SEASONAL VARIATION IN NUTRIENT AVAILABILITY AND UPTAKE BY OAK SAPLINGS FOLLOWING FOUR NITROGEN TREATMENTS ON A MISSOURI RIVER FLOODPLAIN

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Master of Science

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by

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

SEASONAL VARIATION IN NUTRIENT AVAILABILITY AND UPTAKE BY OAK SAPLINGS FOLLOWING FOUR NITROGEN TREATMENTS ON A MISSOURI RIVER FLOODPLAIN

Presented by C. J. Plassmeyer

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

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CHAPTER I

INTRODUCTION

Restoring bottomland hardwood ecosystems is of great interest throughout the central and southern U.S.A., particularly along the lower Missouri River (Dey et al., 2003; Shaw et al., 2003) and within the Mississippi Alluvial Valley (Stanturf et al., 2000; 2001). In these midwestern floodplains, bottomland oak (*Quercus*) species including pin oak (*Quercus palustris* Muenchh.), bur oak (*Quercus macrocarpa* Michx.), swamp white oak (*Quercus bicolor* Willd.), and other nut (hard mast) species were historically members of diverse bottomland forests containing cottonwood (*Populus deltoides* Marsh.), silver maple (*Acer saccharinum* L.), hackberry (*Celtis occidentalis* L.), sycamore (*Platanus occidentalis* L.), and black willow (*Salix nigra* Marsh). In Missouri, oaks were common enough to be recorded on about one-third of the survey transects of the Missouri River Floodplain in the early 1800’s (Bragg and Tatschl, 1977).

Bottomland hardwoods can be described as an assemblage of tree-dominated vegetative communities which occur on soils that are saturated or inundated with water either seasonally or temporarily (Larson et al., 1982). Bottomland oaks have always been among the most highly treasured tree species along the major rivers in central U.S.A. (Gardiner and Lockhart, 2007). Previous evidence suggests that acorns of bottomland oak were a valuable part of the diet consumed by Native Americans living in the region (Gibson, 2001), and the superior wood quality of bottomland oaks led pioneering lumberman into the region (Winters et al., 1938). Oak and other hard mast species were predominately found on higher elevations that flooded less frequently and had better drainage within the bottomlands (Shaw et al., 2003).

As early as 5000 years before present, Native Americans began settling parts of the Lower Mississippi Alluvial Valley (Connaway, 1977; Smith, 1986). It is believed that some of the earliest human impacts, like clearing to make room for villages, began with some of the first Native American populations. By the 1800's, deforestation of the bottomland hardwoods was more significant as European settlers were attracted to the productive soils of this region (Cobb, 1992). The 20th century brought even more extensive deforestation to the Lower Mississippi Alluvial Valley and Lower Missouri River floodplain as the levees were constructed and in the later half of the century, the soybean commanded a premium price at the markets (Sternitzke, 1976). In the Lower Mississippi Alluvial Valley more than 75 percent of the afforested bottomland is privately owned (Gardiner and Oliver, 2005). Today, only 26 percent of the original forested area remains in the Lower Mississippi Alluvial Valley, and most of the remaining forested area consists of small isolated patches (Gardiner and Oliver, 2005).

As grain surpluses began flooding the markets in the 1980's, government programs including the Conservation Reserve Program (CRP) and the Wetland Reserve Program (WRP) were established by the U.S. Department of Agriculture under the 1985 and 1990 Congressional Farm Bills. These programs were established to take highly erosive and wetland soils out of crop production. In addition, extreme floods occurred in 1993 and 1995 throughout the central U.S.A., damaging levees and destroying some bottomlands, damaging bottomland forests, and making other areas unfit for crop production. Flood waters created all sizes of scour holes on some bottomlands, while at the same time depositing deep layers of sand and other sediments on other areas. In Missouri, state and federal agencies including the Missouri Department of Conservation, U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, and other agencies have acquired thousands of hectares of damaged bottomlands that were rendered unsuitable for crop production (Kabrick et al., 2005).

These government agencies are now seeking methods for restoring a variety of native floodplain habitats, including bottomland hardwood forests in abandoned old field sites (Kabrick et al., 2005). Furthermore, private landowners along the lower Missouri and Mississippi Rivers are participating in the Conservation Reserve Program or Wetland Reserve Program to aid in afforestation of their flood-damaged bottomlands.

Importance of Bottomland Hardwood Forests

Bottomland hardwood forests serve a critical role in the watershed, reducing the risk and severity of flooding to downstream communities by providing areas to store floodwaters. In addition, these wetlands improve water quality by filtering and flushing nutrients, processing organic wastes, and reducing sediments before reaching open water (Novitzki et al., 2001). The

Missouri and Mississippi Rivers also serve as major corridors for migrating birds (Sparks, 1995), as well as habitat for many year-round resident wildlife species. Floodplain forests provide a diversity of habitat for many forest dwelling bird species, mammals, amphibians and reptiles (Dwyer et al., 1997; Sparks 1995; Yin et al., 1997). Numerous wildlife species require hard mast for a food source; waterfowl using floodplain forests for wintering areas depend on hardwood mast for the bulk of their diets (Hirsch and Segelquist, 1978). Acorns are relatively high in fat and carbohydrates and are good sources of protein, vitamins, Ca and P which make them a major food source for many species of wildlife including white-tailed deer, gray squirrel, fox squirrel, turkey and bobwhite quail (Goodrum et al., 1971).

Landowners and managers are interested in reforesting these former agricultural bottomlands to improve wildlife habitat, while conserving native bottomland tree species (Dey et al., 2006). Furthermore, while providing a mast crop for wildlife, these oak species will eventually add value to the land, both from a lumber standpoint as well as attracting hunters who hunt the animals that depend on hard mast species.

Evaluation of Recent Techniques in Afforestation of Bottomland Oaks

The use of cover crops, soil bedding, and large container-grown planting stock are techniques used in the afforestation of oaks in the Lower Missouri River floodplain (Shaw et al., 2003). Cover crops can be planted to suppress intense weed competition (Alley et al., 1999), which increases both seedling survival and growth. In 1999, redtop grass (*Agrostis gigantea* Roth) was planted at two conservation areas along the Lower Missouri River as a cover crop to suppress growth of floodplain forbs in competition with the oak saplings. While this cover crop might be invaluable at suppressing weedy forbs, Shaw et al. (2003) found it is also important in controlling seedling damage by rodents. The redtop grass reduced the escape cover available to rodents near the saplings making them more vulnerable to predation (Shaw et al., 2003). The composition and structure of winter cover provided by forbs without redtop grass promoted higher cottontail rabbit (*Sylvilagus floridanus*) densities (7.4 rabbits per ha) than in the redtop grass fields (2.5 rabbits per ha) (Dugger et al., 2003). In the winter, the dead stems of forbs and clumps of johnsongrass (*Sorghum halepense*) remained somewhat erect providing cover that was 1.0 m tall and allowed rabbits to move freely across the natural vegetation fields causing damage to nearly all of the saplings. However, redtop grass matted down to 0.20 m and provided rabbits little hiding cover from predators resulting in less animal damage among the oak saplings at Plowboy Bend and Smoky Waters with a redtop cover crop (Dey et al., 2003). Plowboy Bend and Smoky Waters Conservation Areas are Missouri Department of Conservation owned and managed bottomlands along the Missouri River in central Missouri.

Soil bedding (or mounding) is commonly used as a site preparation method for establishing tree seedlings in poorly drained soils (Derr and Mann, 1977; Londo and Mroz, 2001). Kabrick et al. (2005) found soil bedding reduced bulk density by 7 to 16 percent, reduced gravimetric soil water content by 2 to 5 percent, and increased soil temperature by 1 to 2 ^{o}C in the Missouri River floodplain. However, despite these favorable soil responses, Kabrick et al. (2005) found bedding did not appear to benefit establishment and early growth of planted pin and swamp white oak saplings in the well-drained, sandy soils commonly encountered in the Missouri River floodplain.

Another technique used in afforesting bottomlands has been the use of large containerized seedlings (Lovelace, 1998; Dey et al., 2004). The Root Production Method was developed by Forrest Keeling Nursery (Elsberry, MO) to produce high quality hardwood planting stock marketed as RPM^{TM} seedlings that have large caliper and height, and a substantial fibrous root system (Lovelace, 1998; Dey et al., 2004). Dey et al. (2004) found that the combination of cover crops and RPM^{TM} seedlings have many advantages when afforesting bottomlands along the Lower Missouri River, including, significantly greater survival and basal diameter growth than bareroot seedlings after three years in the Lower Missouri River floodplain. Furthermore, the one- to two-year-old RPM^{TM} seedlings of swamp white oak produced acorns in the first year after planting, while pin oak started producing in year four after planting (Dey et al., 2004).

Although hardwoods especially oaks are highly desired for restoring bottomland hardwoods, major problems exist in their establishment including use of species poorly adapted to frequent flooding, depletion of soil nutrients following row cropping, competition from other light-seeded hardwoods and weedy forbs, lack of natural seed sources, animal damage, and a high soil pH

(Schweitzer and Stanturf, 1998; Allen et al., 2001; Stanturf et al., 2004). Alkaline soils with a pH ranging from 7.5 to 8.5 are common in these bottomland floodplains due to the frequent alluvial deposits from the upstream limestone hillsides and bluffs. High soil pH has the potential to limit the availability of essential macro- and micro-nutrients, especially iron (Fe), manganese (Mn), boron (B), zinc (Zn), and possibly copper (Cu) and inorganic nitrogen (Mills and Jones, 2003).

Increasing Nitrogen Availability

On old agricultural field sites, available soil nitrogen (N) tends to be the nutrient most often limiting hardwood tree growth (Van Sambeek and Garrett, 2004). Recommendations for increasing available soil N to tree crops have included application of synthetic fertilizers and incorporating N-fixing plants into the planting (Ponder, 1997; Van Sambeek et al., 1986; Van Sambeek et al., 1989). Johnson (1980) found responses to applied fertilizers can be variable as only two of five oak species responded to incorporated N (112 kg/ha) within eight years of application. However, Graney and Pope (1976) found that diameter growth of poletimber-size red oak (*Quercus rubra* L.) in Arkansas was 45 and 69 percent greater than the controls after application of 90 and 180 kg/ha N.

With synthetic N fertilizer costs being at all time highs, N-fixing plants can be an option when N is limiting. Also, N-fixing plants are a continuous source of N (Auchmoody, 1996) whereas most N fertilizers are temporary and gradually decline after the first season. Nitrogen-fixing plants are key constituents in many natural ecosystems throughout the world and provide the major source of N that enters the N cycle in these ecosystems (Nitrogen Fixing Tree Association, 1989).

In N limited sites, as N-fixing plant root growth begins, special bacteria (Rhizobia, Frankia) in soil invade root hairs and multiply. These bacteria have the unique ability to fix atmospheric N_2 (Havlin et al., 2005). The roots respond by forming tumor-like structures or nodules on the root surface. The specialized bacteria inside the nodule absorb N_2 from soil air and convert it to ammonium after enzymes break the strong triple bond in N_2. Most of the fixed N_2 is utilized by the host plant, but some may be excreted from the nodule into the soil and used by other nearby plants (Havlin et al., 2005).

Nitrogen-fixing plants can be actinorhizal or leguminous species. Around 220 actinorhizal plant species are known (Bond, 1967; Sprent and Parsons, 2000), with some having fixative capabilities ranging from 50 to 100 kilograms per hectare per year (Steward, 1966). Interplanting N-fixing shrubs with black walnut (*Juglans nigra* L.) on all but the best sites has been shown to improve tree growth (Schlesinger and Williams, 1984). Black walnut saplings showed improved growth as early as four to five years after planting autumn olive (*Eleagnus umbellata* Thunb.) 1.7 to 2.4 m from the tree stem (Funk et al., 1979). In addition, Johnson (1995) reported saplings may benefit from N-fixing shrubs because of increased soil fertility and faster soil formation. Little is known as to whether oak saplings benefit from interplanting N-fixing shrubs.

Objectives

The null hypothesis is that the N treatments will have no significant effect on raising foliar nutrients in pin oak and swamp white oak saplings during the growing season. Also a significant difference in soil nutrients will not exist between the 0-10 and 10-20 cm sampling depths.

Objective 1. To evaluate changes in foliar nutrient concentrations during the growing season in response to N treatments. The leaves of both swamp white oak and pin oak planted in 1999 exhibited severe chlorosis, indicating nutrient deficiencies, by the growing season in 2001. By sampling leaves during the growing season (June through October) it will be determined if the treatments are having an effect on N and other foliar nutrients.

Objective 2. To evaluate changes in soil pH and soil nutrient concentrations under pin oak and swamp white oak during the growing season in response to N treatments.

Objective 3. To determine if there were changes in soil pH and soil nutrient concentration at two different sampling depths during the growing season (0 to 10 cm and 10 to 20 cm).

Objective 4. To determine if foliar N content differed significantly between false indigo (*Amorpha fruticosa*) leaves and oak during the growing season.

CHAPTER 2

STUDY SITE, MATERIALS, AND METHODS

The study site is located at Plowboy Bend Conservation Area near Jamestown, Missouri (Figure 1). The site is on a Missouri River floodplain and protected by a 100-year levee. The study site is part of a larger regional study to evaluate the feasibility to establish hard mast-producing trees on a range of bottomland sites designed to include a range of soil types, oak species, RPM^{TM} versus bare root stock, with and without mounding, and with and without cover crops. At the urging of land managers, pin oak, and swamp white oak are included at most sites to determine their suitability and benefits of the various cultural treatments.

At Plowboy Bend, three plots each 16.2 ha in size were tilled in the fall of 1999 with one field seeded to redtop grass (*Agrostis gigantea* L.), one field allowed to revegetate with a natural succession of floodplain forbs that were initially dominated by dense stands of lambsquarter (*Chenopodium album* L.) and johnsongrass (*Sorghum halepense* (L.) Pers.), and another field served as a control to follow natural regeneration by light-seeded tree species. A composite soil sample was collected at Plowboy Bend and sent to the soil testing laboratory at the University of Missouri. Soil chemical properties of the study site are displayed in Table 1.

