FOLIAR NUTRIENT RESPONSES OF OAK SAPLINGS TO NITROGEN TREATMENTS ON ALKALINE SOILS WITHIN THE MISSOURI RIVER FLOODPLAIN

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Abstract.—Bottomland afforestation is frequently unsuccessful, partly because of low-quality planting stock and low soil fertility following row cropping. In autumn 1999, two 16.2-ha fields at two conservation areas in central Missouri were seeded to redtop grass or allowed to revegetate from the seedbank. In spring 2004, one of five nitrogen (N) treatments was applied to one row of five-row tree plots planted in 2000 with all combinations of bare-root and root production method (RPM) seedlings of swamp white oak and pin oak. In late July 2006, foliar N averaged 1.83 percent after annual application of 83 g of 20N-10P-10K as slow-release ammonium nitrate, 1.82 percent after annual application of 87 g of 19N-6P-9K as slow-release urea, 1.78 percent after planting two N-fixing false wild indigo seedlings adjacent to each oak sapling, 1.79 percent after planting two buttonbush seedlings, and 1.81 percent when left untreated. Foliar N averaged 1.70 percent for swamp white oak from bare-root planting stock, 1.80 percent for swamp white oak from RPM planting stock, and 1.88 percent for pin oak from RPM planting stock. Foliar N averaged 1.74 percent for oaks growing in cover of weeds and 1.81 percent for oaks planted in redtop at one site; no differences were caused by ground cover at the other site (1.83 percent). Compared with estimated sufficiency ranges, foliar phosphorus, potassium, calcium, magnesium, zinc, boron, and copper were adequate for both species. Foliar N, manganese, and iron were deficient for both species with only foliar sulfur deficient for pin oak. A high soil pH likely limited micronutrient availability, especially manganese, and negated any response to applied N. Soil pH will need to be neutralized and quality planting stock planted for bottomland restoration of hard-mast species on moderately alkaline soils within the lower Missouri River floodplains.

INTRODUCTION

Reforestation efforts by public land managers and private landowners within the lower Missouri River and upper Mississippi River region frequently result in failures (Patterson and Adams 2003, Schweitzer and Stanturf 1997, Stanturf et al. 2001). Reasons for the failures included the use of species that are poorly adapted to frequent flooding or wet site conditions, competition from light-seeded hardwoods, altered soil properties, and depletion of soil nutrients following row cropping (Allen et al. 2001, Schweitzer and Stanturf 1997, Stanturf et al. 2004). Soils in these floodplains are frequently alluvial deposits and soil pHs of 7.5-8.0 are common. High soil pHs have the potential to limit the availability of essential macronutrients and micronutrients, especially inorganic nitrogen (N), iron (Fe), manganese (Mn), boron (B), zinc (Zn), and possibly copper (Cu) (Mills and Jones 1996).

Nitrogen is the nutrient that most often limits tree growth in temperate ecosystems. Recommendations for increasing available soil N to tree crops on old-field sites have included applying synthetic fertilizers and incorporating N-fixing plants into the planting (Ponder 1997;

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Van Sambeek et al. 1986, 1989). Johnson (1980) found only two of five oak species had increased growth 8 years after incorporating 112 and 436 kg ha^{-1} of N and phosphorus (P), respectively, at the time of planting. Schlesinger and Williams (1984) reported that planting N-fixing shrubs with black walnut (*Juglans nigra* L.) improves tree growth on all but the best sites. Funk et al. (1979) found that black walnut planted within 1.7-2.4 m of autumn olive (*Eleagnus umbellata* Thunb.) had improved tree growth as early as 4 to 5 years after establishment.

The objectives of our study were to

1. Determine if differences in leaf morphology and nutrient concentrations remain because of site, ground cover, or fertilizer treatments for 7-year-old oak saplings established as bare-root and RPM (root production method, Forrest Keeling Nursery, Elsberry, MO)
2. Evaluate the effectiveness of applying slow-release synthetic N fertilizers or planting N-fixing woody legumes to improve foliar N of planted swamp white oak (*Quercus bicolor* Willd.) and pin oak (*Q. palustris* L.) saplings exhibiting N deficiency symptoms
3. Determine if the uptake of essential macronutrients and micronutrients by established pin or swamp white oak saplings is altered by the N treatments.

Slow-release fertilizer treatments were chosen to provide continuous sources of N that presumably most closely mimic biological sources of N within forest ecosystems.

