Restoring Riparian Forests in the Missouri Ozarks

Kyle L. Steele, John M. Kabrick, Daniel C. Dey, and Randy G. Jensen

ABSTRACT

Restoring the function of riparian forest ecosystems has become a primary objective of many land management agencies throughout the central hardwood region, and consequently, much emphasis has been placed on planting native hardwood tree species in former bottomland agricultural fields. However, there is little information providing successful restoration techniques in old-field riparian ecosystems, especially in the Ozark highlands ecoregion of Missouri. Objectives of this study were to examine the efficacy of two herbicide and three cover-crop vegetation management treatments on the (1) composition and density of competing vegetation, (2) survival and height growth of planted seedlings of 13 native bottomland tree species, and (3) the density and composition of natural reproduction colonizing three old-field riparian sites in the Missouri Ozarks. Overall, we found selection of tree species was a more important determinant of afforestation success (i.e., high survival and height growth) than the type of vegetation management used during establishment. Planting bareroot stock is an important strategy for establishing hardmast species because there is little evidence that they will colonize naturally very quickly following abandonment of tall fescue pastures in Ozark bottomlands.

Keywords: artificial regeneration, natural regeneration, bottomland hardwood forests, ecological restoration

Restoring bottomland hardwood forests in old-field floodplains has remained an important land management objective throughout much of the eastern and southern United States (Dey et al. 2008, Keeton 2008, Stanturf et al. 1998, 2001). In the central hardwood region alone, more than 85% of the native riparian forests were cleared for agriculture or other uses (Dey et al. 2001). This loss of riparian forests has accelerated bank erosion, destabilized stream channels, increased stream temperature, and degraded aquatic and riparian fish and wildlife habitat (Roell 1994). In the Ozark highlands of Missouri, large-scale conversion of bottomland forest to agriculture began in the early 1800s (Jacobson and Primm 1994) and continued to be a common practice into the middle of the 20th century. Most floodplains in the region were originally cleared for row-crop agriculture, which quickly failed due to frequent, often intense flooding in combination with poor soil fertility that is characteristic of the Ozark region. Following abandonment of row-crop agriculture, many floodplains were converted to tall fescue pasture (*Festuca arundinacea* Schreb.), which is the most important forage grass in the region because it is tolerant of infertile soils, short-term drought, and intense grazing (Sleper and Buckner 1995).

Today, the majority of bottomlands in the Ozark highlands where restoration is attempted are flooded, have coarse-textured or gravelly soils, and are mostly monocultures of tall fescue. Although left idle for significant time periods, most sites lack significant natural tree regeneration due to competition and allelopathy from tall fescue (Missouri Department of Conservation 1987, Van Sambeek and Garrett 2004). Consequently, there is growing interest in replanting hardwoods in old fields and former pastures along riparian corridors in the Missouri Ozarks in an effort to mitigate some of the deleterious effects caused by the alteration of riparian habitats (Steele et al. 2008). Most riparian afforestation projects have focused on planting hardmast-producing species, such as oaks (*Quercus* spp. L.), pecan [*Carya illinoinensis* (Wangenh.) K. Koch], and black walnut (*Juglans nigra* L.). Fast-growing, light-seeded species, such as American sycamore (*Platanus occidentalis* L.) and eastern cottonwood (*Populus deltoides* Batr. ex Marsh.), are often omitted, in part, because these species are assumed to naturally establish. However, Allen (1997) and Stanturf et al. (2000) suggested that relying on the natural establishment of light-seeded, wind-dispersed species into agricultural forest conversions may be impractical or unsuccessful, especially in large, open bottomland fields. Consequently, there is increasing interest in including these species in bottomland plantings, although there is little information about the artificial regeneration requirements of these light-seeded species in plantings that have multiple-use objectives.

Regardless of the species being restored, surveys of federal and statewide efforts to re-establish bottomland hardwoods have reported that regeneration success has varied widely, and complete failures were common (Stanturf et al. 1998, 2001). Restoration failures were caused by planting species unsuited for the site, planting small or poor-quality stock, using poor seedling handling and planting methods, and most importantly, high levels of competition for above- and below-ground resources by resident vegetation that

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; kilograms (kg): 1 kg = 2.2 lb; hectares (ha): 1 ha = 2.47 ac.

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inhibited the survival or growth of natural and planted native tree seedlings (Kruse and Groninger 2003, Lawson et al. 1999, Van Sambeek and Garrett 2004).

Vegetation management includes a number of mechanical, chemical, and vegetative methods for controlling competing vegetation in treeplantings. Mechanical methods, including mowing, rarely improve seedling survival and growth (Van Sambeek and Garrett 2004). Chemical methods apply a variety of pre and postemergent herbicides over trees. Broad-spectrum herbicides such as glyphosate (Roundup) are commonly used and have been demonstrated to increase tree seedling growth rates in hardwood plantings (Van Sambeek and Garrett 2004). Grass-selective herbicides such as sethoxydim (Poast Plus) have the potential to control some of the most noxious invasive species affecting riparian treeplantings, such as Johnson grass (*Sorghum halepense* (L.) Pers.), tall fescue (*Festuca arundinacea* Schreb.), and reed canary grass (*Phalaris arundinacea* L.) but have not been as widely evaluated (Van Sambeek and Garrett 2004).