Table 1. Composite sample from the control treatment showing chemical properties of the soil from Plowboy Bend Conservation Area near Jamestown, MO.

pH	N.A.* meq/100g	O.M.** %	Bray I P kg/ha	Ca kg/ha	Mg kg/ha	K kg/ha	CEC*** $\mathrm{cmol_c/100kg}$
8.3	0.0	0.7	14	585	57	49	9.6

*Neutralizable acidity

**Organic matter

***Cation exchange capacity

Plowboy Bend Conservation Area

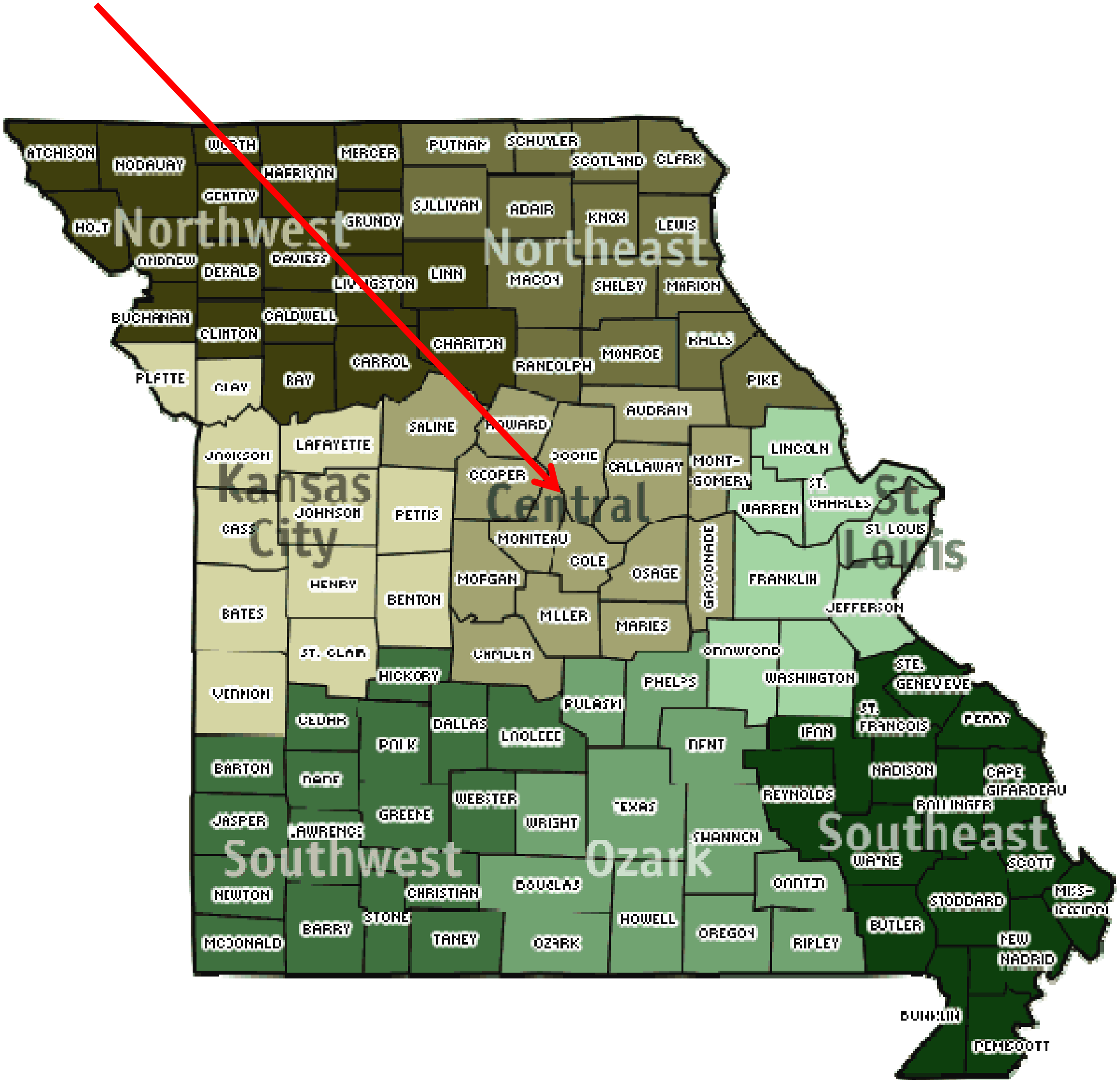

Figure 1. Map of Missouri showing location of Plowboy Bend Conservation Area.

The 16.2 ha control field was abandoned after tillage. The other two 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 plots that each contained five rows. Rows within four plots 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. Kabrick et al. (2005) found bedding had minor effects on soil properties (pH, texture, bulk density, organic carbon, temperature, water content) or plant growth.

Each plot was divided into seven 54.8-m-long sub-plots to be planted with 30 trees of the same species and planting stock type on a 9.1 m x 9.1 m spacing. Planting stock consisted of 1-0 bare-root seedlings; 11-L container-grown, 1.5-year-old RPM saplings; and 19-L container-grown, 2-year-old RPM^{TM} saplings of both swamp white oak and pin oak. A single combination of the two species and the three planting stock type was randomly assigned to the first six sub-plots within each plot. The RPM^{TM} saplings were planted in late November 1999 and the bare-root seedlings in March 2000. For weed control, a 1.2 square 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 33-3-6 (33% N as urea, 3% P as P_2O_5, 6% K as K_2O) fertilizer in March 2000 with no additional fertilizer until spring 2004. The pin oak and swamp white oak saplings exhibited chlorosis by the 2001 growing season with foliage N concentrations of 1.7 to 1.8 percent respectively (Kabrick et al., 2005).

Soil Fertilization, Sampling, and Preparation (2007)

Soil fertilization and sampling took place at Plowboy Bend Conservation Area in the mounded rows of the redtop field only. In May 2007, five pin oak and five swamp white oak were randomly selected within the mounded rows which had previously been assigned to one of five fertilizer treatments in spring 2004. In the 2004 to 2006 study, rows were randomly assigned to one of five different fertilizer treatments. The five treatments included an application of 83 g 20-10-10 (20% N as slow-release ammonium nitrate, 10% P as P_2O_5, 10% K as K_2O) as slow-release ammonium nitrate (Osmocote, Scotts-Sierra Horticultural Products Company, Marysville, OH), 87 g 19-6-9 (19% N as slow-release urea, 6% P as P_2O_5, 9% K as K_2O) as slow-release urea (T&N, Inc., Foristell, MO), N-fixing false indigo, buttonbush (*Cephalanthus occidentalis* L.), and control. In the period from 2004 to 2006, annual spring applications of two synthetic N fertilizers were applied across the weed barrier mat. The N-fixing false indigo and buttonbush were planted in March of 2004 within the tree row on either side of the oak adjacent to the weed barrier mat. In the 2007 study buttonbush was not included due to poor survival. Buttonbush is apparently not a suitable species for the high pH soils at Plowboy Bend. False indigo appears to be adapted to alkaline soils since the survival rate is near 100% (personal observation) since planting in 2004. In addition, the majority of false indigo have increased to multiple stems since planting. In some cases where pin oak or swamp white oak has ceased, the false indigo is now dominating.

In 2007 only four N treatments were included with a total of twenty pin oak and twenty swamp white oak saplings (Figure 2). After selecting the trees they were marked with a global positioning system (GPS) to facilitate mapping and relocating in the future (Figure 2). The rows of trees with the randomly assigned N treatment from the 2004 to 2006 study remained the same for the 2007 study. Application rates and percent N, P, and K remained the same also (Table 2). The N treatments included synthetic fertilizers which were applied on 10 June 2007 across the weed barrier mat at 83 g 20-10-10 (20% N as ammonium nitrate, 10% P as P_2O_5, 10% K as K_2O) as slow-release ammonium nitrate, 87 g 19-6-9 (19% N as Urea, 6% P as P_2O_5, 9% K as K_2O) as slow-release urea, N-fixing false indigo that was planted on either side of the oak adjacent to the weed barrier mat in March 2004, or non-fertilized control.

Table 2. Nitrogen treatments and application rates used in 2007 study at Plowboy Bend Conservation Area near Jamestown, Missouri.

Nitrogen Source	Quantity	Actual N / Tree	Actual N / ha Treated Area
Slow-release ammonium nitrate 20% N 10% P as P_2O_5 10% K as K_2O	83 grams	16 grams	112 kg
Slow-release urea 45% N 6% P as P_2O_5 12% K as K_2O	87 grams	39 grams	112 kg
False indigo	2 per tree	Not available	Not available
Non-fertilized control	0	0	0

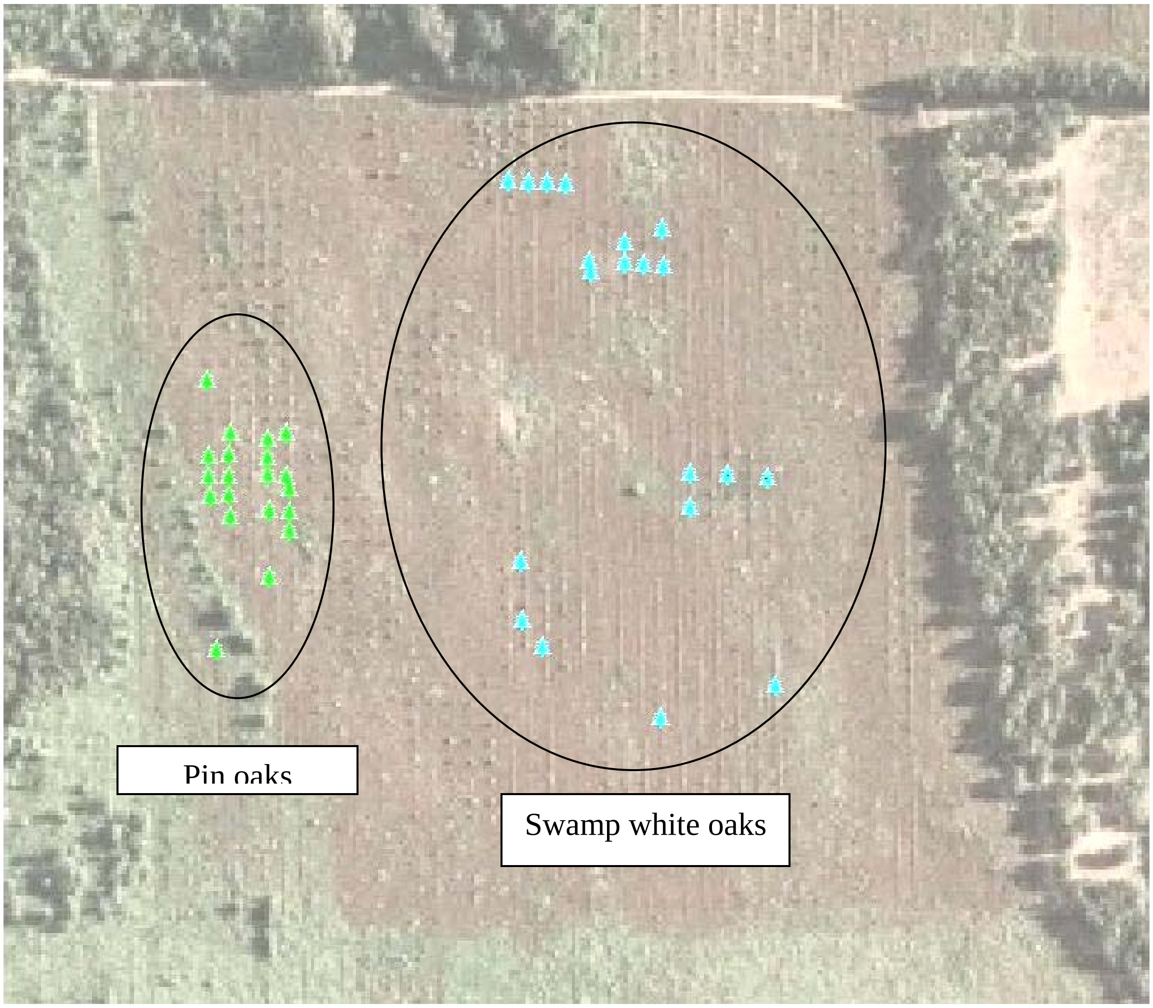

Figure 2. Pin oak (green) and swamp white oak (blue) sapling locations plotted with their global positioning system (GPS) coordinates.

Soil samples were collected four times throughout the 2007 growing season. The first sampling took place June 10 prior to fertilization. The second, third, and fourth samplings were post-fertilization, July 15, August 15, and October 15, respectively.

The soil was collected with a soil probe at sampling depths of 0 to10 cm and 10 to 20 cm on all four sides of the 1.2 square water-permeable mat of black landscape fabric with a total of 80 samples at each sampling period. Soil was placed into properly labeled paper bags that included tree number and treatment. The paper bags of soil were brought back to a greenhouse at Lincoln University in Jefferson City, Missouri where they were opened and allowed to air dry. Soil samples were ground using a mortal and pestle to pass a 2 mm mesh size sieve.

After drying and sieving the soil, pH was determined by using a 2:1 ratio of 20 mL deionized water and 10 g soil (Sparks, 1996). The soil suspension was stirred repeatedly for ten minutes. A glass electrode pH probe was used to measure the hydrogen ion concentration of the soil solution.

The soil samples were then prepared for a microwave acid digestion. An Ethos EZ microwave labstation (Milestone Inc., Shelton, CT 06484, USA) was used for all sample digestion (Figure 3). The ground soil was weighed to be between 0.2 and 0.3 grams and placed into Teflon vessels. Then, 9 mL of nitric acid and 3 mL of hydrofluoric acid were added to the vessel. The vessels were sealed with a torque wrench and placed in the microwave oven to be digested at 180 ^{o}C for 20 minutes. After the acid digestion, the vessels were allowed to cool. After cooling the digested liquid was emptied into labeled plastic containers. The samples were diluted with 25 mL of deionized water and placed in the refrigerator at 4 °C for up to twelve weeks until digestion of all soil samples was complete. Milli-Q water (resistivity of 18.2 MΩ) was used for all sample dilutions, rinses and preparation of diluted standards.

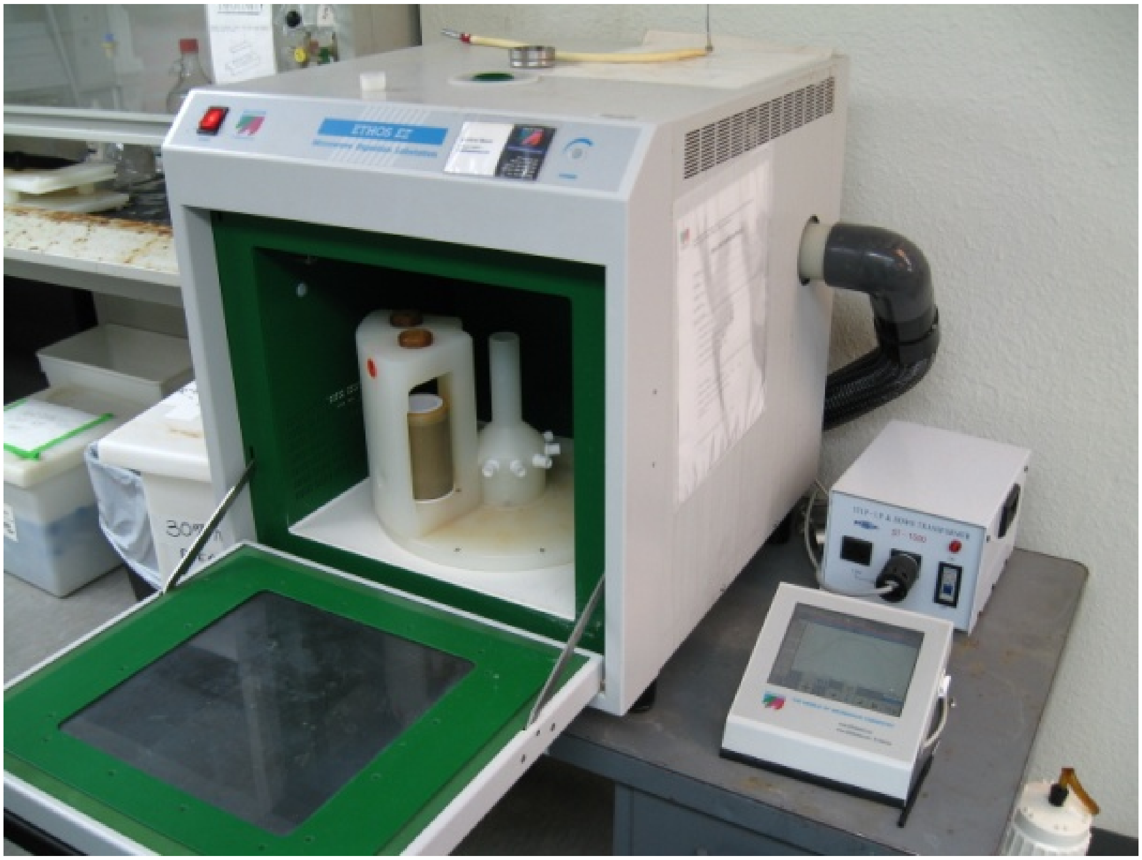

Figure 3. Ethos EZ microwave labstation (Milestone Inc., Shelton, CT 06484, USA) used for sample digestion.