MATERIALS AND METHODS

Our fertilization study began in spring 2004 on two sites within the Missouri River floodplain planted with pin and swamp white oak. We used RPM planting stock in fall 1999 and bare-root stock in spring 2000. Table 1 summarizes each site's location, flooding history, soil types and characterization, site preparation, and planting histories. Soils at the two study sites were remapped by soil survey staff following soil alterations caused by flooding during the 1990s. Soils at the Plowboy Bend site are currently mapped as Lowmo silt loam (coarse-silty, mixed, superactive, mesic Fluventic Hapludolls); Treloar-Sarpy-Kenmoor soils (sandy over loamy, mixed, superactive, calcareous, mesic Oxyaquic Udifluvents; mixed, mesic Typic Udipsamments; and sandy over clayey, mixed, superactive, calcareous, mesic Oxyaquic Udifluvents, respectively); and Buckney fine sandy loam (sandy, mixed, mesic Typic Hapludolls). Soils at the Smoky Waters site are currently mapped as Blencoe silty clay loam (clayey over loamy, smectitic over mixed, superactive, mesic Aquertic Hapludolls); Haynie silt loam (coarse-silty, mixed, superactive, calcareous, mesic, Mollic Udifluvents); and SansDessein silty clay (fine, smectitic, mesic Fluvaquentic Vertic Endoaquolls). The soils at both sites are characterized by high soil pHs (Plowboy Bend ~7.6; Smoky Waters ~7.9) resulting from alluvial deposits eroded from calcareous soils in the midwestern states. At both sites, two square 16.2-ha areas were tilled in fall 1999 with one field seeded to redtop grass (*Agrostis gigantea* L.) and the other field allowed to revegetate naturally from the seedbank. The latter was initially dominated by dense stands of lambsquarter (*Chenopodium album* L.) and rough pigweed (*Amaranthus retroflexus* L.), followed by Johnson grass (*Sorghum halepense* [L.] Pers.), and, most recently, tall tick trefoil (*Desmodium paniculatum* [L.] DC.).

All four 16.2-ha fields were laid out with forty-four 380-m-long rows spaced 9.1 m apart and oriented parallel with the Missouri River. Excluding four border rows, each field was subdivided into eight replications, each of which contained five rows. Rows within four replications were bedded with a levee plow to create 30- to 40-cm-high soil beds approximately 0.6 m wide at the top and 2.1 m wide at the base. Each replication was divided into 54.8-m-long plots to be

Table 1.—Characterization of the study sites at Plowboy Bend and Smoky Waters Conservation areas

	Plowboy Bend Conservation Area	Smoky Waters Conservation Area	Citation
County and location	Moniteau; Section 24 and 25, T47N, R14W	Cole; Section 1, T44N, R10W	Shaw et al. 2003
Latitude	38°45'5" N	38°35'9"N	Shaw et al. 2003
Longitude	92°24'17"W	91°58'3"W	Shaw et al. 2003
Flooding history (1998 to 2007)	100-year levee protected	Flooded in 2001 and 2002 for up to 3 weeks in June	Dey et al. 2006
Soil type	Lowmo silt loam, Treloar-Sarpy-Kenmoor soils, Buckney fine sandy loam	Blencoe silty clay loam, Haynie silt loam, SansDessein silty clay	Web Soil Survey; Kabrick et al. 2005
Texture classes (0–50 cm)	Sandy loam to silt loam	Silt loam to silty clay	Web Soil Survey; Kabrick et al. 2005
Clay (0–50 cm)	3 to 9%; 6 to 7%	16 to 40%; 21 to 33%	Shaw et al. 2003; Kabrick et al 2005
Soil pH (0–50 cm)	7.2 to 7.7; 7.4 to 7.7	7.7 to 8.0; 7.8 to 8.0	Shaw et al. 2003; Kabrick et al. 2005
Organic carbon	0.3 to 0.4%; 0.5 to 0.8%	0.7 to 1.3%; 1.2 to 1.5%	Shaw et al. 2003; Kabrick et al. 2005
CEC ($cmol_c\ kg^{-1}$)	5.1 to 10.3; 5.4 to 8.4	13.6 to 29.7; 21.2 to 27.3	Shaw et al. 2003; Kabrick et al. 2003
Bulk density ($Mg\ m^{-3}$)	1.4 to 1.5	1.2 to 1.4	Kabrick et al. 2003
Soil sulfur ($\mu g\ g^{-1}$)	140 to 210	Not determined	Plassmeyer 2008
Soil iron ($mg\ g^{-1}$)	6.0 to 9.9	Not determined	Plassmeyer 2008
Soil manganese ($\mu g\ g^{-1}$)	130 to 275	Not determined	Plassmeyer 2008
Soil zinc ($\mu g\ g^{-1}$)	25 to 40	Not determined	Plassmeyer 2008
Site preparation	Cropped, offset disked in August 1999; mounded and seeded in September 1999	Cropped, sprayed August 1999; offset disked, mounded, and seeded in September 1999	Shaw et al. 2003
RPM stock planted	Late November 1999	Late November 1999	Kabrick et al. 2005
Bare-root stock planted	Spring 2000	Spring 2000	Shaw et al. 2003
Install weed barrier and fertilize seedlings	March 2000	March 2000	Kabrick et al. 2005
Average water content ($wt\ wt^{-1}$) (0–30 cm)	Redtop = 11% No redtop = 15%	Redtop = 22% No redtop = 27%	Shaw et al. 2003
Swamp white oak foliar nitrogen in July 2002	Redtop = 1.70% No redtop = 1.68%	Redtop = 2.05% No redtop = 2.11%	Kabrick et al. 2005
Mounded pin oak foliar nitrogen in July 2002	Redtop = 1.62% No redtop = 1.61%	Redtop = 1.99% No redtop = 2.03%	Kabrick et al. 2005