Vegetative methods including cover crops have also been shown to be effective in suppressing competing vegetation, leading to improved tree survival and growth (Van Sambeek and Garrett 2004). Grasses such as redtop (*Agrostis gigantea* Roth) have been successfully established in bottomland hardwood plantings in Missouri with minimal investment, high success, and little follow-up management (Dey et al. 2003). Legumes such as clovers (*Trifolium* spp.) have nitrogen-fixing properties and often prove more successful in hardwood treeplantings than both grasses and resident vegetation (Van Sambeek and Garrett 2004). However, interest in native cover-crop species is growing, for which there has been little evaluation in treeplantings, particularly where restoring plant communities is a priority. A number of local managers in Missouri have speculated that Virginia wild rye (*Elymus virginicus* L.) may be a suitable native cover crop because of its general distribution and growth habit. In Missouri, Virginia wild rye grows in a variety of environments, from intact riparian communities to glades and old fields (Yatskievych 1999).

We conducted this study to address some of the remaining information needs for restoring bottomland hardwoods in old-field riparian ecosystems. Our objectives were to compare the efficacy of some of the commonly used herbicide and cover-crop treatments to those that have received little examination on the (1) composition and density of competing vegetation, (2) survival and height growth of planted seedlings of 13 native bottomland tree species, and (3) density and composition of natural reproduction colonizing old field riparian sites in the Missouri Ozarks. In addition to commonly evaluated oaks and other hardmast species, we included a wide variety of light-seeded, and mid- to early-successional tree species because of increasing interest in establishing them in riparian restorations.

Methods

Study Areas

This study was conducted at three conservation areas located within the Ozark Highlands Ecological Section (Nigh and Schroeder 2002) and managed by the Missouri Department of Conservation (Figure 1). Mean annual precipitation in the study region is 102–124 cm, with an average growing season of 205–225 days (Nigh and Schroeder 2002). Soil orders at the sites were identified as Entisols and Alfisols that ranged from excessively well drained with sandy-skeletal texture to somewhat poorly drained with fine, silty texture (Table 1). Streams in the study area were second order (Trace Creek) or fourth order (Roubidoux Creek and the St. Francis River) systems (Strahler 1957). Each site was located on well-developed and relatively stable floodplains subjected to frequent or occasional flooding. Historic natural communities in Ozark bottomlands were largely mesic and dry-mesic bottomland forest (Nelson 2010). At each of the three conservation areas, we selected a single site to conduct the experiment. Sites were about 1.5 to 2.0 ha in area, approximately rectangular in shape, and oriented such that the long side was parallel to the stream channel. Pretreatment vegetation at all sites consisted of monocultures of tall fescue.

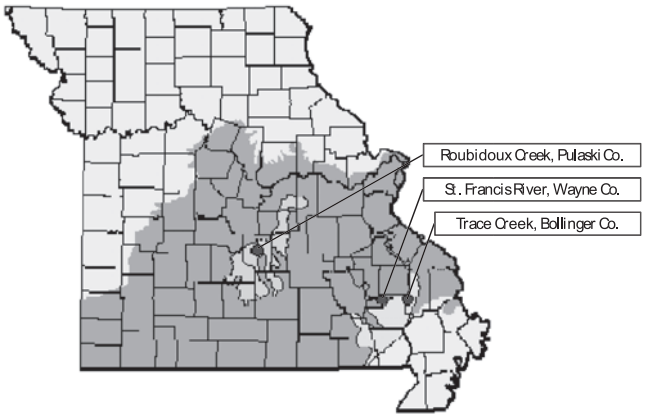

Figure 1. Ozark highlands ecological section (dark gray); filled circles indicate location of project sites within three different ecological subsections, including the Gasconade River Hills (Roubidoux Creek), St. Francis Knobs and Basins (St. Francis River), and the Black River Ozark Border (Trace Creek).

Vegetation Management Treatments

All sites were initially treated with a 2% solution of glyphosate (41% active ingredient, [a.i.]) to eliminate pre-existing cool-season pasture grasses and other agricultural weeds. Treatment units were created by subdividing the rectangular sites into five approximately square areas, each about 0.3–0.4 ha in size and oriented with one side along the stream channel. One of five treatments was randomly assigned to each treatment unit: (1) no additional weed control (hereafter referred to as "Roundup-only"), (2) a single growing season application of a grass-selective, postemergent herbicide sethoxydim (13% a.i., hereafter referred to as "Poast Plus"), (3) redtop grass cover crop, (4) large white clover cover crop with a winter wheat (*Triticum aestivum* L.) nurse-crop, and (5) Virginia wild rye cover crop with a Korean lespedeza (*Kummerowia stipulacea* [Maxim.] Makino) nurse crop. Annual nurse crops for the latter two treatments were planted to slow competition of resident vegetation to help ensure establishment of the cover crop. Following the initial glyphosate application, units receiving the three cover-crop treatments were disked to a depth of 7 cm. Seeds were broadcast with either a hand spreader or tractor-mounted seeder prior to treeplanting in March or April. Each treatment unit was planted separately at the following seed mixtures and rates: (1) redtop at 11.1 kg/ha, (2) large white clover at 4.5 kg/ha and winter wheat at 134.5 kg/ha, and (3) Virginia wild rye at 17.8 kg/ha and Korean lespedeza at 8.9 kg/ha. Following seeding, a section of chain-link fence was dragged behind an all-terrain vehicle on the seeded treatments to maximize seed–soil contact. For the Poast Plus treatment, herbicide was applied when the target grass species were actively growing (i.e., late May–early June). Treatments were replicated once at each of the three sites.