Leaf Sampling and Preparation (2007)

Leaf samples were collected simultaneously with the soil during the same four sampling dates during the 2007 growing season. Eight to ten intact leaves from the mid and upper canopies of the swamp white oak and pin oak saplings were collected (Mills and Jones, 1996). Also, eight to ten leaves were collected from the false indigo shrubs. The leaves were placed in labeled paper bags and stored in coolers on ice until they reached the laboratory at Lincoln University. The leaves were then dried in a forced-air oven at 60 ^{o}C for 48 hours. After drying, the leaves were ground to pass a 2 mm mesh size sieve.

The ground leaf samples were then digested in the microwave similar to the digestion process of the soil samples. The ground leaf tissue was weighed to be between 0.2 to 0.3 grams and placed into Teflon vessels. Then, 15 mL of nitric acid was dispensed into the vessels (Mills and Jones, 1996). After adding the acid, the vessels were sealed with a torque wrench and placed in the microwave oven where they were digested at 180 ^{o}C for 20 minutes. After digestion the loaded vessels were allowed to cool and then emptied completely into labeled plastic storage containers where the digested material was diluted with 25 mL of deionized water. The samples were stored at 4 ^{o}C for up to twelve weeks.

After all digestion was complete, leaf and soil samples were prepared for the Varian Vista PRO inductively coupled plasma-optical emission spectrometer (ICP-OES) (Varian Inc., Walnut Creek, CA 94598, USA) (Figure 4). Exactly 3 mL of liquid digested material was inserted into plastic 20 mL test tubes and 9 mL of deionized water was added to dilute the samples further. All glassware and polyethylene containers in contact with sample digests were previously washed with metal-free soap, rinsed many times, soaked in 50 percent nitric acid for 24 hours and finally rinsed with deionized water.

The ICP-OES was calibrated using ICP tune and calibration solutions from SPEX Certiprep, Inc. (Metuchen, NJ, USA). Standard reference material (SRM 1640: trace elements in natural water) was purchased from the National Institute of Standards and Testing (NIST) Gaithersburg, MD 20899, USA. As part of the quality control protocol, analyses of reagent blanks; method blanks and certified reference water SRM 1640 were carried out on the ICP-OES (Ikem and Egilla, 2008). Table 3 presents the results of the analysis of NIST SRM 1640: trace elements in water. The result of the analysis of SRM 1640 was in agreement with NIST certified values.

Table 3. SRM 1640: Trace elements in natural water expressing NIST certified values used as an ICP check solution with our value averaged across eight ICP runs (± SD).

Element	Certified value	Our value	Recovery (%)
K (ug/l)	994 ± 27	1160 ± 57	116
Ca (mg/l	7.045 ± 0.089	6.03 ± 0.10	86.7
Mg (mg/l)	5.819 ± 0.056	4.87 ± 0.16	84.5
Mn (ug/l)	121.5 ± 1.1	114 ± 4.21	94.6
Fe (ug/l)	34.3 ± 1.6	31.1 ± 0.63	95.1
Cu (ug/l)	85.2 ± 1.2	81.8 ± 5.81	97.3
Zn (ug/l)	53.2 ± 1.1	55.2 ± 8.25	104
Al (ug/l)	52 ± 1.5	52.9 ± 6.32	102
Mo (ug/l)	46.75 ± 0.26	42 ± 4.89	90.3
Se (ug/l)	21.96 ± 0.51	17.9 ± 6.15	83.4
As (ug/l)	26.67 ± 0.41	24.4 ± 5.23	93.1
Na (mg/l)	29.35 ± 0.31	19.7 ± 2.55	68.1
Ba (ug/l)	148 ± 2.2	141 ± 4.56	96.7
Ni (ug/l)	27.4 ± 0.8	24.7 ± 4.94	92.8
Co (ug/l)	20.28 ± 0.31	17.9 ± 5.18	89.6
Be (ug/l)	34.94 ± 0.41	33.9 ± .10	98.2
Cr (ug/l)	38.6 ± 1.6	34.7 ± 5.23	93.7

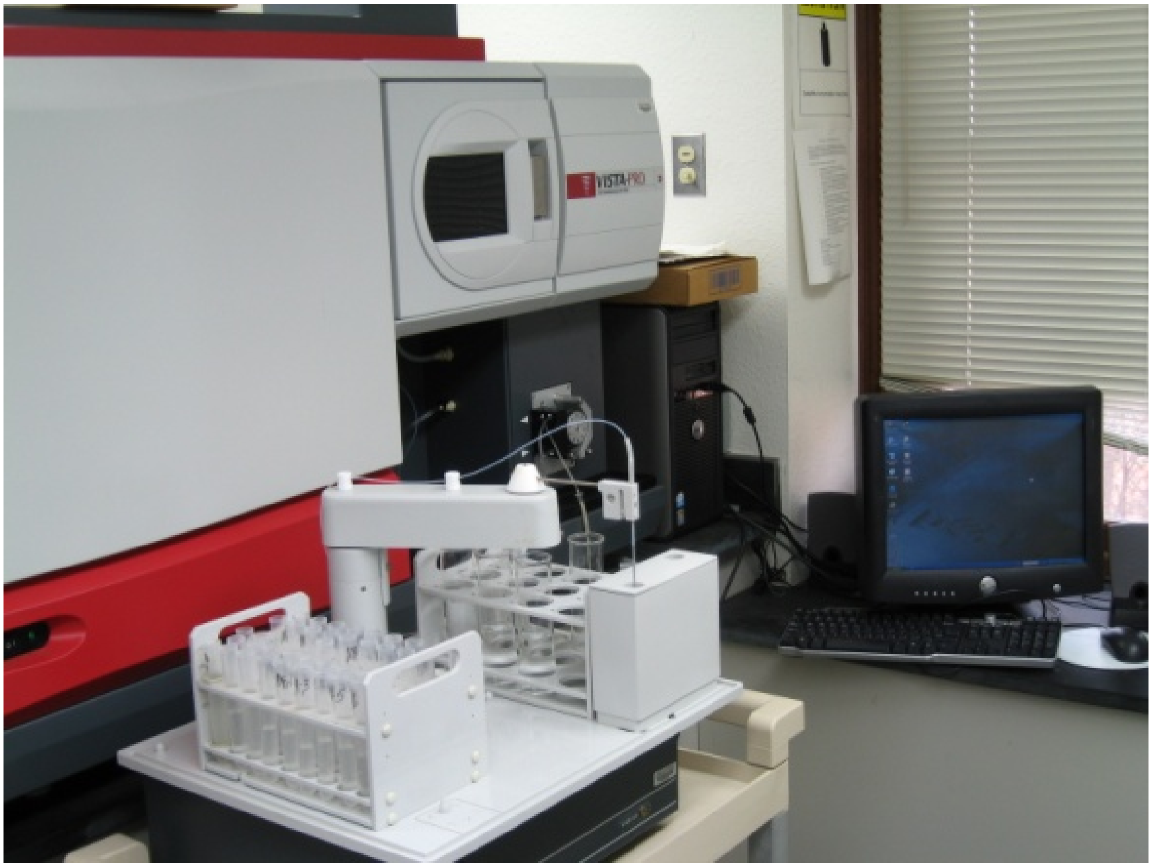

Figure 4. Varian Vista PRO inductively coupled plasma-optical emission spectrometer (ICP-OES) (Varian Inc., Walnut Creek, CA 94598, USA) used in determining macro- and micronutrients in leaves and soil**.**

The ICP-OES was used to determine the concentrations for nearly all the essential elements for plant growth including phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn). After analysis, numerical results became available and were saved directly into the computer operating the ICP-OES. The results were transferred to a Microsoft Excel spreadsheet where the dilution factor was applied to express the data into ppm.

Leaf samples were also prepared for the determination of Kjeldahl N using the FOSS® KJELTEC 2300 (©FOSS Tecator AB 2001) model (AOAC Official

Method 990.02) N analyzer. Approximately one gram of ground, well-mixed leaf sample was placed onto a tared N-free weighing paper and the weight recorded. The weighing paper was then folded around the sample and dropped into a numbered 250 mL Kjeldahl tube where 12 mL of concentrated sulphuric acid (H_2SO_4) was added along with two Kjeltab Cu catalyst tablets. The samples were digested on a heated block for 60 minutes at 420 ^{o}C. After cooling the tared sample weight was entered into the machine before each sample was tested and results were recorded as they became available.

Data Entry and Statistical Analysis

All data were recorded into two Microsoft Excel spreadsheets and then subjected to a procedure in SAS known as ‘PROC UNIVARIATE PLOT NORMAL FREQ’. This procedure was used to check for normal frequency, outliers and keyboarding errors. After computation, some of the micronutrients were determined to be below detection limits of the ICP-OES (Appendix) and therefore were left out of any further analysis. After running the procedure, values three or more quartiles from the mean were identified and changed to missing values in Microsoft Excel (McClave and Sincich, 2000). A new column was added to the spreadsheet in Excel to record outlying values. After outlying values were removed, the original data set was replaced by a revised Excel spreadsheet. The ‘PROC UNIVARIATE PLOT NORMAL FREQ’ procedure was computed a second time on the revised Microsoft Excel spreadsheet to plot their frequency distribution and check for normality before proceeding with analysis of variance

(ANOVA). Treatment, date, species, and depth means were then analyzed for statistical differences using ANOVA with a split-split plot design (Table 4). Main effects were tested at α = 0.05 and Duncan’s new multiple range test was used for mean separations of statistically significant differences. Interactions were tested at α = 0.05 and Fisher’s unprotected least significance difference was used for mean separations of statistically significant interactions.

Table 4. Analysis of variance (ANOVA) models.

ANOVA Model I*

Source	df
Species (S)	1
N-Treatment (N)	3
S * N	3
Error A ~ N * Rep(S)	32
Date (D)	3
S * D	3
N * D	9
S* N * D	9
Residual Error	96
Total***	159

ANOVA Model II**

Source	df
Depth (De)	1
N-Treatment (N)	3
De * N	3
Error A ~ N * Rep(De)	32
Date (D)	3
De * D	1
N * D	3
N * De * D	3
Residual Error	96
Total***	159

*ANOVA for analysis of foliage and soil samples (0 to 20 cm depth).
**ANOVA for analysis of soil nutrients by depth assuming no species effect.
***Total maximum df if no outliers or missing values were present.

CHAPTER 3

RESULTS AND DISCUSSION

Soil pH

Soil pH is defined as a negative logarithmic function of hydrogen ion (H^+) activity or acidity measured in soil solution (Yang et al., 2004). Soil acidity is one of the most important properties of soil, and the single most diagnostic chemical measurement that indicates potential soil productivity and chemical condition in terms of soil management and remediation schemes (McBride, 1994).

Soils at the Plowboy Bend study site have a very high pH (>8). Yang et al. (2004) suggests that in general, soil pH or acidity results from weathering and leaching processes of parent materials in soil genesis that is modified by plant roots and soil microbial activity, agricultural practices, and, subsequently, pollution from industrial, mining, or other human activities. The high soil pH at Plowboy Bend is partly caused by frequent alluvial deposits from upstream limestone hillsides and bluffs. High soil pH has the potential to limit the availability of some essential macro- and micro-nutrients and in extreme cases can result in death plants (Mills and Jones, 1996; Tisdale et al., 1993). Furthermore, Gardiner and Miller (2004) suggest that Fe, Zn, Mn, and macronutrient P may be deficient in soils of high pH; while boron, chloride, and molybdenum are more available.

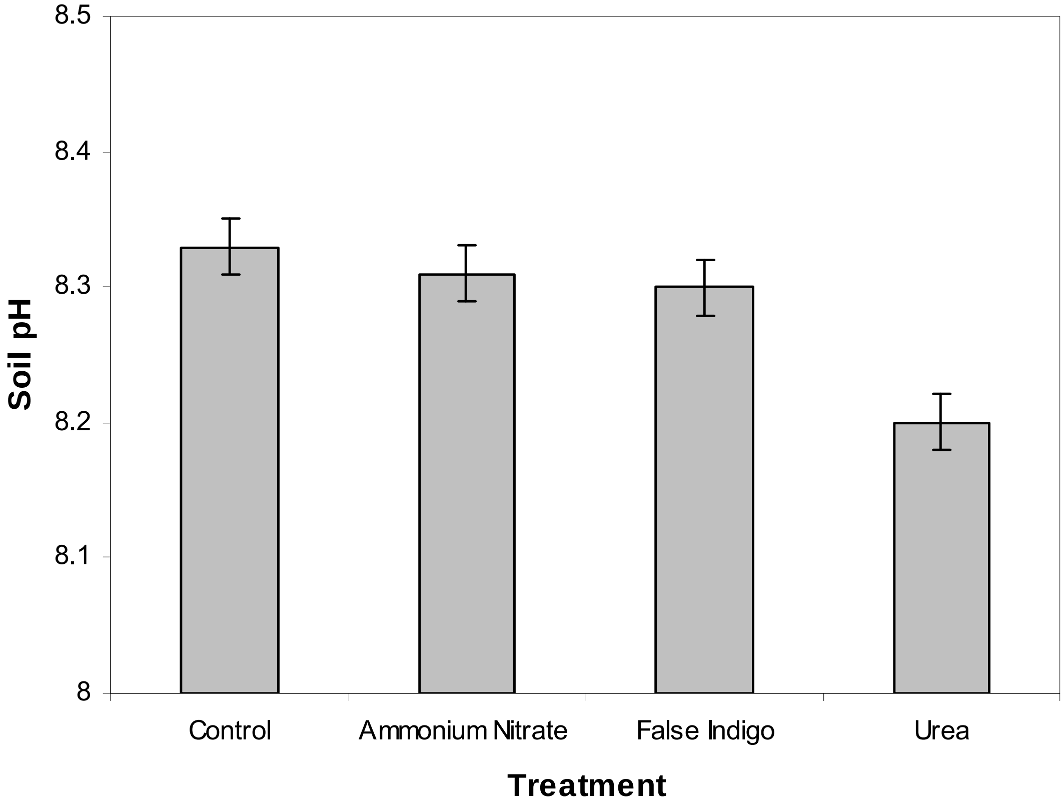

Figure 5. Nitrogen treatment effects on soil pH (± SE) averaged across pin oak and swamp white oak from a depth of 0-20 cm and averaged across four sampling periods during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

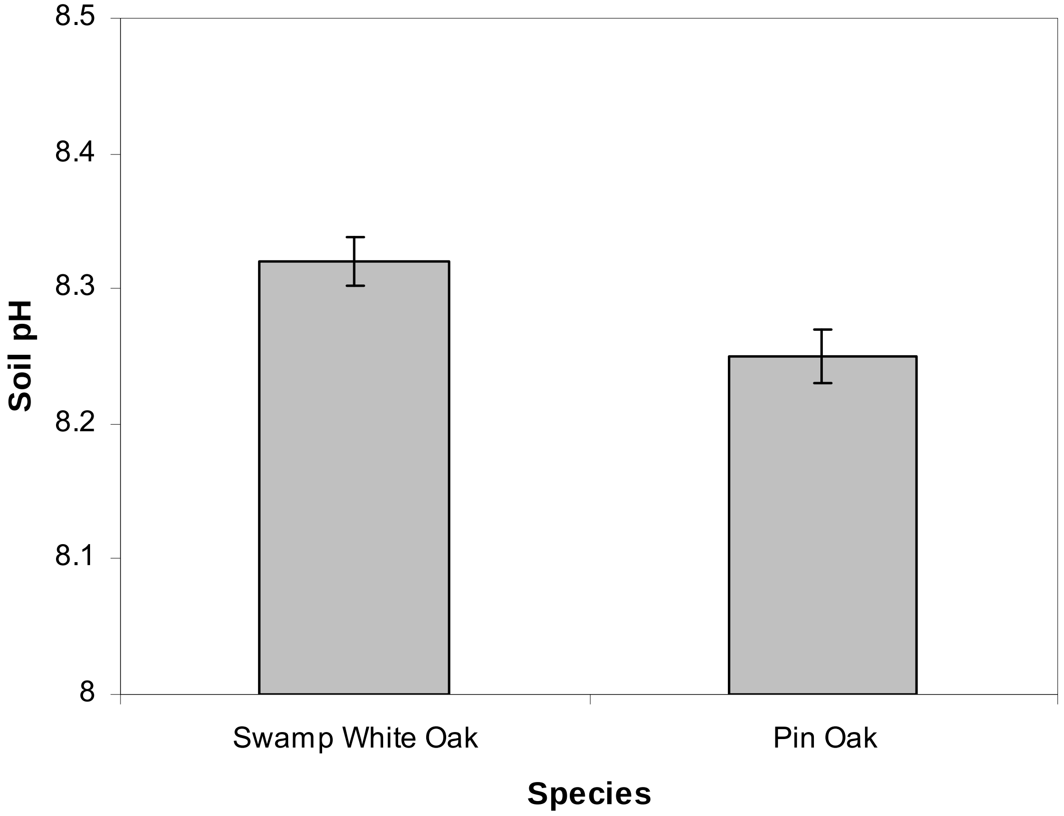

Figure 6. The effect of pin oak and swamp white oak on soil pH (± SE) averaged across four N treatments and two sampling depths during the 2007 growing period at Plowboy Bend Conservation Area near Jamestown, MO.