planted with 30 trees on a 9.1 m × 9.1 m spacing. Planting stock consisted of 1-0 bare-root seedlings; 11-L container-grown, 8-month-old RPM saplings; and 19-L container-grown, 22-month-old RPM saplings of both swamp white oak and pin oak. RPM was used to produce large containerized seedlings that have a dense, fibrous root system as a result of air-root pruning (Lovelace 1998, 2002; Walter et al. 2013). A single combination of the two species and the three planting stock types was randomly assigned to the first six plots within each replication. The RPM saplings were planted in late November 1999 and the bare-root seedlings in March 2000. For weed control, a 1.2-m^2 water-permeable mat of black landscape fabric (DeWitt, Sikeston, MO) was placed around each tree. All trees received approximately 30 g of a slow-release 33N-3P-6K fertilizer across the weed barrier mat in March 2000 with no additional fertilizer until spring 2004.

A fertilization study was superimposed on the original study in spring 2004 after most saplings exhibited leaf chlorosis with low foliar N concentrations (1.7 to 1.8 percent) during the second growing season (Kabrick et al. 2005). One of five treatments was randomly assigned to each row within mounded and nonmounded replications. Fertilizer treatments applied to each oak sapling within a row included applying 83 g of 20N-10P-10K as slow-release ammonium nitrate (Osmocote, Scotts-Sierra Horticultural Products Company, Marysville, OH) in the spring each year; applying 87 g of 19N-6P-9K as slow-release urea (T&N, Inc., Foristell, MO) in spring each year; planting two N-fixing false wild indigo (*Amorpha fruticosa* L.) seedlings; planting two buttonbush (*Cephalanthus occidentalis* L.) seedlings; and leaving an unfertilzed control. Fertilizers were broadcast across the weed barrier mat annually in spring 2004, 2005, and 2006. Wild false indigo and buttonbush seedlings were planted 0.6 m on either side of the oak seedlings adjacent to the weed barrier mat within the tree row.

To determine prefertilization foliar N values, an intact leaf was harvested in late July 2003 from both the middle and upper canopies of approximately ten trees within each plot within three bedded and three nonbedded replications from all four plantings. In late July 2006, leaves were again harvested from the middle and upper canopies of up to ten trees within each plot of the four bedded replications in all four plantings. Leaves in both 2003 and 2006 were dried in a forced-air oven at 60 °C for 48 h, weighed, and ground to pass a 1-mm mesh screen. The collected leaves from each plot in 2006 were counted, photographed, and scanned to determine leaf area before oven drying. Leaf samples were analyzed by the Arkansas Diagnostic Laboratory to determine N content in 2003 and 2006 by combustion on a LECO FP428 (AOAC International official method 990.03) and to determine other macronutrients and micronutrients using inductively coupled plasma atomic emission spectrometry of a nitric acid digest. Kabrick et al. (2005) had previously reported that neither the size of RPM planting stock nor the bedding showed treatment differences for oak growth or foliar N in any of the four fields, so leaves from the saplings planted as 11-L and 19-L RPM planting stock within the same replication were combined into one composite sample before chemical analyses.

Foliar leaf area, dry weight, specific leaf mass, and macronutrient and micronutrient concentrations were subjected to analysis of variance for a nested design with four blocks nested within two plantings and two different ground covers with three species-planting stock type combinations and five N treatments as subplots to determine effects of treatment variables and their interactions (Table 2). High mortality of the bare-root pin oak saplings in all four plantings negated current and future analyses of factorial combinations of species and planting stock (RPM or bare-root seedlings).

Table 2.—ANOVA probability of a significant F-value when planting stock types and fertilizer treatments were nested within planting site and ground cover

Variance Source	df	Foliar nitrogen (%)	Leaf area (cm^2)	Specific leaf mass (g cm^{-2})	Nitrogen specific leaf mass (g N cm^{-2})
Planting location (P)	1	0.036	0.109	<0.001	<0.001
Ground cover (C)	1	0.059	0.490	0.205	0.030
Error A = Blocks (P x C)	12	------	-------	-------	-------
Species stock type (S)	2	<0.001	<0.001	<0.001	<0.001
N fertilizer treatment (N)	4	0.296	0.097	0.589	0.499
S x N	8	0.716	0.857	0.833	0.904
P x S	2	0.059	0.354	0.178	0.093
P x T	4	0.996	0.013	0.539	0.589
P x S x T	8	0.780	0.182	0.352	0.735
C x S	2	0.011	0.385	0.016	<0.001
C x N	4	0.312	0.468	0.525	0.440
C x S x N	8	0.294	0.290	0.493	0.738
P x C x S	2	0.477	<0.001	0.326	0.253
P x C x N	4	0.092	0.806	0.006	0.143
P x C x S x N	8	0.583	0.600	0.066	0.096
Error B = Residual error mean squares	169	0.013854	104.576	696.292	518.078

RESULTS AND DISCUSSION

A significant planting × ground cover × species-stock type interaction was observed for nearly all variables analyzed. When this interaction was not found, a significant ground cover × species-stock type was frequently observed. Nearly all variables showed strong main effects between the two planting sites and among the three species-stock type combinations either when included or not found as part of these interactions.