Table 1. Soils and associated physical characteristics of each study area.

Study site	Soil series	Landform type	Drainage class	Taxonomic class
St. Francis River	Bucklick	Footslope	Well	Fine, mixed, active, mesic Typic Hapludalfs
	Crider	Footslope	Well	Fine-silty, mixed, active, mesic Typic Paleudalfs
	Fourche	Terrace	Moderately well	Fine-silty, mixed, active, mesic Glossaquic Paleudalfs
	Freeburg	Terrace	Somewhat poorly	Fine-silty, mixed, superactive, mesic Aquic Hapludalfs
	Raccoon	Terrace	poorly	Fine-silty, mixed, superactive, mesic Typic Endoaqualfs
	Secesh	Terrace	Moderately well	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs
Trace Creek	Razort	Floodplain	Well	Fine or coarse-loamy, mixed, active, mesic Mollic Hapludalfs
	Secesh	Floodplain	Well	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs
	Tilk	Floodplain	Well	Loamy-skeletal, siliceous, active, mesic Ultic Hapludalfs
Roubidoux Creek	Kickapoo	Floodplain	Moderately well	Coarse-loamy, mixed, superactive, nonacid, mesic Typic Udifluvents
	Sandbur	Floodplain	Somewhat excessively	Coarse-loamy, siliceous, superactive, nonacid, mesic Mollic Udifluvents
	Relfe	Floodplain	Excessively	Sandy-skeletal, siliceous, mesic Mollic Udifluvents

Table 2. Species, number of seedlings (*n*), and species group (based on seed morphology) used in this study.

Common name	Scientific name	*n*	Species group
Bur oak	*Quercus macrocarpa* Michx.	378	Oak hardmast
Swamp white oak	*Q. bicolor* Willd.	212	
White oak	*Q. alba* L.	367	
Northern red oak	*Q. rubra* L.	374	
Pin oak	*Q. palustris* Muenchh.	204	
Shumard oak	*Q. shumardii* Buckl.	373	
Pecan	*Carya illinoinensis* (Wangenh.) K. Koch	367	Other hardmast
Black walnut	*Juglans nigra* L.	430	
Green ash	*Fraxinus pennsylvanica* Marsh.	383	Light-seeded or or softmast
White ash	*F. americana* L.	363	
American sycamore	*Platanus occidentalis* L.	375	
Eastern cottonwood	*Populus deltoides* Batr. ex Marsh.	311	
Hackberry	*Celtis occidentalis* L.	364	

Seedling Planting

In each treatment unit, we planted 13 tree species native to the Ozark highlands (Table 2). Seedlings and cuttings were obtained from the George O. White State Tree Nursery near Licking, Missouri. Eastern cottonwood was planted as 30-cm-long cuttings. For all other species, 1–0 bareroot seedling stock was used, which is the most widely available stock type in the region (Dey et al. 2008). Prior to planting, seedlings of all species were randomly packaged together to ensure random placement in the field. All seedlings were machine planted in March or April 2006 in rows parallel to the stream channel within treatment units. A minimum of 20 seedlings of each species was planted per treatment at each site (Table 2), for a total of 4,501 seedlings. Two species, swamp white oak and pin oak, were inadvertently only planted at two sites. Planting spacing was approximately 3 m × 3 m (i.e., 1,111 trees/ha). A work crew followed the tree planter and replanted any poorly planted seedlings as needed.

Data Collection

Ground flora was inventoried during peak vegetative productivity in the growing season (i.e., middle July–early August) during 2006 and 2007 to quantify the composition, abundance, and structure of cover crops and competing vegetation within each site and treatment type. Twenty-five to 30 1 m^2 sample quadrats were randomly assigned to each treatment per site. For each species, percent cover was estimated to the nearest percent for each species within the quadrat area. Cover was included in the estimate regardless of its vertical location to the quadrat frame. Therefore, it was possible that with vertical layering of vegetation, the sum of all species together could equal more than 100%. Foliar coverage by height class (above the ground) was also measured using a 2.5 m tall by 0.3 m wide vegetation profile board, with alternating black and white painted bands at each 0.25-m interval (Nudds 1977). The profile board was oriented along the outside edge of the 1 m^2 quadrat frames used for the ground flora sampling. A metal tape was used to establish a preselected, unbiased random observation point 15 m from the profile board. The amount of all vegetation (regardless of species or species groups) obscuring each 0.25-m interval on the profile board was estimated to the nearest percent for each observation point. Observer's estimates of cover were made in a horizontal line-of-sight for each height class. These data were collected at every other quadrat location.

Planted seedlings were measured immediately after planting and again after the first and second growing seasons. Information collected included the status (live or dead), height, and obvious indications of wildlife damage, including girdling and browsing. Severely damaged seedlings (e.g., completely severed stems) were omitted from the analyses. In all, 538 of the 4,501 total seedlings were removed from the dataset, most of which were severed at their base by rabbits.

Natural reproduction was inventoried in plots established after the second growing season to determine the contribution of tree reproduction from adjacent seed sources and to analyze differences by treatment type. Ten 0.04 ha plots were randomly placed in each treatment unit. Tree species, number of stems, and height class (0–0.3 m, 0.3–0.9 m, and > 0.9 m) were recorded. For reproduction density, species were grouped into three types: light-seeded (i.e., wind-dispersed), hardmast, and softmast.