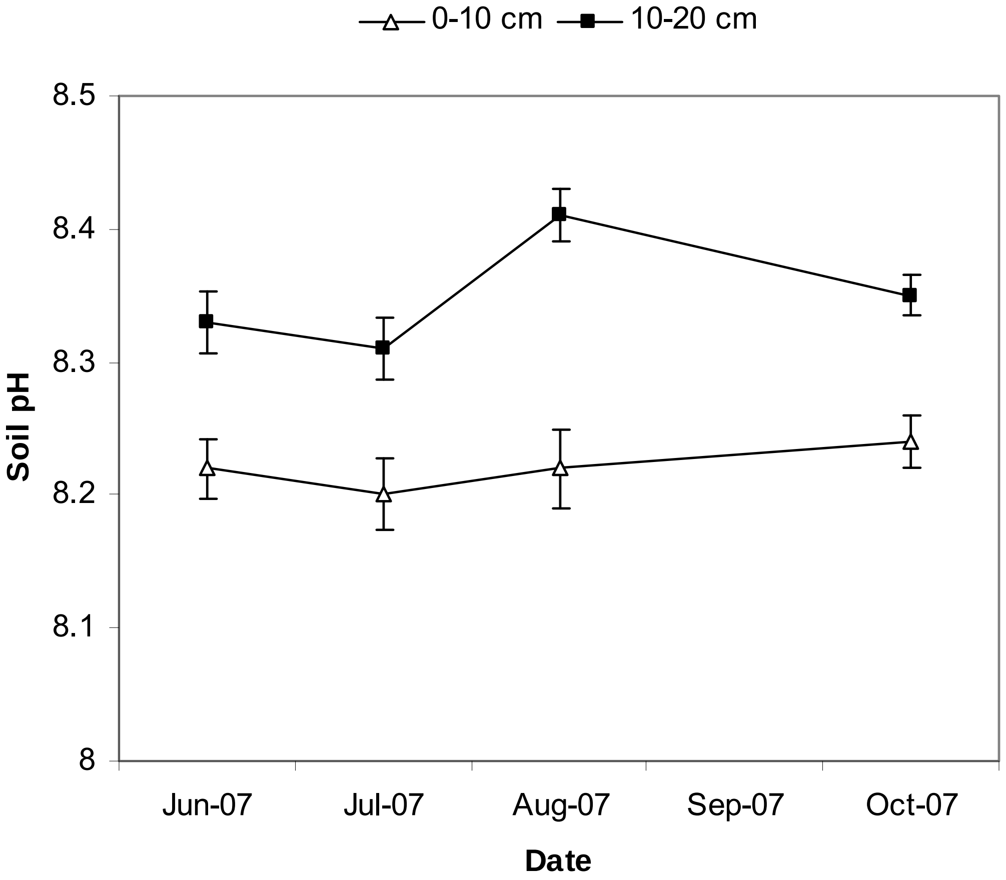

Figure 7. The interaction between depth and date of sampling on soil pH (± SE) averaged across four N treatments and two oak species during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Analysis of variance for soil pH revealed significant differences for N treatments (p = 0.007), for species (p = 0.0098), and a significant interaction for date*depth (p = 0.0001).

Slow release urea had the greatest effect on lowering soil pH (Figure 5). Monsat et al. (2008) found that as urea is hydrolyzed by urease into ammonium and plants take it up, there are more cations than anions taken into the root cell;

consequently H^+ is exuded to regulate cytosolic pH and therefore rhizosphere pH decreases. Urea hydrolysis is illustrated as follows:

$$CO(NH_2)_2 + H+ + 2H_2O \xrightarrow{\text{Urease}} 2NH_4^+ + HCO3^-$$

$$NH_4^+ \longrightarrow NH_3 + H^+$$

The chemical form of N taken up by a plant can distinctly influence the rhizosphere pH (Nye, 1981; Gijsman, 1990; Tang and Rengel, 2003). According to Mills and Jones (1996), when urea or ammonium N is incorporated into the soil, soil bacteria can convert it to nitrate N. This process, known as nitrification, is an acidic transformation, therefore lowering the soil pH. The nitrification of ammonium N and nitrite N brought by *Nitrosomonas* and *Nitrobacter* depends considerably on soil pH, because these bacteria prefer more neutral soil conditions (Mengel and Kirkby, 1978). The nitrification process is illustrated as follows:

$$\underset{\text{ammonium}}{NH_4^+} \xrightarrow[]{\substack{\textit{Nitrosomonas}\\ \text{bacteria}}} \underset{\text{nitrite}}{NO_2^-} \xrightarrow[]{\substack{\textit{Nitrobacter}\\ \text{bacteria}}} \underset{\text{nitrate}}{NO_3^-}$$

Furthermore, Monsat et al. (2008) reported large differences existed in rhizosphere pH in response to three different N forms in a fertilization study with ammonium N having the lowest pH, urea having the next highest, and nitrate N having the greatest effect on increasing rhizosphere pH.

Soils under pin oak had a significantly lower pH than did soils under swamp white oak (Figure 6). Marschener (1998) reports that root processes can affect rhizosphere pH and redox potential. Liu et al. (2004) reports different rhizosphere effects and root growth between two maize (*Zea mays* L.) genotypes and greater ability of genotype 181 to acidify its rhizosphere over genotype 197. Since pin oak is normally found on acidic soils (Gilman, 1997) it could be a way for the plant to adapt to the unsuitable alkaline soils of the Missouri River bottom.

Soil pH also changed by depth during the growing season (Figure 7). The depth from 0 to 10 cm had a significantly lower soil pH than the 10 to 20 cm depth. The nitrogen fertilizers were broadcasted on top of the weed barrier mat suggesting that more ammonium is in the top 10 cm of the soil and as ammonium goes through nitrification, hydrogen is released lowering pH (Mills and Jones, 1996). The microbial decomposition of organic matter also produces ammonia which can be oxidized in the soil causing a decrease in pH (Mengel and Kirkby, 1978). Since most organic matter is in the top several centimeters of the soil (Gardiner and Miller, 2004) pH would likely decrease in the 0 to 10 cm sampling depth, as it did in this study, because of the microbial decomposition and the resulting release of hydrogen.

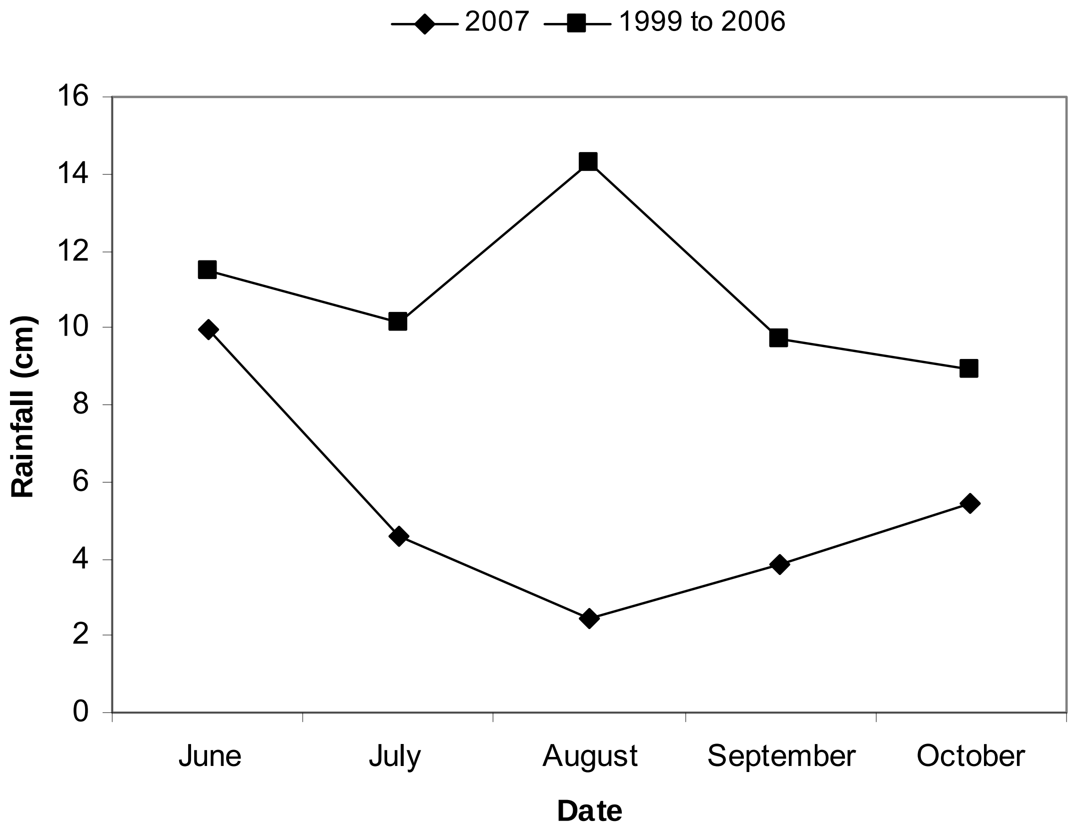

Figure 8. Monthly rainfall during the study period.
Source for data: Missouri Weather Stations-AgEBB located at Sanborn Field at University of Missouri-Columbia in Columbia, Missouri located approximately 10 miles from Plowboy Bend Conservation area near Jamestown, MO.

Macronutrients in Foliage and Soil

Foliage N

The analysis of variance revealed a significant species*date interaction (p = 0.0149) between foliar N concentration of pin oak, swamp white oak, and false indigo during the growing season. Furthermore, N treatment had a significant effect on pin oak and swamp white oak foliar N. No treatment*species interaction occurred between pin oak and swamp white oak and the fertilizer treatments.

Although there were no differences in foliar N between the oaks early in the growing season, at the end of the growing season in October the average foliar N concentration for swamp white oak was significantly less than pin oak (Figure 9). This can result in differences in foliar nutrient concentrations and in the allocation of minerals within a tree (Scherzer et al., 2003). It was observed that many of the pin oak lost their leaves in August and produced a second flush of leaves at the end of the growing season in October with high foliage N concentrations. It is believed that pin oak saplings abscised leaves in response to drought stress during the unseasonably dry August. The new leaf flush is believed to have been the result of increased rainfall and decreased average high temperature in late September that followed an unseasonably dry August (Figure 8).

Table 5. Swamp white oak foliar macro- and select micro-nutrient concentrations averaged across four N treatments (slow-release urea, slow-release ammonium nitrate, false indigo, and control) and across four sampling dates (June 10, July 15, August 15, and October 15) ± standard deviations during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

	Study Results	Sufficiency Range Swamp White Oak*
Nitrogen (%)	1.7 ± 0.2	2.02 - 2.29
Phosphorus (%)	0.16 ± 0.03	0.15 - 0.26
Potassium (%)	0.70 ± 0.11	1.15 - 1.20
Calcium (%)	0.32 ± 0.03	0.33 - 1.07
Magnesium (%)	0.19 ± 0.03	0.13 - 0.31
Sulfur (%)	0.11 ± 0.01	0.13 - 0.16
Manganese (mg/kg)	28.3 ± 12	121 - 323
Iron (mg/kg)	79.7 ± 32	47 - 149
Zinc (mg/kg)	28.1 ± 10.8	16 - 26
Copper (mg/kg)	6.3 ± 2.20	8.0 - 10

*Sufficiency ranges for swamp white oak are from Mills and Jones 2003.

Table 6. Pin oak foliar macro- and select micro-nutrient concentrations averaged across four N treatments (slow-release urea, slow-release ammonium nitrate, false indigo, and control) and across four sampling dates (June 10, July 15, August 15, and October 15) ± standard deviations during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

	Study Results	Sufficiency Range Pin Oak*
Nitrogen (%)	1.9 ± 0.30	2.00 - 2.33
Phosphorus (%)	0.14 ± 0.04	0.16 - 0.39
Potassium (%)	0.64 ± 0.22	0.76 - 1.25
Calcium (%)	0.31 ± 0.03	0.40 - 1.36
Magnesium (%)	0.15 ± 0.03	0.14 - 0.28
Sulfur (%)	0.12 ± 0.02	0.16
Manganese (mg/kg)	40.1 ± 18.20	218 - 633
Iron (mg/kg)	69.3 ± 33.80	45 - 180
Zinc (mg/kg)	51.7 ± 7.70	29 - 88
Copper (mg/kg)	6.3 ± 2.10	7.0 - 38

*Sufficiency ranges for pin oak are from Mills and Jones 2003.

Table 7. Mean separations for nitrogen treatments effect on swamp white oak and pin oak foliage at Plowboy Bend during the 2007 growing season.*

Pin Oak										
	N	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Cu**	**Mn**	**Zn**
Treatment										
Control	1.78b	1325a	5565b	1122a	3147a	1665a	76.65a	5.16c	40.34b	51.56a
Ammonium Nitrate	1.89ab	1380a	5804b	1208a	3211a	1524ab	75.95a	6.69ab	54.10a	52.01a
Urea	1.94a	1450a	6681ab	1155a	3136a	1406b	58.47b	6.00bc	38.07b	56.48a
False Indigo	1.90ab	1434a	7534a	1242a	3117a	1544ab	66.43ab	7.36a	28.56c	46.90a
Swamp White Oak										
Treatment										
Control	1.72ab	1485c	6878a	1114a	3156a	1972ab	77.06ab	6.23ab	28.53a	26.66a
Ammonium Nitrate	1.69b	1571bc	7018a	1118a	3163a	1786b	82.22ab	5.62b	29.99a	28.17a
Urea	1.77a	1741a	7128a	1117a	3256a	1864ab	88.13a	6.75a	27.03a	30.48a
False Indigo	1.73ab	1684ab	7207a	1163a	3276a	2012a	71.07b	6.50ab	27.52a	26.94a
ANOVA Statistical Significance**										
Species	0.03	0.0003	0.03	0.08	0.24	0.0001	0.01	0.84	0.0001	0.0001
Treatment	0.66	0.05	0.05	0.23	0.91	0.09	0.11	0.03	0.002	0.33
Species x Treatment	0.86	0.75	0.2	0.75	0.44	0.49	0.02	0.02	0.015	0.81

*Mean separations are results from separate ANOVA by individual species.