Foliar Nitrogen Concentration

When established as traditional bare-root planting stock, 7-year-old saplings of swamp white oak had a greater average foliar N concentration at Plowboy Bend (1.79 percent) than at Smoky Waters (1.69 percent) (Table 3). After 7 years, redtop continues to dominate the ground cover in the two plantings seeded to redtop except in depressions at Smoky Waters that remained flooded for more than 3 weeks after the 2001 spring flood. No differences in foliar N (1.79 percent) were found for swamp white oak saplings from bare-root planting stock established in a ground cover of redtop or vegetation from the seedbank at Plowboy Bend. In contrast, swamp white oak saplings from bare-root planting stock established in redtop had greater foliar N (1.78 percent) than saplings grown with a succession of forbs from the seedbank (1.61%) at the Smoky Waters site. Dey et al. (2004, 2006) indicated that bare-root planting stock was less likely to be shaded by redtop grass than by a ground cover of mixed seedbank forbs. This may also have contributed to the greater foliar N in the bare-root stock planted into redtop.

Swamp white oak saplings established as RPM planting stock also had greater foliar N at Plowboy Bend (1.84 percent) than at Smoky Waters (1.75 percent). Unlike for saplings from bare-root planting stock, no differences in foliar N were found between RPM saplings growing in redtop or vegetation from the seedbank at either Plowboy Bend or at Smoky Waters.

Table 3.—Mean percent foliar nitrogen (N), leaf area, specific leaf mass (SLM), and N specific leaf mass (NSLM) after applying five N treatments for 3 years to 4-year-old saplings of swamp white oak or pin oak at two conservation areas with a ground cover of either seeded redtop grass or naturally regenerating forbs

Stock type, Species, and Location	Nitrogen treatment	Ground Cover								
		Redtop grass					Mixed forbs from seedbank			
		N	Area	SLM	NSLM		N	Area	SLM	NSLM
		%	cm^2	$mg\ cm^{-2}$	$\mu g\ cm^{-2}$		%	cm^2	$mg\ cm^{-2}$	$\mu g\ cm^{-2}$
SWAMP WHITE OAK FROM BARE-ROOT PLANTING STOCK										
Plowboy Bend	Check	1.82	69.0	11.5	210		1.65	71.4	12.3	204
	NH_4NO_3	1.83	58.6	12.4	227		1.82	61.0	12.0	219
	Urea	1.75	70.6	13.3	232		1.78	72.1	12.3	220
	False indigo	1.67	54.0	11.8	196		1.72	63.1	12.4	214
	Buttonbush	1.83	71.9	12.9	236		1.65	71.2	13.0	214
Smoky Waters	Check	1.69	58.0	11.1	188		1.65	63.1	10.4	171
	NH_4NO_3	1.76	70.9	10.8	191		1.68	67.4	10.0	168
	Urea	1.82	57.1	10.7	195		1.63	50.7	10.5	170
	False indigo	1.82	56.8	11.5	208		1.51	61.8	10.0	151
	Buttonbush	1.80	60.1	11.4	205		1.59	51.8	9.8	155
SWAMP WHITE OAK FROM RPM CONTAINER PLANTING STOCK										
Plowboy Bend	Check	1.88	83.6	11.9	222		1.80	70.7	12.9	232
	NH_4NO_3	1.86	72.3	12.4	230		1.83	70.2	13.1	239
	Urea	1.88	81.6	13.3	251		1.85	68.0	13.2	244
	False indigo	1.82	74.8	12.3	224		1.88	66.6	12.9	244
	Buttonbush	1.81	83.8	12.2	221		1.88	72.1	12.4	232
Smoky Waters	Check	1.81	77.4	10.7	193		1.74	75.1	11.6	201
	NH_4NO_3	1.74	58.6	11.8	204		1.77	88.1	11.1	196
	Urea	1.80	57.4	11.0	198		1.75	73.9	11.5	202
	False indigo	1.77	58.3	11.1	197		1.77	76.2	11.6	204
	Buttonbush	1.76	55.0	11.1	195		1.70	83.1	11.2	191
PIN OAK FROM RPM CONTAINER PLANTING STOCK										
Plowboy Bend	Check	1.90	17.6	10.2	192		1.97	16.1	10.2	201
	NH_4NO_3	1.89	19.0	10.2	193		1.85	18.2	10.6	196
	Urea	1.91	20.0	10.3	197		1.90	24.3	9.9	190
	False indigo	1.85	17.4	10.7	197		1.97	14.9	9.5	180
	Buttonbush	1.86	18.5	9.9	184		1.84	18.5	10.1	187
Smoky Waters	Check	1.83	15.0	9.7	178		1.93	18.5	7.5	145
	NH_4NO_3	2.00	8.0	10.5	210		1.97	17.0	7.4	145
	Urea	1.89	20.8	7.7	147		1.81	13.5	9.7	175
	False indigo	1.81	16.4	9.0	164		1.81	15.6	9.1	164
	Buttonbush	2.00	17.9	10.8	216		1.74	19.6	8.1	140
	Average 5% LSD =	0.17	14.3	1.4	32		0.17	14.3	1.4	32

