishment of oak seedlings regardless of stocking criteria.

Nuttall oak was judged the most successful of the three oak species tested, confirming results by others. Greater density of Nuttall oak seedlings was likely the result of its greater flood tolerance compared with water oak and willow oak, ability to establish better on heavy clay soils, and larger acorn size to provide new germinates with a greater competitive ability against herbaceous competition. No differences were found between direct seeding acorns and planting oak seedlings or between hand and machine planting oak seedlings.

Results from this study indicate that no single site preparation treatment will consistently result in the greatest number of sph 6 years after treatment (Tables 3 and 4). Therefore, decisions made in planning an afforestation project in the Lower Mississippi Alluvial Valley must include setting objectives so success measures can be developed (such as sph after a designated number of years), matching species to site conditions (including soil texture), and applying the appropriate level of site preparation for the given field conditions and afforestation objectives. The species and density of competing vegetation will also dictate the level site preparation. Finally, non-controllable weather factors, such as late spring–early summer flooding or a first-year post-planting drought, will also influence the success of the afforestation project.

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