**p-values are results from ANOVA combining treatment, species, and species * treatment.

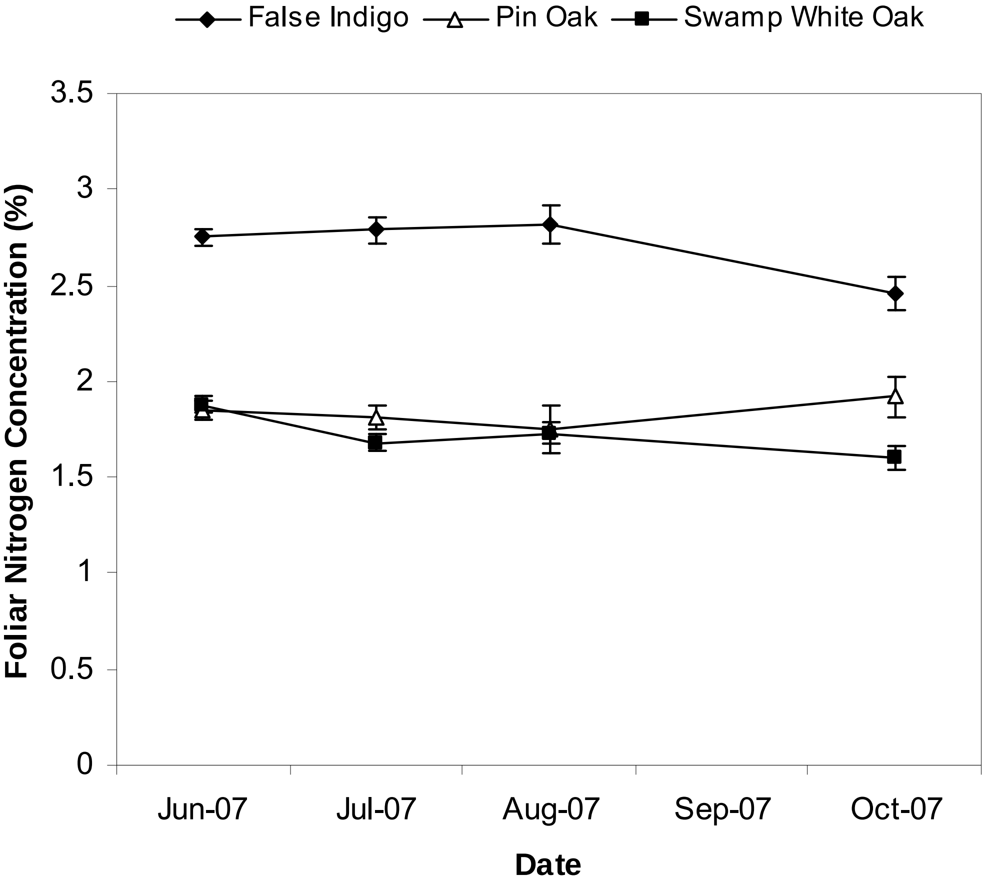

Figure 9. Foliar N concentration (± SE) for pin oak, swamp white oak, and false indigo averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Walker (1991) determined that redistribution of deciduous foliage nutrients occurs in late summer or autumn. This might suggest that the pin oak is not a well adapted species for the high calcareous sandy soils of the Missouri River bottom and probably under a lot of stress since it is flushing out a second time when conditions for growth were again favorable. Instead of retranslocation of N from the foliage to the perennial tissue (stem, roots, limbs), the pin oak are continuing to add more N to the newly flushed leaves resulting in the increase in N prior to leaf abscission for pin oak.

Swamp white oak showed no sign of a second flush in October even though foliar N for swamp white oak was below the sufficiency range reported by Mills and Jones (1996). Furthermore, at the end of the growing season (October) foliar N for swamp white oak decreased to its lowest level of 1.57% indicating retranslocation of nitrogen from the foliage into the perennial tissue (van den Driessch, 1984).

A significant species*date interaction occurred between the foliar N concentration of the oak trees and the false indigo during the growing season (Figure 9). At the end of the growing season in October, false indigo had significantly higher foliar N than the average of both oak trees. Naverette et al., (2003) found false indigo N levels at 2.3% in the fall. Although there is some indication of retranslocation by false indigo, the litterfall from false indigo is likely a better source of N in the future than oak leaves both because of higher foliage N content and less lignin that facilitates their rapid degradation (Sierra and Nygren, 2006).

Van Sambeek et al. (2008) reported that interplanting and underplanting of nodulated N-fixing plants in tree plantings can increase early growth and foliage N content of hardwoods. On low fertility sites, N-fixing plants can obtain up to 70 percent of their N through fixation within root nodules (Tripp et al., 1979). Some of this N can become available to adjacent non-N-fixing plants through root exudates or decomposition in soil of leaves and roots (Friedrich and Dawson, 1984; Avery, 1991; Dawson et al., 1992).

Furthermore, N treatment had a significant effect on pin oak and swamp white oak foliar N (Table 7). The pin oaks within the urea N treatment had significantly higher foliar N than the control N treatment. The swamp white oaks within the urea N treatment had significantly higher foliar N than the ammonium nitrate treatment.

Foliage and Soil Phosphorus

Analysis of variance revealed a significant species*date interaction (p = 0.0046) for foliar P between swamp white oak and pin oak during the growing season. Also, separate ANOVAs for each species individually showed N treatment had a significant effect on swamp white oak foliar P. Furthermore, analysis of variance for soil P revealed a significant species*date interaction (p = 0.0318) and a significant depth*date interaction (p = 0.0062) during the growing season. No significant N treatment effects occurred in pin oak foliar P levels.

Mills and Jones (2003) provide a sufficiency range of 0.16 to 0.39% for foliar P concentration of pin oak (Table 5). This suggests that pin oak foliar P concentrations are below the sufficiency range. As stated earlier, a significant species*date interaction existed between leaves of swamp white oak and leaves of pin oak (Figure 10). Swamp white oak had significantly higher foliar P at the end of the growing season than pin oak. Swamp white oak is better suited for a high pH (Gilman, 1997) which might allow the tree to have a greater tolerance to the alkaline soils and a better ability to take up more P then pin oak which is sensitive to a high pH.

Separate ANOVAs for both species showed N treatments had a significant effect on swamp white oak foliar P but not pin oak foliar P (Table 7). The swamp white oaks within the urea N treatment had significantly higher foliar P than the swamp white oaks within the control and ammonium nitrate N treatments.

There was also a significant species*date interaction for soil P concentrations during the growing season (Figure 11). The trend for soil P concentration (Figure 11) closely resembles the pH trend (Figure 7) during the growing season. This suggests that as the ammonium fertilizers lower pH after the first sampling period, P becomes more soluble, allowing more to be taken up by the tree and surrounding vegetation. Phosphorus is most available at pH 6.5 for mineral soils (Gardiner and Miller, 2004). Gardiner and Miller (2004) also report that total P in an average soil is approximately 0.05% by weight, which is higher than the soil at the study site of 0.04% by weight.

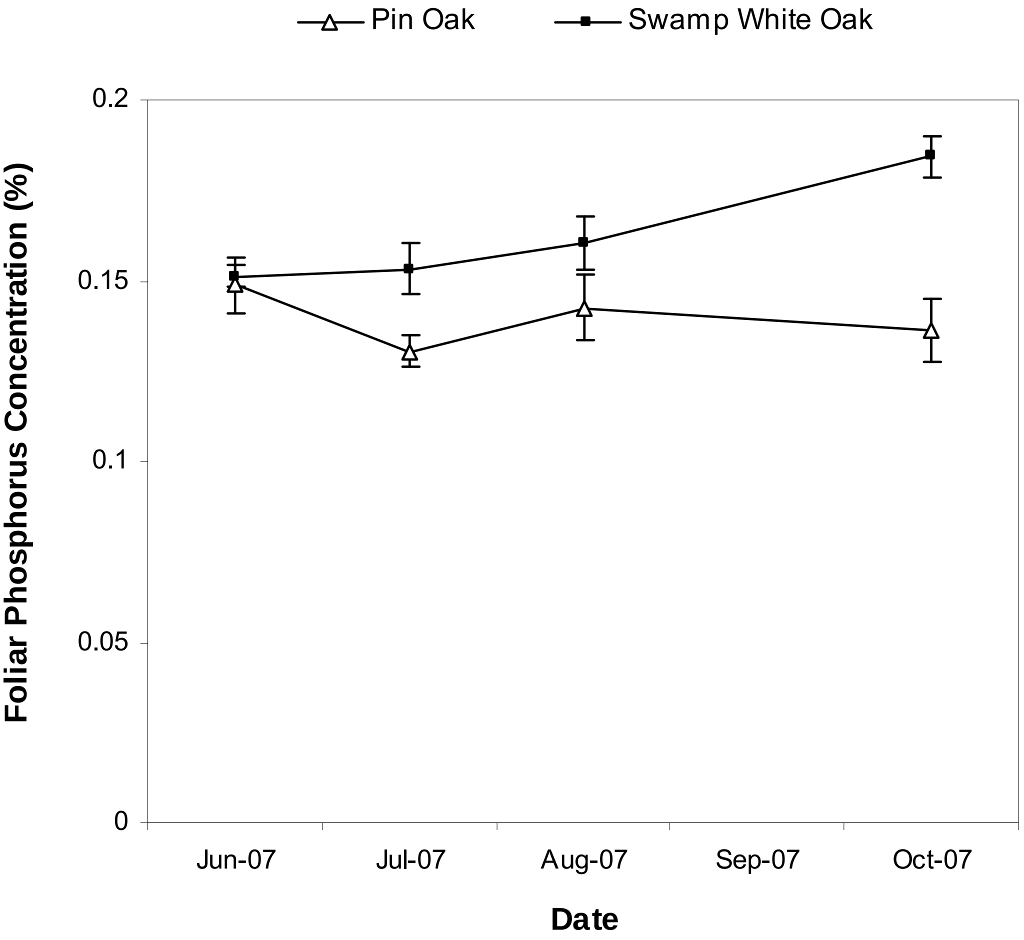

Figure 10. Foliar P concentration (± SE) for pin oak and swamp white oak averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

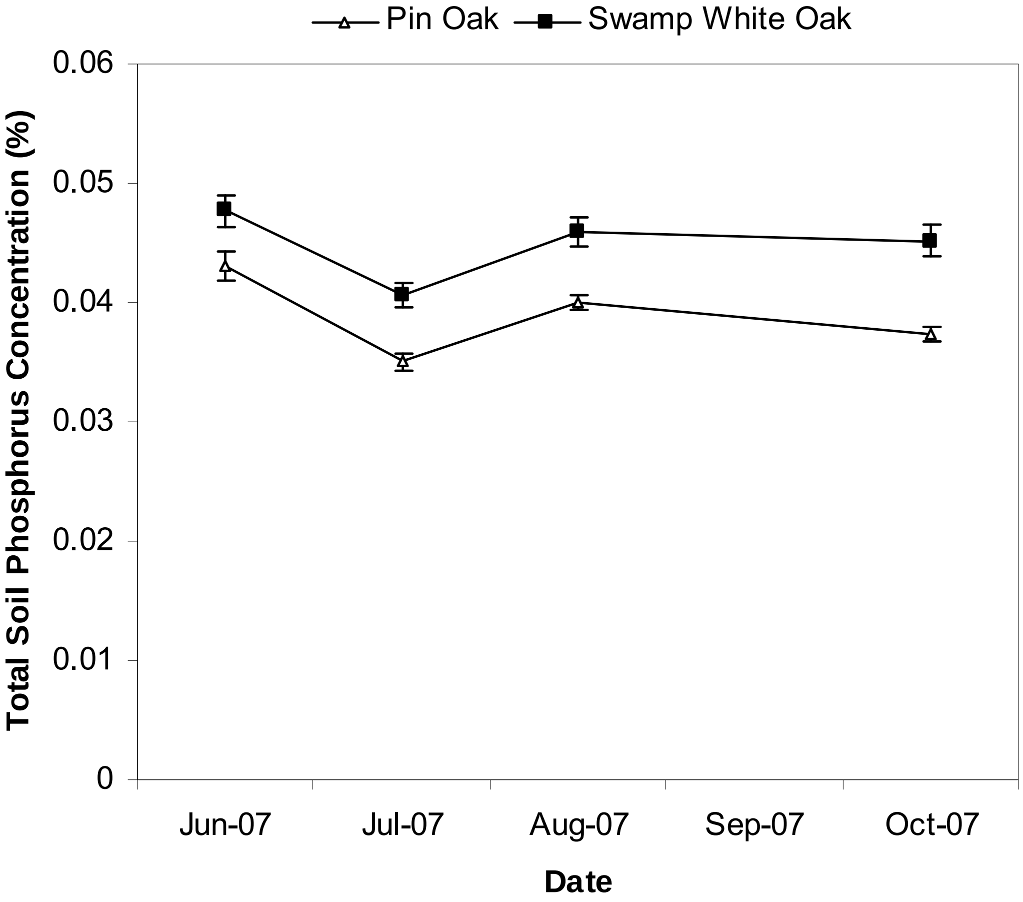

Figure 11. Soil P concentration (± SE) under pin oak and swamp white oak averaged across four N treatments and two sampling depths during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

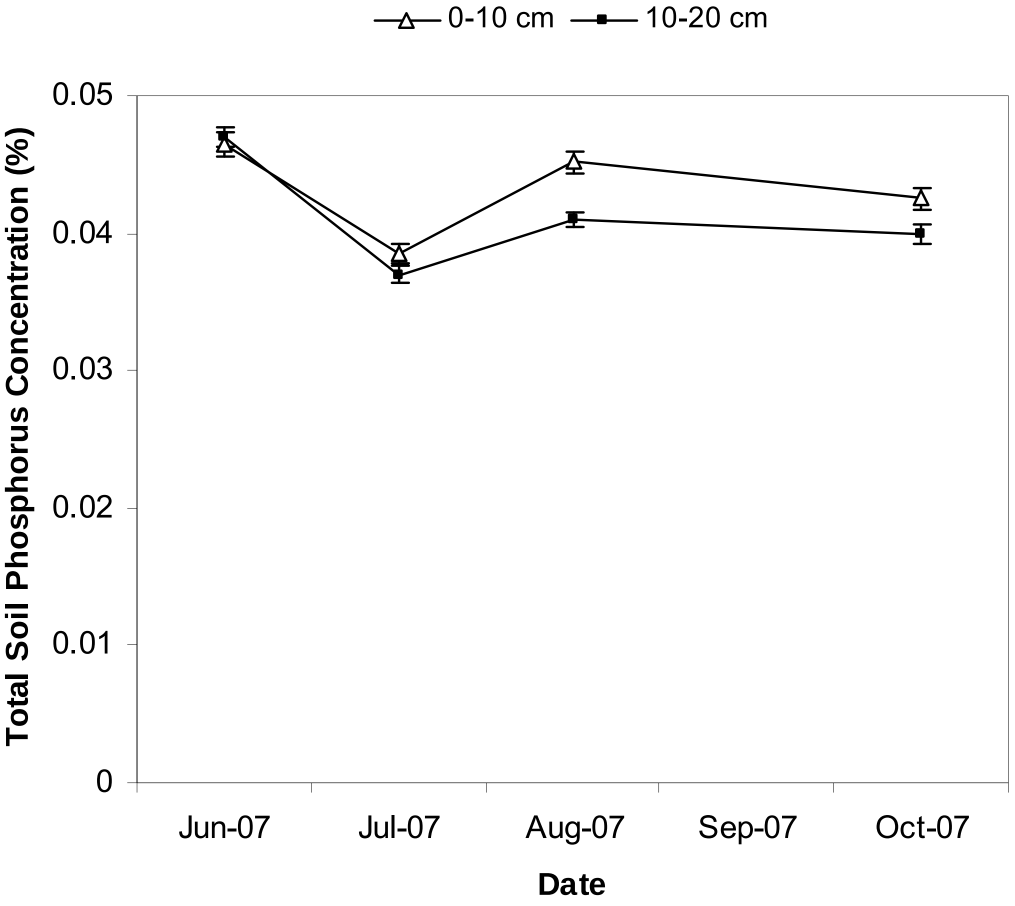

Figure 12. Soil P concentration (± SE) at two sampling depths (0-10 and 10-20 cm) averaged across four N treatments and two oak species during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

A significant date*depth interaction also existed for soil P concentration during the August and October sampling periods (Figure 12). The inorganic fertilizers were applied immediately after the June samples were collected. One sampling period after fertilization, there was an unexplainable decline in P. A possible explanation for the P decline in July could be that the fertilizers had not yet dissolved into the soil under the weed mat due to lack of rainfall. By the July and August sampling periods, the fertilizers began becoming apparent in the soil samples, with significantly higher P levels at the top 0 to 10 cm level of the soil. The October sampling period still had not shown that the P fertilizer had increased in the lower sampling depth (Figure 12).