Unlike with swamp white oak saplings, no differences were found for pin oak saplings established as RPM planting stock in average foliar N (1.89 percent) at the Smoky Waters and Plowboy Bend sites. Likewise no differences in foliar N were found for pin oaks of either planting stock type when established in redtop or successional vegetation from the seedbank. Van Sambeek and Garrett (2004) found that most grasses reduce hardwood growth and presumably foliar N concentrations more than a cover of broad-leafed forages or weeds. Our results confirm previous reports that redtop may not be as competitive as most other grasses and can be recommended over most grasses as a living mulch in tree plantings.

Color photographs of the leaves collected from representative plots of each treatment show wide ranges in leaf area, color, and amount of chlorosis (Fig. 1). Compared to foliar N concentration for oak saplings in the nontreated control rows (1.83 percent), annual application of 16.6 g of N for 3 years to each tree as slow-release ammonium nitrate or urea N failed to increase foliar

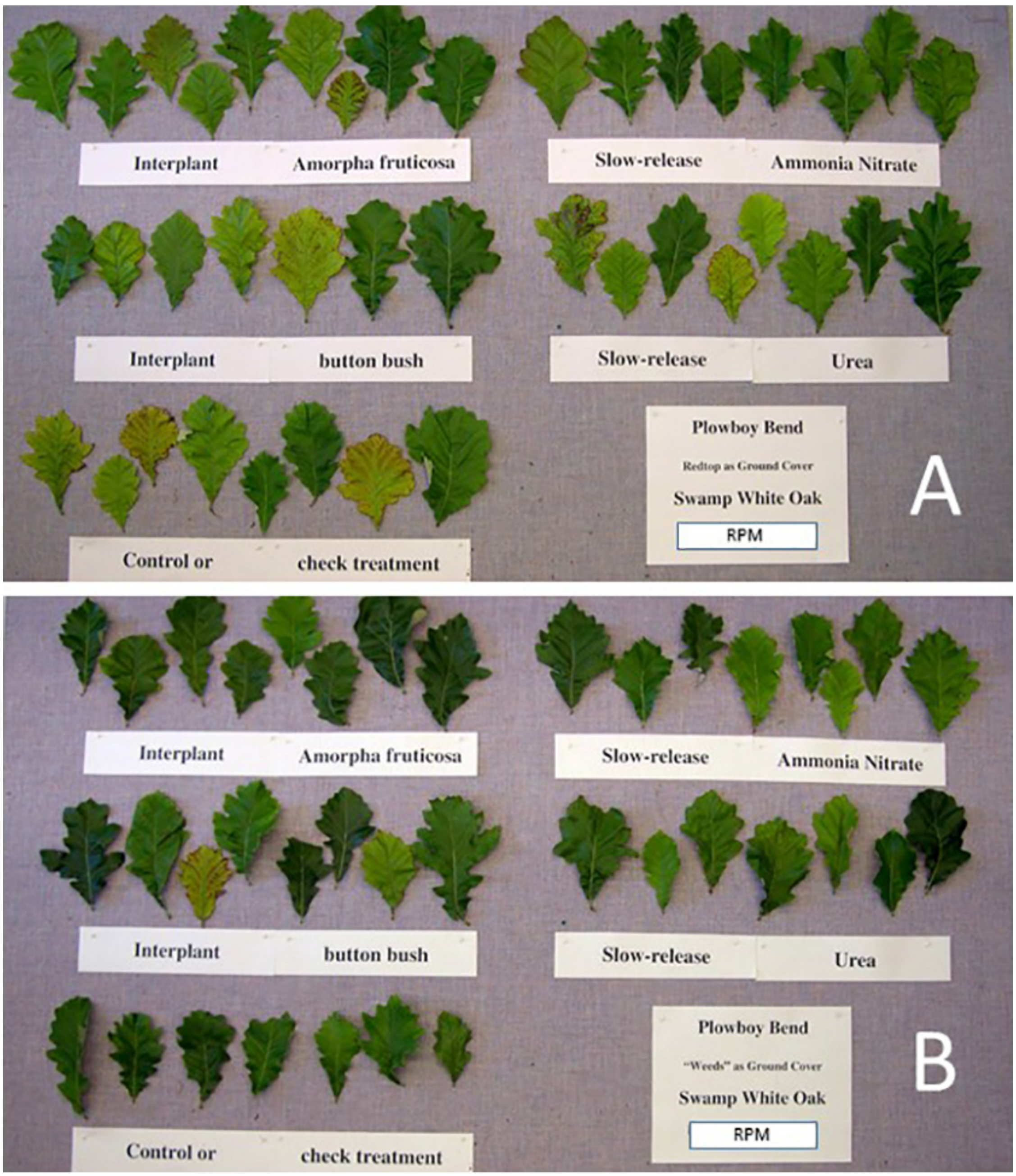

Figure 1.—Variation in leaf area and color of swamp white oak saplings from RPM planting stock growing at Plowboy Bend in (A) redtop grass or (B) seedbank vegetation 3 years after initiating five nitrogen fertilization treatments. Additional photos are available from the authors. Photographs by Jerry Van Sambeek, U.S. Forest Service.

N (1.82 percent). Our fertilization rates of 50 g N per sapling may have been too low. Johnson (1980) found only two of five oak species had increased growth 8 years after incorporating 112 kg ha^{-1} of N at the time of planting. Himelick et al. (1965) reported increased stem diameter growth of 7-year-old pin oak by applying 272 g of N as either ammonium nitrate or urea grown on nearly neutral silt loam soils.

Three years after planting two N-fixing false indigo seedlings adjacent to each oak sapling, foliar N in the oak saplings was no different than when two buttonbushes had been planted adjacent to the oak saplings (1.80 percent and 1.79 percent, respectively). There is good evidence that false indigo should have added N to the ecosystem. Navarrete et al. (2003) found that false wild indigo seedlings are readily nodulated by rhizobial bacteria in greenhouse studies. Plassmeyer (2008) and Van Sambeek et al. (2008) reported that foliar N for false wild indigo leaves averaged more than 3 percent in July. The high summer foliar N is a strong indication that false wild indigo had been nodulated by native rhizobia that can fix atmospheric N. Plassmeyer (2008) also found that foliar N of false wild indigo remained high through abscission (more than 2.5 percent), producing N-rich leaf litter.