Data Analysis

Data were analyzed using the SAS statistical software package (version 9.1, SAS Institute, Inc., Cary, NC). The MIXED procedure was used for normally distributed data. The GLIMMIX procedure with specified data distribution was used for data that could

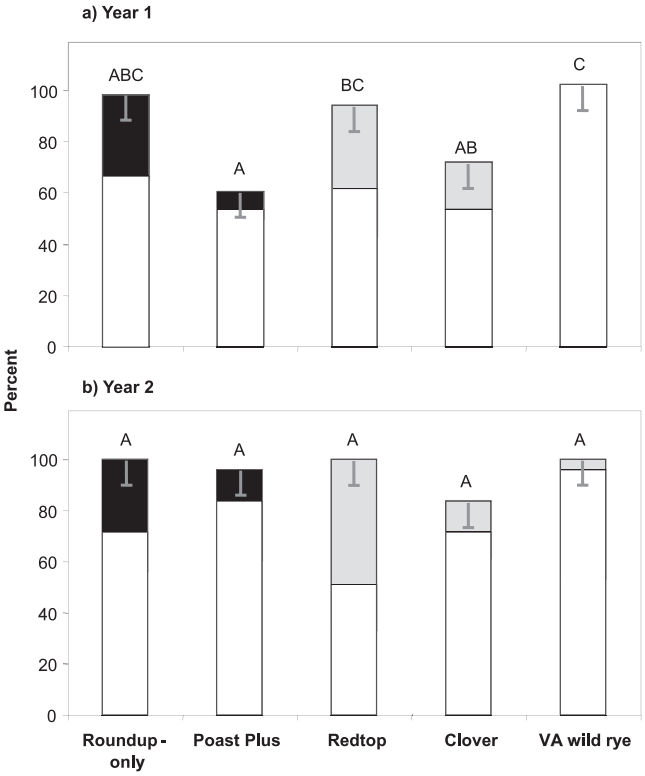

Figure 2. Mean ground flora foliar coverage and standard error by treatment, during the first growing season (a) and the second growing season (b). Filled portion of the bars indicates the proportion of "target" vegetation for each treatment relative to resident vegetation. Gray shading shows the percentage of cover crops and black shading shows the percentage of grass species for the herbicide-only treatments. Letters indicate significant differences among treatments ($\alpha = 0.05$).

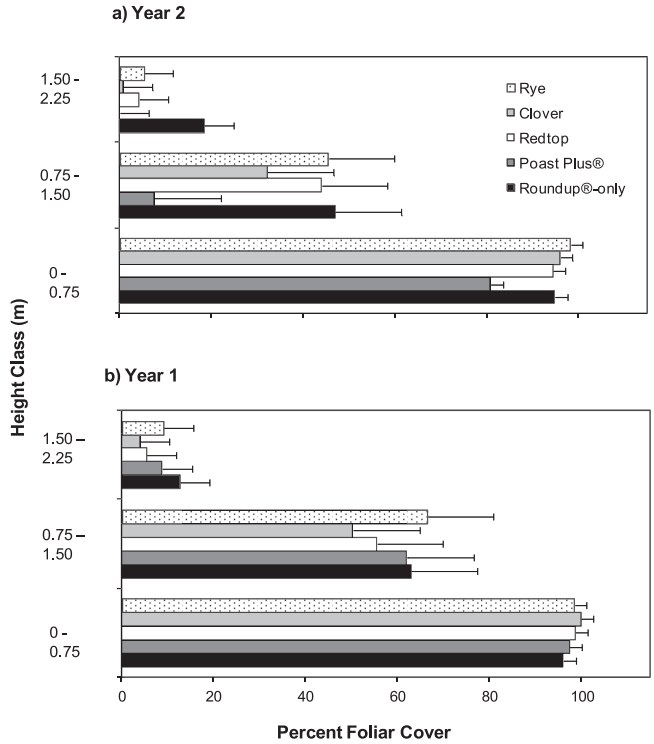

Figure 3. Foliar coverage and standard error by treatment of all competing vegetation at three 0.75 m vertical strata during the second growing season (a) and the first growing season (b) following establishment.

not be normalized. For the ground flora coverage and natural reproduction density analyses, the five vegetation management treatments were analyzed as fixed effects and the site by treatment interaction was the random effect used as the error term. For seedling survival and growth, a repeated measures split-plot design was used, with the five vegetation management treatments as whole plots and the 13 tree species as split plots. For survival, binary data were analyzed with logistic regression using the GLIMMIX procedure, fitting the data with a beta distribution function. For all repeated measures by year, compound symmetry and autoregressive covariance structures were evaluated, and the one with the lowest value of Akaike's information criterion (AIC) was selected. Site was treated as a blocking factor and all interactions with site were considered random effects in the error term for the survival and growth analyses. For significant effects, Fisher's least significant differences were calculated using the least squares means for all mean separations. An alpha of 0.05 was used for all tests.

Results

Density and Height of Competing Vegetation

Foliar cover of competing ground cover differed among vegetation management treatments during the first growing season, but by the second growing season, cover of competing vegetation was similar in each treatment (Figure 2). Of the herbicide-only treatments, the Poast Plus treatment decreased the proportion of grasses (particularly tall fescue and Johnson grass) fourfold compared to the Roundup-only treatment. Among the cover crops, the redtop sod averaged 33% coverage compared to resident vegetation in year one, increasing to 50% coverage in the second year. The clover did not establish as well, accounting for about a quarter of all vegetative cover in the first year and much less in the second year. The establishment of Virginia wild rye was a failure the first year and it had very low coverage during year two.