Foliage and Soil Potassium

Analysis of variance for foliar and soil K revealed a significant species*date interaction (p = 0.0107 foliage, p = 0.0001 soil) between swamp white oak and pin oak during the growing season. Separate ANOVAs for each species individually showed N treatment had a significant effect on pin oak foliar K levels. No significant differences were found between N treatments of swamp white oak or between the two sampling depths of swamp white oak and pin oak during the growing season.

Foliar K concentrations of pin oak and swamp white oak were less than the sufficiency range of 0.76 to 1.25% during the growing season as reported by Mills and Jones (1996). The significant interaction at the last sampling period in October showed pin oak had significantly lower foliar K than swamp white oak (Figure 13). Bockheim and Leide (1991) found that K in oak foliage peaked in midsummer, generally in late July. In our study, pin oak foliar K concentration peaked in August and swamp white oak concentration peaked in July and decreasing thereafter indicating resorption (Figure 13). Also, Sampson and Samisch (1935) report a pronounced resorption of K in *Quercus gambelii* and *Quercus kelloggii* in the fall just before leaf abscission. Pin oak may conserve K by redistribution back into perennial tissue prior to leaf abscission unlike swamp white oak which had relatively stable concentrations.

In addition, separate ANOVAs showed N treatment had an effect on foliar K levels of pin oak but not swamp white oak. Pin oaks within the false indigo N treatment had significantly higher foliar K than pin oaks within the control or ammonium nitrate N treatments (Table 7).

There was also a significant species*date interaction for soil K between swamp white oak and pin oak during the growing season (Figure 14). Furthermore, both foliar K and soil K follow similar trends in both species at the August and October sampling periods (Figures 13 and 14).

The soil K concentration was significantly lower under swamp white oak than under pin oak at the third sampling period (August 14). Foliar K concentration of swamp white oak also dipped in August. Mills and Jones (1996) found K remains soluble in the soil and undergoes little chemical or biological transformation. August of 2007 was an unseasonably dry month (Figure 8) and may have resulted in decreased decomposition of organic matter and less movement of K into the soil. Jack pine (*Pinus banksiana*) was found to conserve more nutrients by investing lower amounts in leaves and therefore lower amounts in litterfall than pin oak (Bockheim and Leide, 1991). This shows that there are inherent differences among species in their role of absorption and utilization of mineral nutrients from the soil (Goddard and Hollis, 1984).

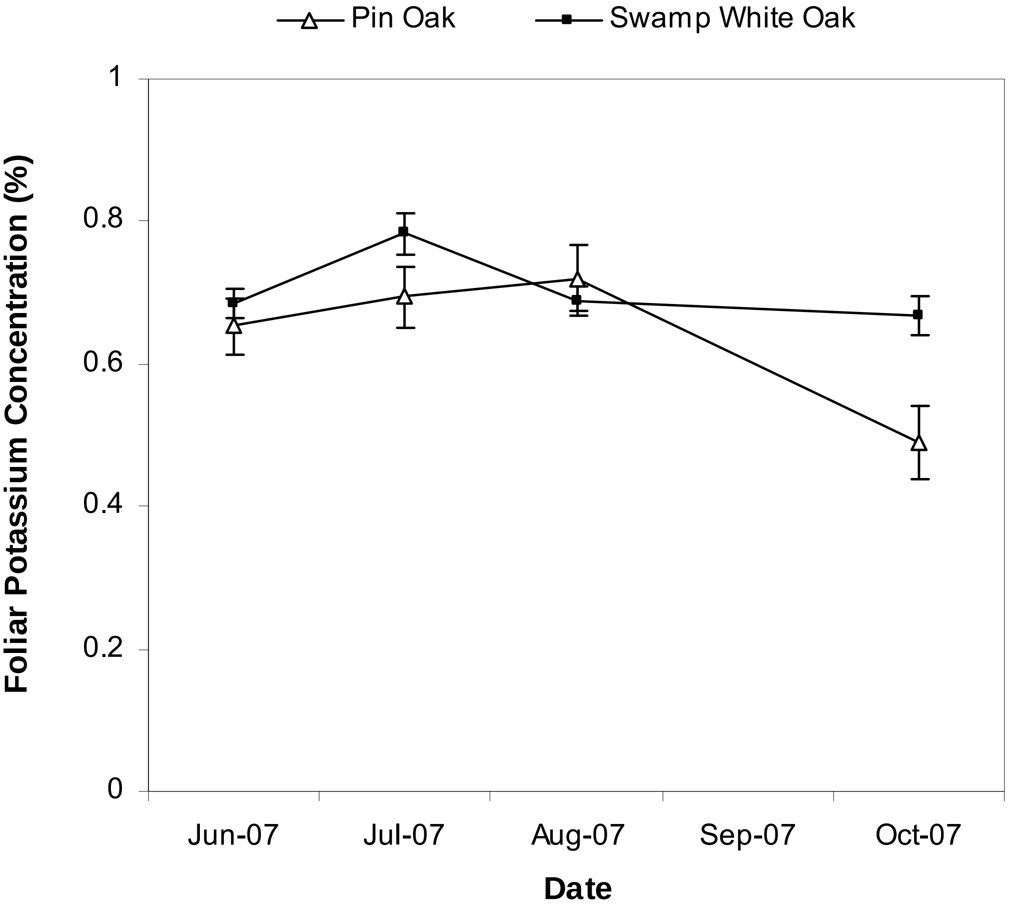

Figure 13. Foliar K concentration (± SE) for pin oak and swamp white oak averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

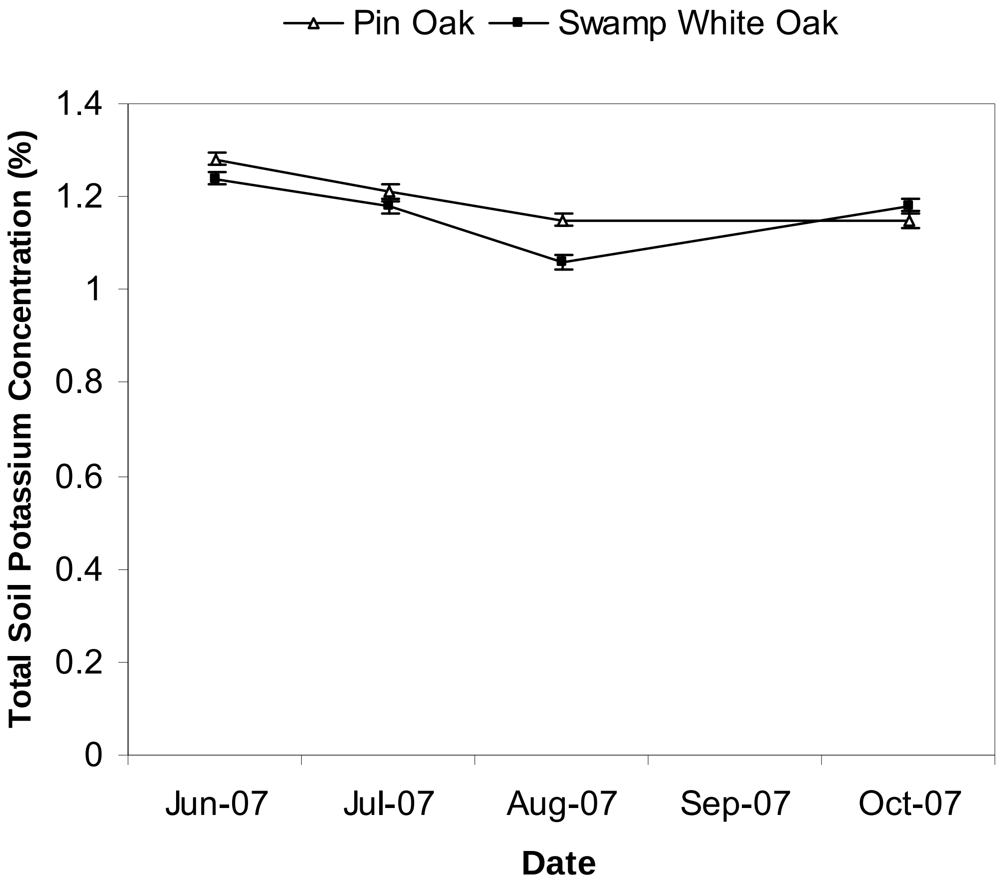

Figure 14. Soil K concentration (± SE) for pin oak and swamp white oak averaged across four N treatments and two sampling depths during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Foliage and Soil Calcium

Analysis of variance revealed significant differences between foliar Ca concentrations of swamp white oak and pin oak during the growing season ($p = 0.0491$). Also, analysis of variance for soil Ca revealed a significant difference ($p = 0.0001$) between the soil under swamp white oak and the soil under pin oak. No significant differences or interactions were found for N treatment or depth during the growing season.

Foliar Ca concentration for swamp white oak and pin oak at the June sampling period (0.33%) was significantly higher than the July sampling period (0.30%). The foliar Ca concentration increased significantly again by the August sampling period to 0.33%. Bockheim and Leide (1991) report that concentrations of immobile elements in deciduous foliage such as Ca normally increase over the growing season. This does not explain the significant drop in foliage Ca at the July sampling. However, Mills and Jones (1996) report Ca uptake can be reduced when root tips are chemically altered by ions such as ammonium. Calcium uptake is also depressed by competitive uptake with ammonium and K (Mills and Jones 1996). The inorganic fertilizers were applied in mid June. The foliar Ca concentrations one sampling period later after fertilization were significantly lower suggesting that the ammonium fertilizer could have caused a significant decline in foliar Ca concentrations.

The species effect showed that swamp white oak had significantly more Ca in the soil rhizosphere than did pin oak during the growing season (Figure 15). Lipton et al. (1987) found that when some plants adapt to calcareous soils, exudation of compounds from the root promote mineral dissolution, organic matter mineralization, and root uptake of barely soluble nutrient pools from the rhizosphere. This suggests that pin oak may exude organic acids from its roots causing dissolution of metal complexes such as Ca-P and allow more Ca to become available. If the plants do not take up the newly available Ca, then some may be lost to leaching out of the soil rhizosphere (Fisher and Binkley, 2000), possibly explaining the lower soil Ca in the rhizosphere surrounding pin oak. In contrast, swamp white oak has a higher soil Ca concentration which can be a result of differences among species and their role to absorb and utilize nutrients from the soil (Goddard and Hollis, 1984).

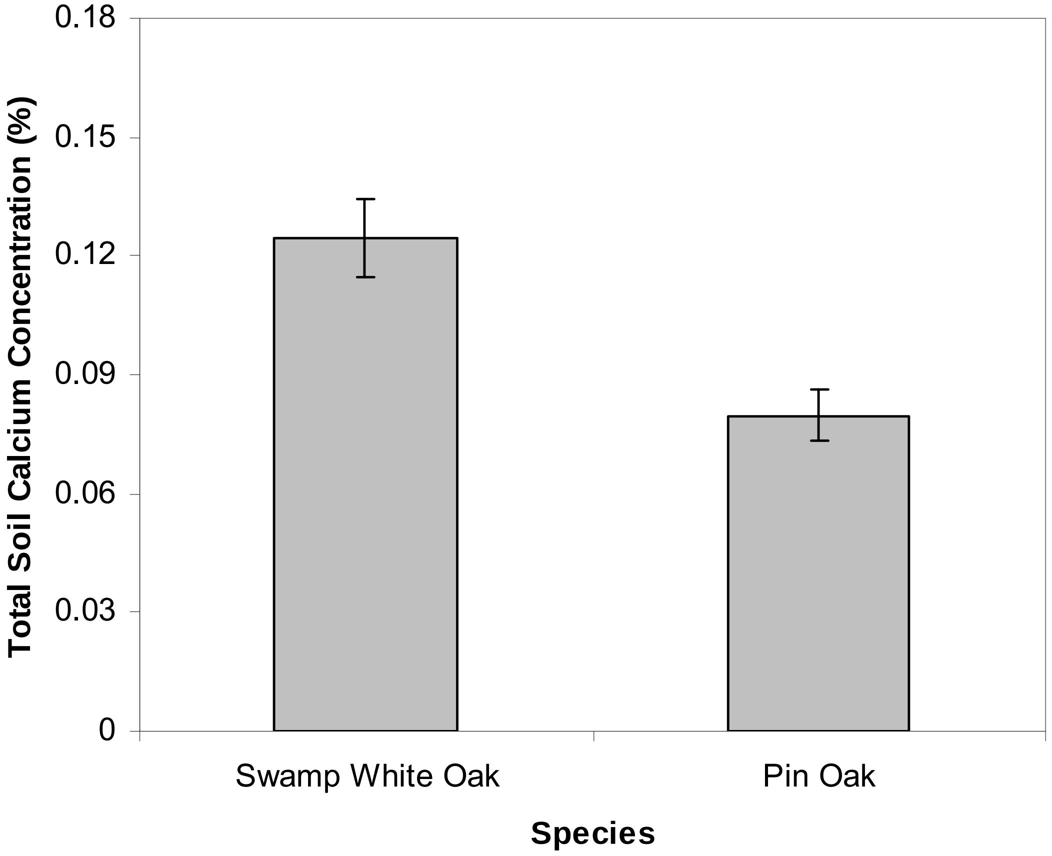

Figure 15. Soil Ca (± SE) under pin oak and swamp white oak saplings averaged across four N treatments and two sampling depths during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Foliage and Soil Sulfur

Analysis of variance for foliar S showed a significant species*date interaction (p = 0.0018) between swamp white oak and pin oak during the growing season. Furthermore, a significant species effect (p = 0.0001) and a significant date*depth interaction (p = 0.0081) was detected for soil S concentration under swamp white oak and pin oak during the growing season. No significant interactions occurred between N treatments and their effect on S uptake by plants during the growing season.

A significant species*date interaction existed between pin oak and swamp white oak during the growing season (Figure 16). Pin oak exhibited significantly lower foliar S in June than swamp white oak. However, by the end of the growing season it was opposite, with pin oak having significantly higher S concentration than swamp white oak. According to Mills and Jones (1996), swamp white oak was not within the sufficiency range for foliar S. However, pin oak was just within the sufficiency range at the end of the growing season. Furthermore, according to Mills and Jones (1996), S deficiencies are relatively uncommon, but can occur in sandy, highly-leached soils that are low in organic matter (which are common soil properties of the study site) since the negatively-charged sulfate ion is not retained in the soil. This may explain why swamp white oak and pin oak might be deficient in foliar S concentration.

Woodwell (1974) showed that S increased slightly throughout the life of the leaves of *Quercus alba*, *Quercus coccinea*, and *Pinus rigida.* This validates the increase in pin oak foliar S concentration during the growing season in this study. However, swamp white oak foliage S decreased from July through October. This suggests that by July the leaves had reached maturation and had begun the process of resorption of foliar S back into the perennial tissue. Pin oak continued to increase in foliar S indicating leaves were not mature. Bockheim and Leide (1991) report that by their July 26 sampling period of pin oak foliage, maximum leaf nutrient amounts had occurred. Pin oak had significantly higher foliage S at the end of the growing season which could be due to the new leaf flush.

A significant species effect occurred in the soil under swamp white oak and pin oak during the growing season (Figure 17). The soil rhizosphere around swamp white oak had a significantly higher S concentration than did pin oak. Swamp white oak had a dense full canopy resulting in a greater amount of leaf litter (therefore more organic matter) than pin oak at the end of the growing season. Gardiner and Miller (2004) suggested that in leached soils, decomposition of organic matter can release major portions of S.