Changes in the ground cover also suggest N in the soil is not readily available to any non-N-fixing plants. Mortality of the buttonbush has been high, but many of the false wild indigo have survived and are growing well (personal observation). In addition, *Desmodium* species now dominate the ground cover. Houx et al. (2009) found these native legumes are readily nodulated by rhizobial bacteria. The soils have not been tested to see if there are any changes in total and available soil N. We suspect the high soil pH may directly or indirectly suppress uptake of available soil N. Nannipieri et al. (1982) reported that soil ureases involved in the process for conversion of plant-bound N to available nitrate N can be strongly inhibited by high soil pH.

Leaf Area and Specific Leaf Mass

Increased allocation of N to leaves can result in changes to leaf morphology without changing percent foliar N (Takashima et al. 2004). As with foliar N, neither area nor dry weight per leaf increased in response to any of the treatments (Table 3). Leaf area showed a planting × ground cover × species-stock interaction primarily because swamp white oak from RPM planting stock at Plowboy Bend had a greater leaf area when grown in redtop (79 cm^2) than in seedbank vegetation (70 cm^2). In contrast, swamp white oak from RPM stock at Smoky Waters had a greater leaf area when grown in seedbank vegetation (79 cm^2) than when grown in redtop (62 cm^2). Pin oak averaged 19 cm^2 at Plowboy Bend and 16 cm^2 at Smoky Waters with no differences caused by ground cover.

Increased allocation of N into leaves could also result in changes in leaf thickness or specific leaf mass, with thicker leaves having higher photosynthetic rates. Although a planting × ground cover × species-stock interaction was not found (Table 2), specific leaf mass was greater at Plowboy Bend (11.7 mg cm^{-2}) than at Smoky Waters (10.4 mg cm^{-2}). At Plowboy Bend, specific leaf mass for N averaged 12.4 mg cm^{-2} for swamp white oak from bare-root planting stock and averaged 12.7 and 10.1 mg cm^{-2} for swamp white oak and pin oak from RPM planting stock, respectively; no differences were caused by ground cover. In contrast, at Smoky Waters, specific leaf mass of swamp white oak from bare-root stock averaged 10.1 and 11.1 mg cm^{-2} in seedbank vegetation and redtop, respectively, with no differences found between ground covers for swamp white oak from RPM planting stock. At Smoky Waters, specific leaf mass for pin oak was substantially lower when grown in seedbank vegetation (8.4 mg cm^{-2}) and when grown in redtop (9.5 mg cm^{-2}).