Differences in vegetative coverage by vertical height class were more pronounced in the first year than the second (Figure 3). In year one the Poast Plus treatment had very short vertical competition (< 0.75 m) compared to the Roundup-only treatment, where vegetation often exceeded 2 m in height. Although data were not analyzed due to unusual data distribution, vegetative coverage by height class appeared to be similar for the other treatments and for all treatments in year two.

Survival and Height Growth of Planted Seedlings

After two growing seasons, survival of all planted seedlings (i.e., all species together) was similar among vegetation management treatments and ranged from 81% in the Roundup-only treatment to 87% in the Poast Plus treatment. For all species and treatments combined, first-year survival was 93% and decreased significantly to 84% following the second growing season ($P < 0.01$). Large differences in survival rates occurred among species and even among species within species groups (Table 3). Ten of the 13 species had greater than 92% survival after the first growing season. Survival of most species decreased by only 5–10% by the end of the second growing season, but some species suffered significantly greater mortality, including pecan (74–58%, $P < 0.01$), sycamore (88–74%, $P < 0.01$), and cottonwood (41–16%, $P < 0.01$). Green ash and

Table 3. Percent seedling survival and standard error (SE) by species, year within species group, and all seedlings by year. Uppercase letters indicate differences between years and lowercase letters indicate differences among species (α = 0.05).

Species group	Species	Mean survival ± SE	
		Year	
		1	2
		Percent	
Oak hardmast	Bur oak	95 ± 2 A ab	91 ± 5 B ab
	Swamp white oak	97 ± 2 A ab	92 ± 4 B ab
	White oak	93 ± 3 A bc	81 ± 8 B bc
	Northern red oak	95 ± 2 A ab	89 ± 5 B ab
	Pin oak	92 ± 4 A bc	81 ± 9 B bc
	Shumard oak	94 ± 3 A bc	87 ± 6 B b
Other hardmast	Pecan	74 ± 10 A d	58 ± 12 B d
	Black walnut	97 ± 1 A ab	89 ± 5 B ab
Light-seeded or softmast	Green ash	98 ± 1 A a	98 ± 1 A e
	White ash	96 ± 2 A ab	95 ± 3 A ae
	American sycamore	88 ± 5 A c	74 ± 10 B cd
	Eastern cottonwood	41 ± 12 A e	16 ± 7 B f
	Hackberry	95 ± 2 A ab	85 ± 7 B bc

white ash had greater than 95% survival after both years. Overall, the oaks, black walnut, and hackberry had comparable survival both years, with second-year survival ranging between 81% (pin and white oak) and 92% (swamp white oak).

Seedling height of all species combined among vegetation management treatments was only nominally different by treatment (Figure 4), with greater height growth in the cover-crop treatments than in the herbicide-only treatments. In general, the relationship of seedling height by treatment during both years was as follows: redtop and clover > rye > herbicide-only. There was not a significant treatment by species or treatment by year interaction in seedling height, suggesting all species responded similarly by treatment each year.

Mean height and height growth increment varied greatly among tree species by year (Figure 4). Initially, the white oak group (i.e., swamp white oak, bur oak, and white oak) seedlings were the shortest, ranging from 34 to 44 cm. However, swamp white oak had the greatest height growth increment of all oak species planted. The red oak group (northern red oak, pin oak, and Shumard oak) seedlings were initially taller than the white oaks, ranging from 48 to 50 cm immediately after planting. Of the red oak group, pin oak had the greatest growth increment and was nominally the tallest of all oaks and hardmast-producing species. The other hardmast-producing species (black walnut and pecan) were initially similar in height but black walnut gradually gained in height by the end of year two and pecan gradually died back. Of the light-seeded and softmast-producing species, sycamore was initially taller and averaged 79 cm in height. After 2 years, surviving sycamore ($P < 0.01$) and cottonwood ($P < 0.01$) seedlings were significantly taller than the others, growing to 125 cm and 95 cm, respectively. Sycamore seedlings grew minimally in the first year but rapidly the second year; it was the tallest of all 13 species by the end of year two. Although the ashes and hackberry were initially similar (53 and 55 cm, respectively), green ash grew to 78 cm in 2 years, white ash to 69 cm, and hackberry progressively declined in height to nearly 40 cm due to shoot dieback.

Composition and Density of Natural Reproduction

By the end of the second growing season, 27 tree species were identified in the natural regeneration inventory (Table 4). Elms, sycamore, persimmon, and green ash were most abundant and collectively totaled more than 75% of all stems found. The remaining species individually comprised less than 4% of all stems. Overall, light-seeded species comprised the majority of all stems (67%), while the remaining 20% were softmast species and 13% were hardmast species. Of all stems, 70% were in the 0.3–0.9 m height class, followed by 23% in the < 0.3 m class and 7% in the > 0.9 m class after 2 years.

Significant differences in the density of natural reproduction occurred among vegetation management treatments (Table 5, $P < 0.01$). Similar trends were observed in reproduction density in all height classes and species groups. Density of natural reproduction was always greater in the herbicide-only treatments than in the cover-crop treatments: Poast Plus > Roundup-only > cover crops. The density of total stems inventoried by treatment was: Poast Plus (1,791/ha), Roundup-only (1,265/ha), clover (362/ha), rye (362/ha), and redtop (291/ha). When examined by species group, the density of light-seeded reproduction was significantly greater in the herbicide treatments than in the cover-crop treatments ($P < 0.01$). The softmast and hardmast producers were not significantly different by treatment.