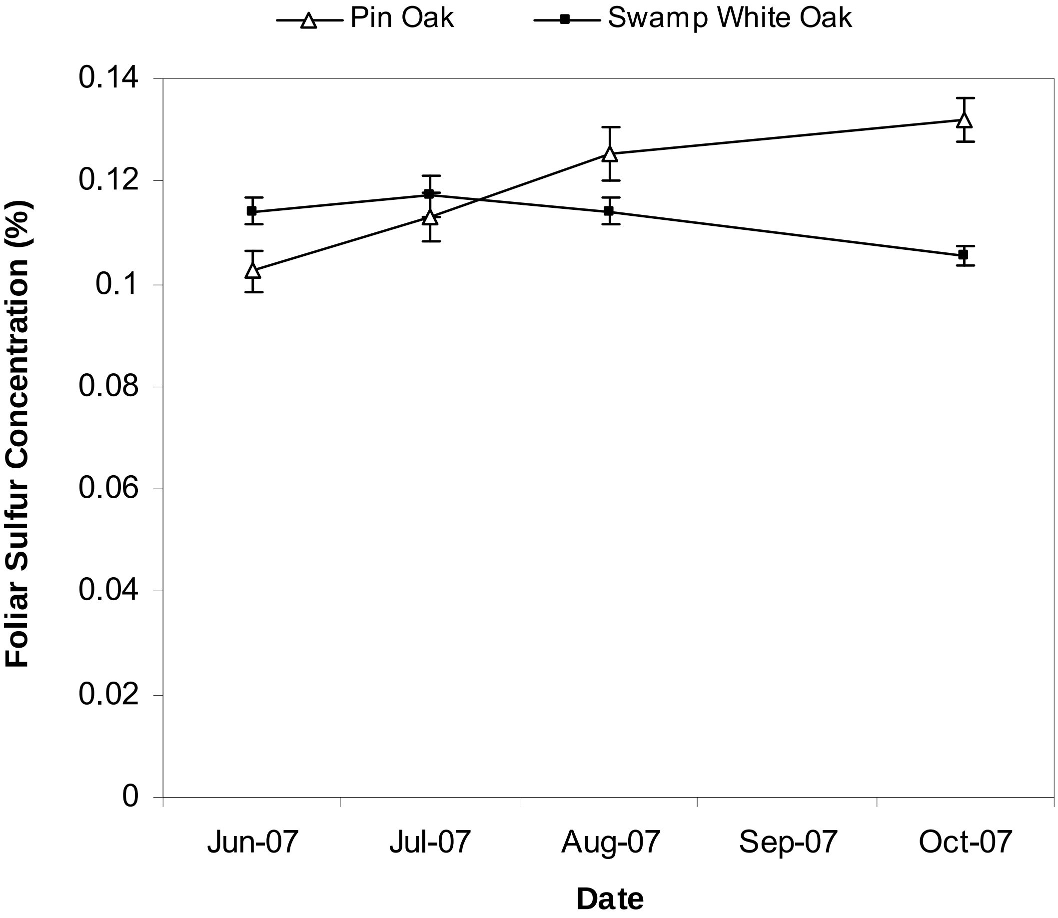

Figure 16. Foliar S concentration (± SE) for pin oak and swamp white oak averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

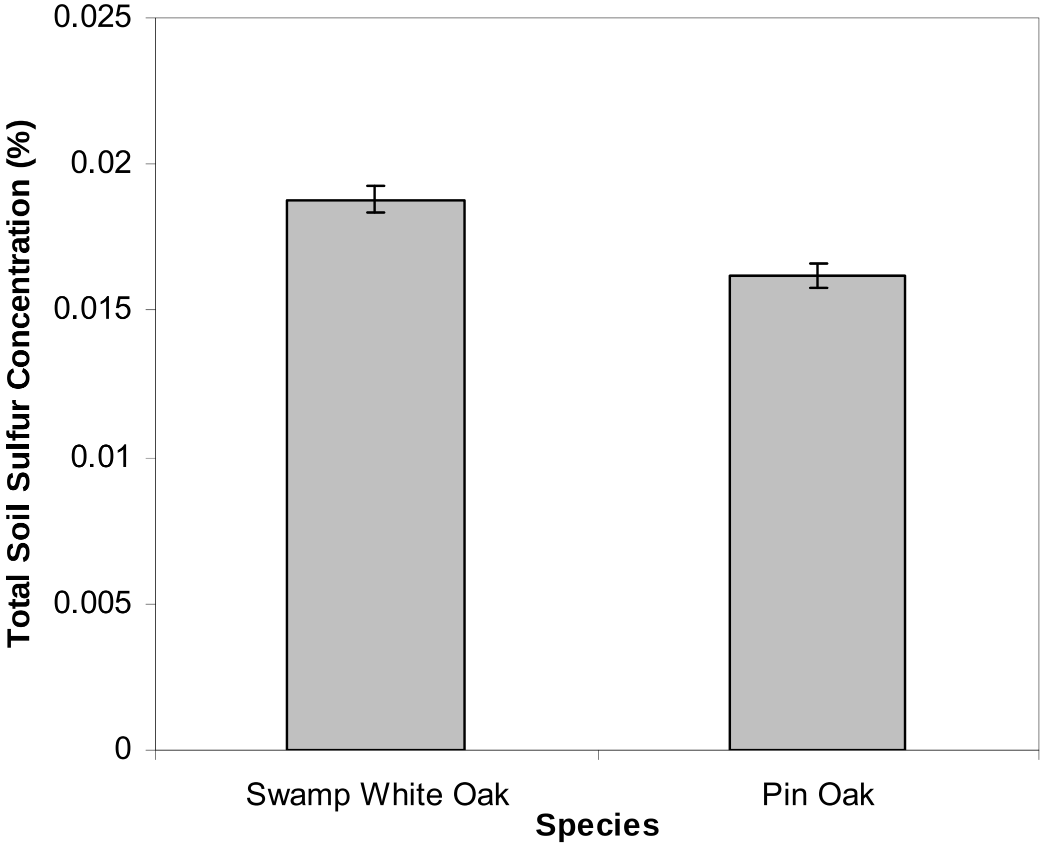

Figure 17. Soil S concentration (± SE) for pin oak and swamp white oak averaged across two sampling depths and four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

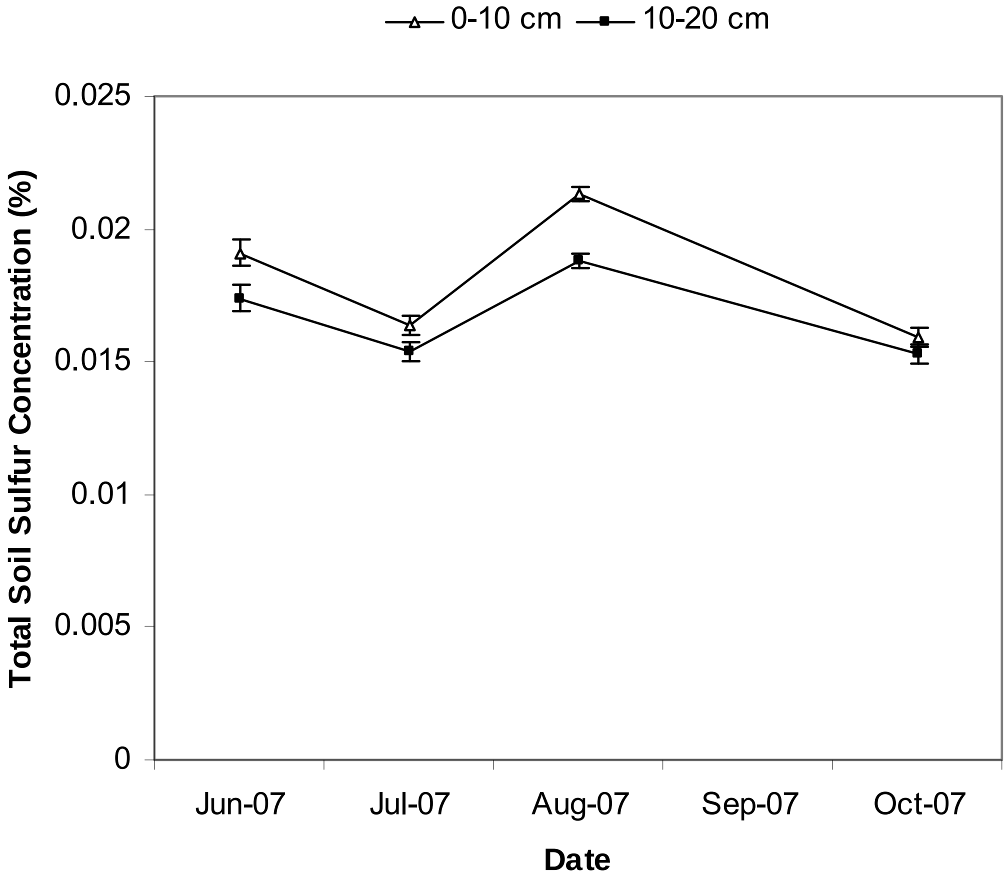

Figure 18. Soil S concentration (± SE) at two sampling depths (0-10 and 10-20 cm) averaged across four N treatments and two oak species during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Furthermore, there was a significant date*depth interaction for soil S during the sampling period (Figure 18). Sulfur was more concentrated in the top 0 to 10 cm layer of the soil. According to Tisdale et al., (1993) the top several centimeters of the soil are usually enriched in organic matter because of the plants growing on the surface resulting in more soil S due to decomposition of plant residues (Gardiner and Miller, 2004).

Foliage and Soil Magnesium

Analysis of variance for foliar Mg revealed a significant species*date interaction (p = 0.0006) between swamp white oak and pin oak during the growing season. Separate ANOVAs for each species showed significant differences between N treatments and their effect on foliar Mg existed within each oak species. No significant interactions or differences were found for soil Mg by species, N treatment, depth, or date.

Swamp white oak had significantly higher foliar Mg than pin oak (Figure 19). Foliar Mg was significantly lower for pin oak in June, August, and October, but not July, than for swamp white oak. The average foliar Mg concentration for pin oak and swamp white oak (0.15 and 0.19%, respectively) during the growing season was within the sufficiency range according to Mills and Jones (1996) of being between 0.13 to 0.31%. Woodwell (1974) found that foliar Mg concentrations during the growing season varied greatly between *Quercus coccinea* and *Quercus alba*. *Quercus alba* declined through July and August, rose in September, and declined at the time of abscission versus *Quercus coccinea* where a regular increase existed during the growing season. Furthermore, Bockheim and Leide (1991) found that during senescence northern pin oak leaves decreased in foliar Mg concentration.

There were also significant differences that occurred with respect to N treatments within pin oak and swamp white oak (Table 7). The pin oaks within the control N treatment had significantly higher foliar Mg than the pin oaks within the urea N treatment. The swamp white oaks within the false indigo N treatment had significantly higher foliar Mg than the swamp white oaks within the ammonium nitrate N treatment.

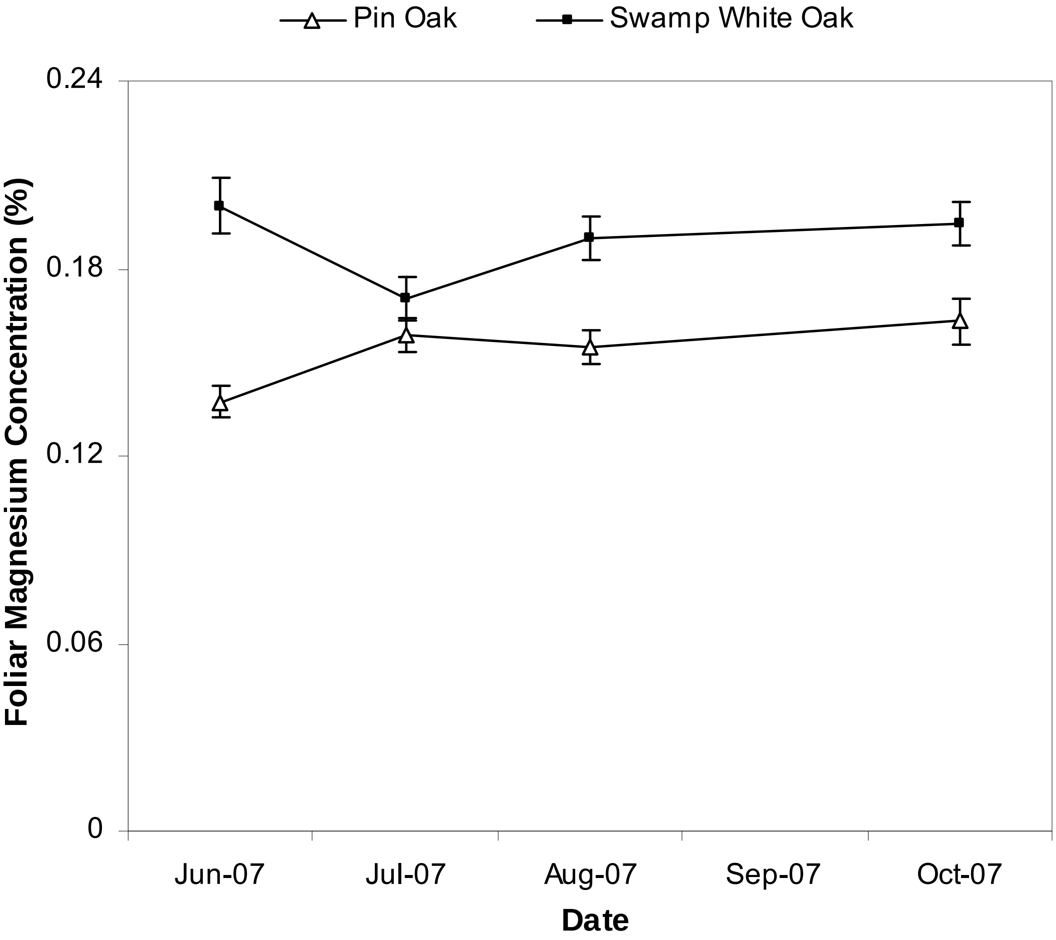

Figure 19. Foliar Mg concentration (± SE) for pin oak and swamp white oak averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Foliage and Soil Copper

Analysis of variance for foliar Cu revealed a significant species*date interaction (p = 0.0107) between swamp white oak and pin oak during the growing season. Also, ANOVA revealed a significant species*treatment effect (p = 0.0119). Furthermore, a significant date and species effect (p = 0.0001 for both) occurred in the soil Cu concentration under swamp white oak and pin oak during the growing season. No significant difference occurred in soil Cu between the two sampling depths.

Swamp white oak had significantly higher foliar Cu at the beginning of the growing season than pin oak, but, just prior to leaf abscission it was the opposite, with pin oak having significantly higher foliar Cu concentration than swamp white oak (Figure 20). The significant interaction that occurred at the last sampling period, where pin oak had a higher foliar Cu concentration is possibly due to the new leaf flush by the pin oak. Mills and Jones (1996) report a sufficiency range from 8 to 38 mg/kg for swamp white oak and pin oak. The average foliar concentration for both species was only 6.3 mg/kg during the growing season (which is deficient). Leaves at the beginning of the growing season in June had the highest Cu level. The concentrations in June were within the sufficiency range according to Mills and Jones (1996). The sufficiency range reported by Mills and Jones (1996) is from mature leaves of current year growth that were sampled in the summer (July and August). Although, the leaves were within the sufficiency range early in the season, by July and August (summer) they were well below the adequate range.