Nitrogen-Specific Leaf Mass

Sage and Pearcy (1987) found that maximum photosynthetic rates for C_3 plants are linearly correlated with leaf N concentrations. The leaf N concentrations average 0.15 to 0.2 μmol CO_2 m^{-2} s^{-1} for each μg N cm^{-2} increase, depending on leaf temperature (maximum photosynthetic rates range from 40 to 50 μmol CO_2 m^{-2} s^{-1} in full sun). Although a planting × ground cover × species-stock interaction was not found, specific leaf mass for N was greater at Plowboy Bend (215 μg cm^{-2}) than at Smoky Waters (184 μg cm^{-2}). At Plowboy Bend, specific leaf mass for N averaged 218 μg cm^{-2} for swamp white oak from bare-root planting stock and averaged 234 and 191 μg cm^{-2} for swamp white oak and pin oak from RPM planting stock, respectively, with no differences caused by ground cover (Table 3). In contrast, at Smoky Waters, specific leaf mass for N averaged 154 and 183 μg cm^{-2} for pin oak in seedbank vegetation and redtop, respectively. Specific leaf mass for N of swamp white oak from RPM planting stock averaged 198 μg cm^{-2} in both ground covers; specific leaf mass for N of swamp white oak from bare-root stock averaged 162 and 197 μg cm^{-2} in seedbank vegetation and redtop, respectively. This suggests that using large swamp white oak planting stock continued to show benefits for more than 7 years after planting.

Macronutrient and Micronutrient Concentrations

Foliar macronutrient and micronutrient concentrations before (summer 2003) and 3 years after the fertilization study began (summer 2006) were for the most part unchanged by the fertilizer treatments for swamp white oak or pin oak (Table 4). Although no differences were found between oak species in foliar potassium (K) and sulfur (S), swamp white oak foliar nutrients were greater in P, calcium (Ca), magnesium (Mg), Fe, Cu, and B than were pin oak foliar nutrients. In contrast, pin oak foliar nutrients were greater in Zn and Mn than for swamp white oak. In general, foliar nutrients for the oaks tended to be greater at Smoky Waters than Plowboy Bend except for N and Fe. Kabrick et al. (2005) reported that the cation exchange capacity and concentrations of K, Ca, and Mg in the soils at Smoky Waters are two to three times greater than at Plowboy Bend. The greater foliar Fe of the oaks at Plowboy Bend than at Smoky Waters is likely a consequence of the higher soil pH at Smoky Waters that are limiting Fe availability in the soil.

Examining the literature for acceptable foliar nutrient concentrations for pin and swamp white oak yielded few publications reporting sufficiency ranges at which healthy trees appear normal and capable of acceptable growth. When ranges for foliar nutrients are found, they can vary considerably both within species and section depending on collection time and growing environment. Sufficiency ranges for broad-leaved plants are also not very useful because oak foliar nutrients tend to deviate from the expected ratios of 1 N:1 K, 4 K:1 Ca, and 2 Ca:1 Mg for plants in general (Mills and Jones 1996).

Table 4 shows estimated sufficiency ranges for the red and black oak group (Section *Lobatae*) and the white oak group (Section *Quercus*) based on average values for reported minimum and maximum values of the different oak species (compiled primarily from Blinn and Bucker 1989, Gerloff et al. 1964, Kennedy 1993, Kennedy et al. 1986, Mills and Jones 1996, Mitchell 1936, Ponder 1993, Scherzer et al. 2003). These sufficiency values suggest the foliar nutrients of swamp white oak are deficient in N, Mn, and Fe, and the foliar nutrients of pin oak are deficient in N, S, Mn, and Fe. Mills and Jones (1996) indicate fertilization to correct for N deficiencies is unlikely to be successful if an element other than N is limiting plant growth. Soil pHs >7.5 limited availability of Mn and Fe in the soil and may in turn limit the ability of the trees to take up the applied ammonium nitrate, applied urea, or any fixed N added to the soil by the false wild indigo.

Table 4.—Foliar macronutrient and micronutrient concentrations with standard deviations for swamp white oak and pin oak saplings before (July 2003) and 3 years after (July 2006) initiating a fertilizer study along with estimated sufficiency ranges for oak species within the *Quercus* and *Lobatae* Sections