Discussion

Vegetation Management Effects on Competing Vegetation

The redtop cover crop was the only treatment to greatly alter coverage of other competing vegetation during both years. The redtop sod germinated uniformly, established quickly, and outcompeted other vegetation much like as has been reported for plantings in loamy soils of the Missouri River floodplain (Dey et al. 2004). The white clover germinated uniformly at all sites but lost vigor during both summers, especially by the second year, presumably due to the combination of heat, drought, and gravelly soils having a low water-holding capacity. Drought may have been the most important factor as precipitation during the growing seasons of 2006 and 2007 was as much as 60% below the 30-year average throughout much of the study region (USDA National Agricultural Statistics Service 2010). The Virginia wild rye established poorly at all sites, and hence, competing vegetation was dominated by invasive weedy species, such as Johnson grass, tall fescue, sericea lespedeza [*Lespedeza cuneata* (Dum.Cours.) G.Don], goldenrods (*Solidago* spp. L.), crown-vetch (*Coronilla varia* L.), and annual brome grasses (*Bromus* spp. L.).

The ground cover and vertical height of competing vegetation was greatly lowered by using Poast Plus during the first year (Figures 2 and 3, respectively). Not only was coverage of grass species nearly four times lower in the Poast Plus treatment, but competing vegetation was also shorter and total foliar coverage was less. In the second year, even though grass cover nearly doubled in the Poast Plus treatment (from 8 to 15%), it was still less than half of the grass coverage in the Roundup-only treatment. However, total foliar cover in both herbicide treatments was similar in year two. This suggests that to control competing vegetation with herbicides, applications should be made in more than just the first year following treeplanting.

Vegetation Management Effects on Planted Seedlings

Despite the differences in composition and vertical density of the competing vegetation, there were no differences in survival and growth of the planted seedlings among the vegetation management

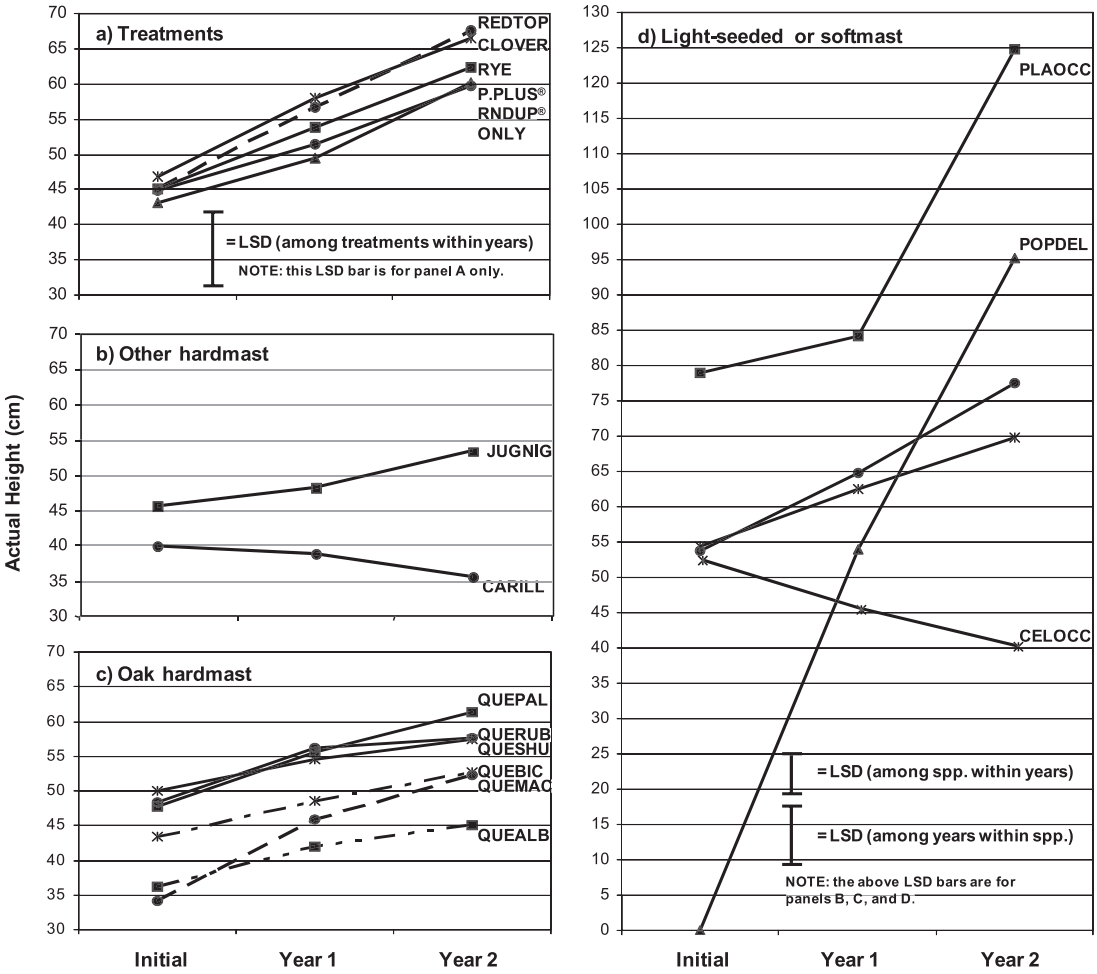

Figure 4. Average seedling height by year by treatment (a) and by species (b–d). Bars in (a) and (d) indicate least significant differences (LSD, $\alpha = 0.05$) for comparing treatments on a given year (a) and species on a given year or differences among years for a given species (d). Species are coded using the first three letters of the genus followed by the first three letters of the species.