	Swamp white oak (*Quercus*)			Pin oak (*Lobatae*)		
	July 2003 foliage	July 2006 foliage	Section sufficiency ranges[a]	July 2003 foliage	July 2006 foliage	Section sufficiency ranges[a]
LEAF PROPERTIES:						
Foliage samples (#)	85 - 86	175 - 182	------	70 - 73	63 - 77	-----
Leaf dry mass (mg)	-----	802 ± 214	------	------	168 ± 45	-----
Leaf area (cm^2)	-----	68.6 ± 14.9	------	------	17.6 ± 4.3	-----
MACRONUTRIENTS:						
Nitrogen (mg/kg)	17.15 ± 1.53	17.67 ± 1.32	19.1 - 22.7	18.57 ± 1.51	18.83 ± 1.43	19.6 – 21.8
Phosphorus (mg/kg)	1.53 ± 0.19	1.60 ± 0.16	1.4 - 1.7	1.38 ± 0.16	1.52 ± 0.17	1.4 – 2.0
Potassium (mg/kg)	9.72 ± 1.32	8.64 ± 0.85	8.3 - 9.7	9.81 ± 1.16	8.78 ± 1.16	8.0 – 10.2
Calcium (mg/kg)	15.90 ± 4.64	21.28 ± 4.35	9.0 – 11.2	8.40 ± 1.20	11.25 ± 2.35	8.1 – 10.3
Magnesium (mg/kg)	3.10 ± 0.60	3.28 ± 0.66	1.7 - 2.3	2.13 ± 0.29	2.14 ± 0.31	2.0 - 2.6
Sulfur (mg/kg)	1.17 ± 0.09	1.27 ± 0.09	1.2 - 1.5	1.14 ± 0.12	1.23 ± 0.11	1.4 - 1.6
MICRONUTRIENTS:						
Manganese (µg/kg)	26.8 ± 14.7	35.1 ±12.9	320 - 900	69.2 ± 44.0	62.4 ± 24.0	600 - 1000
Iron (µg/kg)	45.4 ± 21.0	28.1 ± 9.9	75 – 100	45.2 ± 27.8	20.4 ± 6.7	70 – 110
Zinc (µg/kg)	23.2 ± 4.2	25.8 ± 8.9	15 - 25	43.0 ± 8.6	48.2 ± 12.4	30 - 45
Boron (µg/kg)	31.3 ± 7.9	47.8 ± 10.1	40 - 60	27.5 ± 7.1	32.9 ± 8.9	25 - 50
Copper (µg/kg)	10.5 ± 1.2	6.1 ± 1.2	5 - 8	9.3 ± 1.1	5.1 ± 1.2	6 – 10

[a] Sufficiency ranges are average values of the minimum and maximum values of the ranges reported in the literature for summer foliage of nine oak species within the *Quercus* section and 12 species within the *Lobatae* section. Values were compiled primarily from Blinn and Bucker (1989), Gerloff et al. (1964), Kennedy (1993), Kennedy et al. (1986), Mills and Jones (1996), Mitchell (1936), Ponder (1993), and Scherzer et al. (2003).

Ponder et al. (2008) found that the addition of ferrous sulfate with N fertilizers decreased soil pH slightly and increased foliar N and Mn concentrations of planted pin and swamp white oak saplings. The greater nutrient contents for the oaks established as RPM seedlings may in part be due to residual carryover of the available Mn and Fe in the potting medium.

CONCLUSIONS

Three years after initiating a fertilizer study to correct for deficiencies in foliar N of pin and swamp white oak, the trees had not yet responded with an increase in foliar N, leaf area, or leaf thickness. Van Sambeek et al. (1986) found forage legumes increased soil N within 1 to 3 years correlated with increased tree growth after three growing season. Oak saplings were found to also be deficient in foliar Mn and Fe. Soil pHs >7.5 limit the availability of these micronutrients in the soil and may be limiting the ability of the oak saplings to take up the applied ammonium nitrate, applied urea, or N fixed by false wild indigo or the invading *Desmodium* ground cover. The greater nutrient contents for the oaks established as RPM seedlings may in part be due to residual carryover of the available Mn and Fe in the potting medium.

The usual approach to neutralizing alkaline soils is application of elemental S or aluminum sulfate ions; however, this is not economically practical for large-scale use on the floodplains along the lower Missouri River. Application of N as ammonium sulfate or S-coated urea may gradually acidify the soil and correct the problem. A more practical approach may be the foliar application of N fertilizers supplemented with micronutrients (Lovatt 1999).

A more feasible approach to reforesting the Missouri River bottomlands (other than trying to ameliorate the soil condition) would be to choose hardwood species better adapted to alkaline soil such as bur oak (*Q. macrocarpa* Michx.), Shumard oak (*Q. shumardii* Buckl.), or the relatively slow growing chinkapin oak (*Q. muehlenbergii* Engelman) on higher elevations. Pin and swamp white oak were selected for this study because of their importance as a source of acorns for migratory waterfowl. Suggested pH ranges are 5.0 to 6.5 for pin and up to 7.0 for swamp white oak, although the published ranges for swamp white oak may need to be re-evaluated based on the acceptable growth of this species on the alkaline soils at one of the floodplain sites. Future plantings should evaluate other oaks found in the lower Mississippi and Missouri River floodplains such as northern selections of *Q. lyrata* Walt. (overcup), *Q. pogoda* Rufinesque-Schmaltz (cherrybark), and *Q. nuttallii* Palmer (nuttall) for survival, growth, and precocity in reforestation projects, especially when established using high-quality RPM planting stock. Successful reforestation projects will likely require a better mix of flood-tolerant oak species, higher-quality planting stock than bare-root, nursery-grown seedlings, and possibly foliar application of N fertilizers supplemented with micronutrients on these moderately alkaline soils within the lower Missouri River floodplains.

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