treatments. Consequently, we regard these management treatments to be equally effective for establishing trees in agricultural bottomlands in the Ozark highlands. However, there were nominal differences in seedling height growth among vegetation management treatments that merit discussion. Namely, seedling height growth was greater where seedlings were planted with a cover crop compared to those planted where only herbicides were applied. Had we successfully established all of the cover crops each in their respective treatment units we would have assumed that the cover crop itself was beneficial to the planted seedlings. The fact that the Virginia wild rye established poorly but that the rye treatment had nominally higher seedling growth rates than the herbicide-only treatments suggested that something other than the cover crop was benefiting the planted seedlings. We suspect the disking that was done prior to study establishment may have loosened and improved the soil, creating a slightly better medium for the planted tree seedlings. We also observed that the disking had the added benefit of physically removing competing vegetation and retarding the reestablishment of the resident fescue and weedy vegetation during the critical period of seedling establishment.

We found that the most influential factor affecting seedling survival and growth was not the vegetation management treatment but rather the species that were planted. Green ash and white ash had the highest survival of all species and each had significant increases in height (especially green ash). Green ash is a very adaptable species (Kennedy 1990) that can withstand successive droughty growing seasons that can occur in the Ozark highlands. Krinard et al. (1979) reported that 5-year-old green ash seedlings tolerated vegetation competition better than all other species that were tested, including sycamore, tulip-poplar (*Liriodendron tulipifera* L.), and several oak species. Despite the early success of the ashes, establishing them in bottomland plantings is questionable considering the likely spread of the emerald ash borer (*Agrilus planipennis* Fairmaire) into the Ozark highlands and throughout North America.

All of the oaks in our study had similar survival, ranging between 81 and 92% after 2 years. However, there were differences in height among the oak species in both years, with the white oak group seedlings generally shorter than the red oak group. Notably, swamp white oak height growth was the greatest of all the oaks and fourth greatest among all 13 species after 2 years in this study. In comparison to other oak species, swamp white oak is reportedly both drought tolerant and flood tolerant and does exceptionally well in bottomland plantings in Missouri (Coggeshall 2008, Dey et al. 2004, Kabrick et al. 2007). Pin oak seedlings also grew well and were the tallest of the oak species at the end of the second year (although only nominally taller than northern red and Shumard oak). Although pin oak is of scattered occurrence in the Ozark highlands, its ability to tolerate low pH soils and grow well in full sunlight makes

Table 4. Proportion of all stems by species through all treatments of natural tree regeneration inventoried.

Common name	Scientific name	% of all stems	Species group
Black walnut	*Juglans nigra* L.	4	Hardmast
Shumard oak	*Quercus. shumardii* Buckl.	4	
Shingle oak	*Q. imbricaria* Michx.	2	
Bur oak	*Q. macrocarpa* Michx.	1	
Hickory	*Carya* spp. Nutt.	1	
Willow oak	*Q. phellos* L.	<1	
Bitternut hickory	*C. cordiformis* (Wangenh.) K. Koch	<1	
Pecan	*C. illinoinensis* (Wangenh.) K. Koch	<1	
Ohio buckeye	*Aesculus glabra* Willd.	<1	
Persimmon	*Diospyros virginiana* L.	14	Softmast
Honey-locust	*Gleditsia triacanthos* L.	3	
Redbud	*Cercis canadensis* L.	1	
Hawthorn	*Crataegus* spp. L.	1	
Black cherry	*Prunus serotina* Ehrh.	1	
Sassafras	*Sassafras albidum* (Nutt.) Nees	1	
Eastern red cedar	*Juniperus virginiana* L.	<1	
Red mulberry	*Morus rubra* L.	<1	
American sycamore	*Platanus occidentalis* L.	26	Light-seeded
American elm	*Ulmus americana* L.	23	
Winged elm	*U. alata* Michx.	7	
Green ash	*Fraxinus pennsylvanica* Marsh.	6	
Box elder	*Acer negundo* L.	2	
Maple	*A.* spp. L.	1	
White ash	*F. americana* L.	<1	
Slippery elm	*U. rubra* Muhl.	<1	
Silver maple	*A. saccharinum* L.	<1	
American hornbeam	*Carpinus caroliniana* Walt.	<1	

Table 5. Natural reproduction density and standard error (SE) by treatment for all species combined and by species groups. Lowercase letters indicate significant differences among treatments within a species group (α = 0.05).

Light-seeded	Roundup-only	Poast Plus	Redtop	Clover	VA wild rye
Light-seeded	1,170 ± 353 a	1,279 ± 384 a	179 ± 54 b	235 ± 71 b	214 ± 65 b
Hardmast	32 ± 12 a	178 ± 68 a	91 ± 35 a	93 ± 36 a	69 ± 27 a
Softmast	83 ± 58 a	356 ± 251 a	52 ± 36 a	66 ± 47 a	58 ± 41 a
All species	1,265 ± 363 a	1,791 ± 525 a	291 ± 85 b	362 ± 106 b	362 ± 107 b

it well-suited for many bottomland sites in the Ozarks (McQuilkin 1990, Meinert et al. 1997). Pin oak has also been distinguished as a species that transports well as a seedling and seems to be a plausible option for use in many bottomland hardwood plantings (Dickson et al. 1965, McQuilkin 1990, Moser 1978, Motsinger et al. 2010). Northern red oak, Shumard oak, and bur oak each had similar survival and heights. White oak was the shortest oak after two growing seasons, but height growth increment was similar to the other oak species (with the exception of swamp white oak and pin oak).

Black walnut growth and survival was similar to that of the oaks. Black walnut is reportedly sensitive to site conditions and generally achieves reduced growth or poor form in soils having poor drainage, high gravel content (common in each of the sites included in this study), or in soils that are shallow (Williams 1990). Among the additional species, there were great differences in seedling survival and height growth. Pecan performed very poorly, ending with nearly the lowest survival and growth. This is consistent with findings from other studies evaluating planted pecan seedlings. In a flood tolerance study in Missouri, Kabrick et al. (2007) found pecan to survive but grow poorly on all flood treatments, including a nonflooded control. Stanturf et al. (1998) found that pecan to be the shortest of several species 15 years after planting in an afforestation study located in the lower Mississippi alluvial valley. Pecan may be unsuitable for planting in many Ozark bottomlands, as it has been noted to have poor success in droughty conditions or when plant competition is high (Peterson 1990).

Of the light-seeded or softmast species, hackberry had good survival but gradually died back in height much like pecan. In general, this species has been known to exhibit drought and flood tolerance and is moderately tolerant of shade (Krajicek and Williams 1990). Regardless of hackberry's high survival rate, negative growth occurred during both years, and it is likely that this species will have difficulty becoming part of the future forest. According to Hodges (1997), hackberry occurs as a mid- to late-seral species in better-drained major bottoms of the Mississippi alluvial valley (sugarberry [*Celtis laevigata* Willd] to the south). It is possible that this species does not perform well in early-seral, full sunlight environments and may require a partial canopy and little or no herbaceous competition. Although eastern cottonwood reportedly has early survival rates usually exceeding 70–90% (Cooper 1990), we observed a second-year survival rate of 16%. Survival of cuttings may be lower than that of bareroot seedlings because cuttings have the additional challenge of producing a root system after they are planted. Despite high mortality, the surviving cottonwoods grew an average of nearly 1 m after two growing seasons. Sycamore seedlings also had lower survival than most of the other species examined but it was still above 70% after two growing seasons. Survivors had rapid height growth, particularly during the second growing season when their height increased by more than eight times compared to the first year. This delayed growth response is likely due to initial outplanting shock, which seemed to affect sycamore more than the other species.

Composition and Density of Natural Reproduction

Natural reproduction was more abundant in the herbicide-only treatments compared to the cover-crop treatments. The vast majority of volunteer trees were of early-successional and light-seeded or softmast origin, all of which generally have epigeal seed germination (Allaby 2004, Bazzaz 1979, Burns and Honkala 1990). We expected the disking in the cover crops during the time when many tree species were disseminating seed (e.g., elms, cottonwood, sycamore) would provide a more suitable seedbed for epigeal species. However, we found that was not the case. All treatments were initially sprayed with Roundup during the late fall or early spring to kill cool-season grasses. During site preparation, existing seedlings were not actively growing and were likely not greatly affected by the herbicide. After removing this competition, suppressed seedlings in the herbicide treatments were able to effectively compete for growing space and the seedbank was able to germinate. Conversely, the disking in the cover crops likely smothered existing seedlings with soil and may have buried any epigeal seeds too deep to germinate. Although this study provides only 2 years of information following plantation establishment, these data suggest that supplemental planting of light-seeded species may be necessary to establish a mixed-species restoration, and may provide "nurse trees" for better growth and development of the hardmast species (Allen 1997, Lockhart et al. 2008, Ouchley et al. 2000, Twedt and Portwood 1997).

Conclusions

Vegetation management treatments including cover crops of redtop, white clover, or Virginia wild rye or an application of grass-selective Poast Plus did not significantly increase the survival or growth of planted bareroot tree seedlings or cuttings in old fields compared to the application of only Roundup. However, there were nominal benefits of the cover-crop treatments that appeared to be due to the improved physical properties of the soil caused by the tillage used to establish the cover crops. Cover crops reduced the cover of less desirable weedy species. However, cover crops also reduced the natural regeneration of trees, particularly of light-seeded species, that may be desirable for some restoration efforts. Depending on restoration goals, cover crops may benefit some plantings if there is concern about aggressive competition with hardmast-producing species.

The most important factor governing the successful establishment of bareroot seedlings was the selection of species. Although early survival rates for most species were high (with the exception of cottonwood cuttings), the height growth rates of many of the light-seeded species, including sycamore, cottonwood, green ash, and white ash, far exceeded most of the oaks and other hardmast-producing species.

Although we found the development of some natural reproduction during the first 2 years following treatment establishment, our data suggested that most were light-seeded species and few were hardmast or softmast species. This suggests that light-seeded species may not need to be planted in small Ozark bottomland fields. However, the use of cover crops will reduce the establishment of softmast species.

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