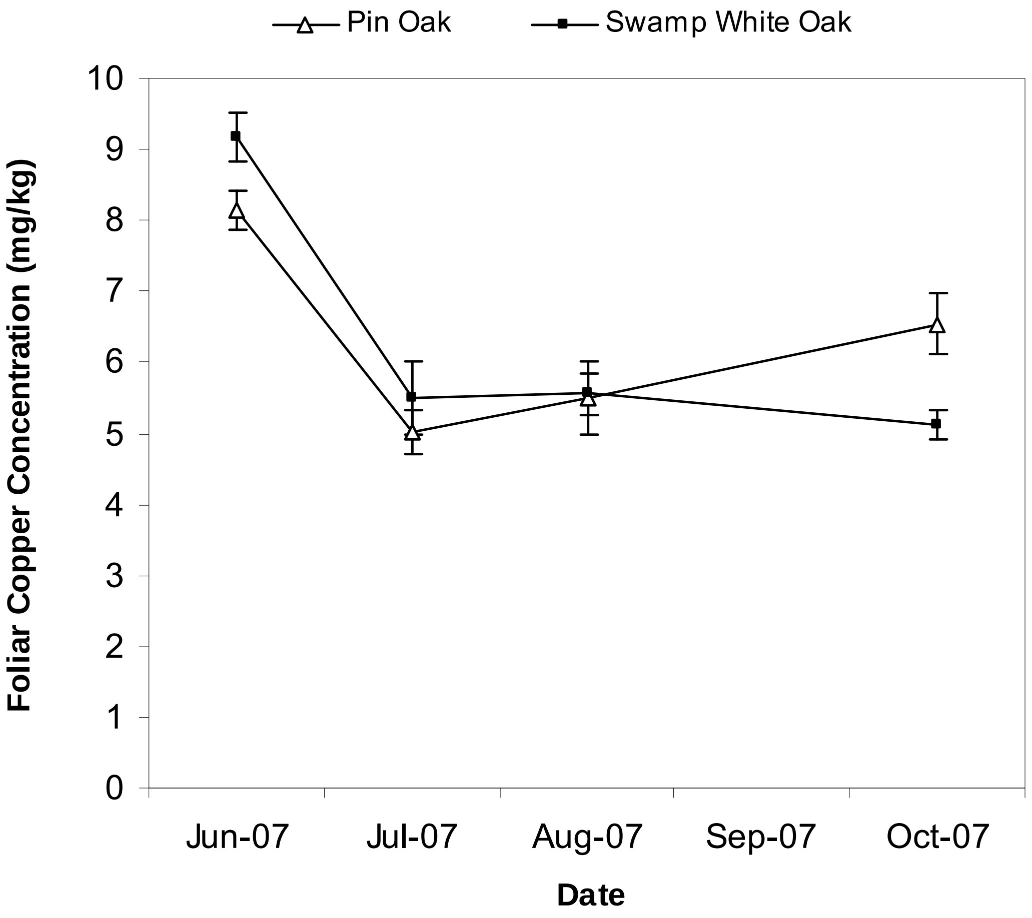

Figure 20. Foliar Cu concentration (± SE) for pin oak and swamp white oak averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

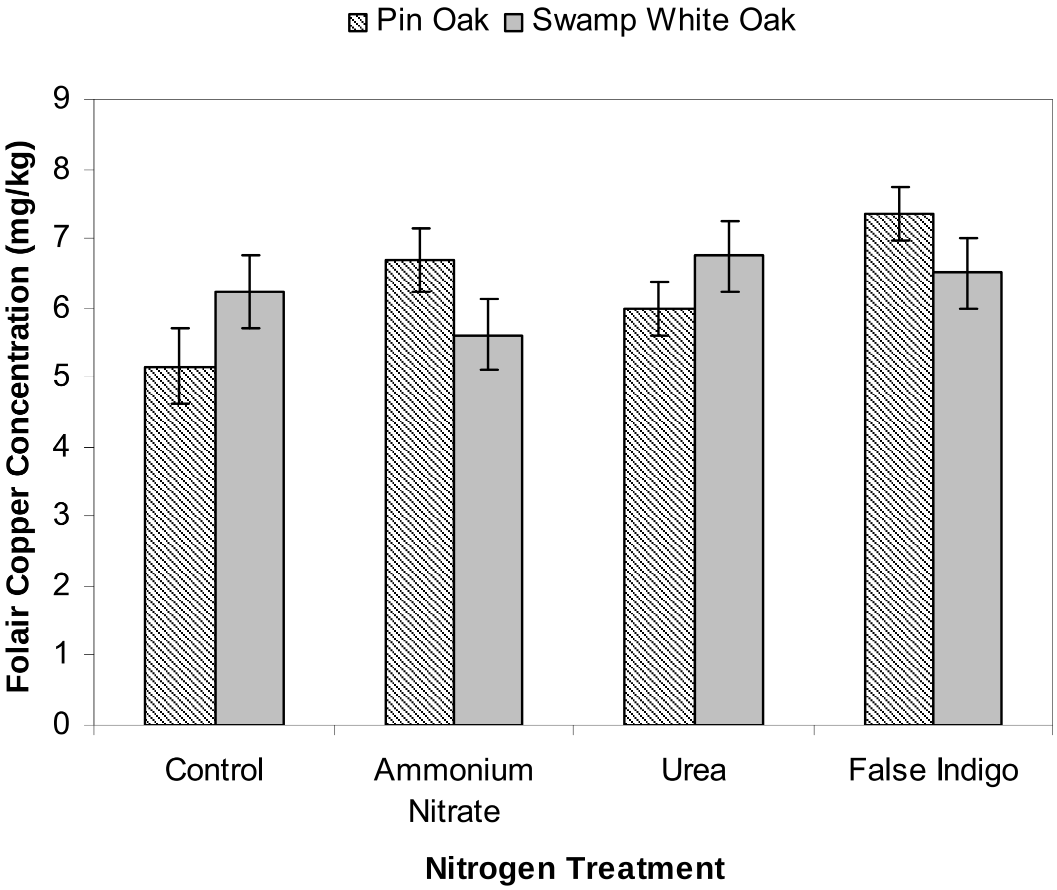

Figure 21. The relationship between oak species and N treatment effect on foliar Cu concentration (± SE) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

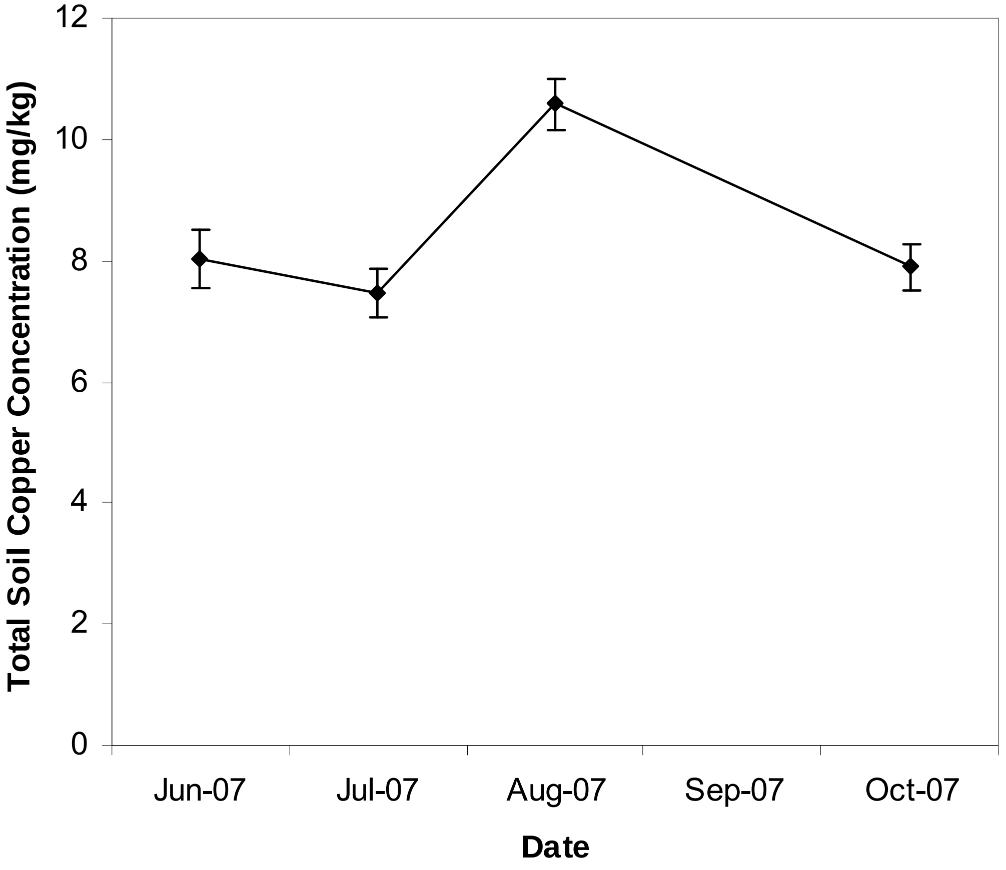

Figure 22. Soil Cu concentration (± SE) at a depth of 0-20 cm averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

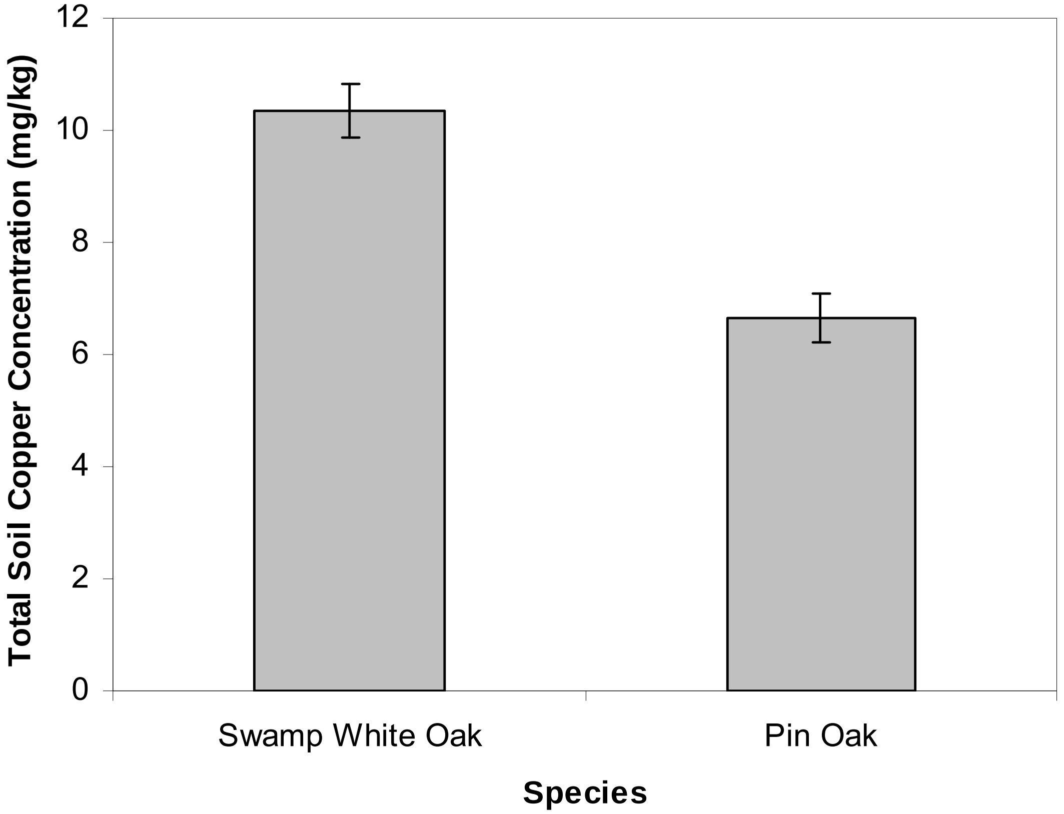

Figure 23. Soil Cu concentration (± SE) under pin oak and swamp white oak averaged across two sampling depths, four N treatments, and four sampling dates during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Gardiner and Miller (2004) report calcareous soils with a high pH of 8.0 to 8.4 have low Cu solubility. In addition, sandy soils often have low total Cu contents (Gardiner and Miller, 2004). The study site at Plowboy Bend Conservation Area has both a high pH (8.3) and sandy soils. This might suggest why a deficiency problem exists for foliar Cu.

Furthermore, a significant species*treatment effect occurred between pin oak and swamp white oak foliar Cu (Figure 21). Pin oaks had significantly higher foliar copper than swamp white oaks within the ammonium nitrate treatment. There were also significant differences that occurred between N treatments within pin oak and swamp white oak (Table 7). The pin oaks within the false indigo N treatment had significantly higher foliar Cu than the pin oaks within the urea or control N treatment. The swamp white oaks within the urea N treatment had significantly higher foliar Cu than the swamp white oaks within the ammonium nitrate N treatment.

Also, a significant date effect occurred in the soil Cu concentration under swamp white oak and pin oak during the growing season (Figure 22). The August sampling period was significantly higher than any other sampling period. Tisdale et al. (1993) report that cooper availability and movement are influenced by soil texture, pH, cation exchange capacity, organic matter, and hydrous oxides. Copper content is usually lower in excessively leached calcareous soils than in any other soil type (Tisdale et al., 1993). August was the driest month during the growing season, suggesting that less soil Cu was leached from the rhizosphere. This might help explain the significant increase in soil Cu during the August sampling period.

Furthermore, a significant species effect existed between soil under swamp white oak and soil under pin oak during the growing season (Figure 23). It was found through visual observation that swamp white oak had dense healthy crowns and pin oak had thin unhealthy crowns (Figure 24 and 25). The dense crown of the swamp white oak allowed for less vegetation around the weed barrier mat due to the shading of the canopy, whereas pin oak had a thick mixture of forbs and grasses surrounding the weed mat that might have taken up more Cu resulting in less soil Cu. Also, rainfall could pass through the pin oak crown more easily and have a greater effect on leaching of Cu down through the soil horizons.

Foliage and Soil Iron

Analysis of variance for foliar Fe showed a significant species*treatment interaction ($p = 0.0170$) and a significant date effect ($p = 0.0001$) for pin oak and swamp white oak during the growing season. Furthermore, a significant species*date interaction ($p = 0.005$) occurred in the rhizosphere under swamp white oak and pin oak during the growing season. No significant differences were found for Fe between the two sampling depths.

Figure 24. A nine year old pin oak study tree during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO. Conservation Area.

Figure 25. A nine year old swamp white oak study tree during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO. Conservation Area.

Foliar Fe concentration increased significantly between all sampling periods, starting at 48 mg/kg in June, 65 mg/kg in July, 78 mg/kg in August, and by October foliar concentration was the highest at 113 mg/kg (Figure 26). Although foliar Fe is within the sufficiency range reported by Mills and Jones (1996) deficiency symptoms still may occur. So-called Fe efficient plants have the ability to release hydrogen ions at their root surface and to produce Fe-complexing substances that enhance Fe uptake through the root surface (Mills and Jones, 1996). Furthermore, since the soil has a very basic pH, it could be limiting Fe uptake even though the leaves are within the sufficiency range.

Woodwell (1974) found that Fe increased slightly throughout the life of the leaves of two oak species. However, the findings of Bockheim and Leide (1991) are in contrast to the work of Woodwell, claiming that absolute amounts of Fe in oak foliage peaked in midsummer. This could explain that site conditions may be affecting the availability of nutrients to the oak trees.

In addition, a significant species*treatment effect occurred between swamp white oak and pin oak foliar Fe (Figure 27). The swamp white oaks had significantly higher foliar Fe than pin oaks within the urea treatment. Also, N treatments tested with separate ANOVAs within each individual species were significantly different in their effect on foliar Fe (Table 7). Pin oaks within the control and ammonium nitrate treatment had significantly higher foliar Fe than pin oaks within the urea or false indigo N treatment (Table 7). Swamp white oaks within the urea N treatment had significantly higher foliar Fe than swamp white oaks within the false indigo N treatment.

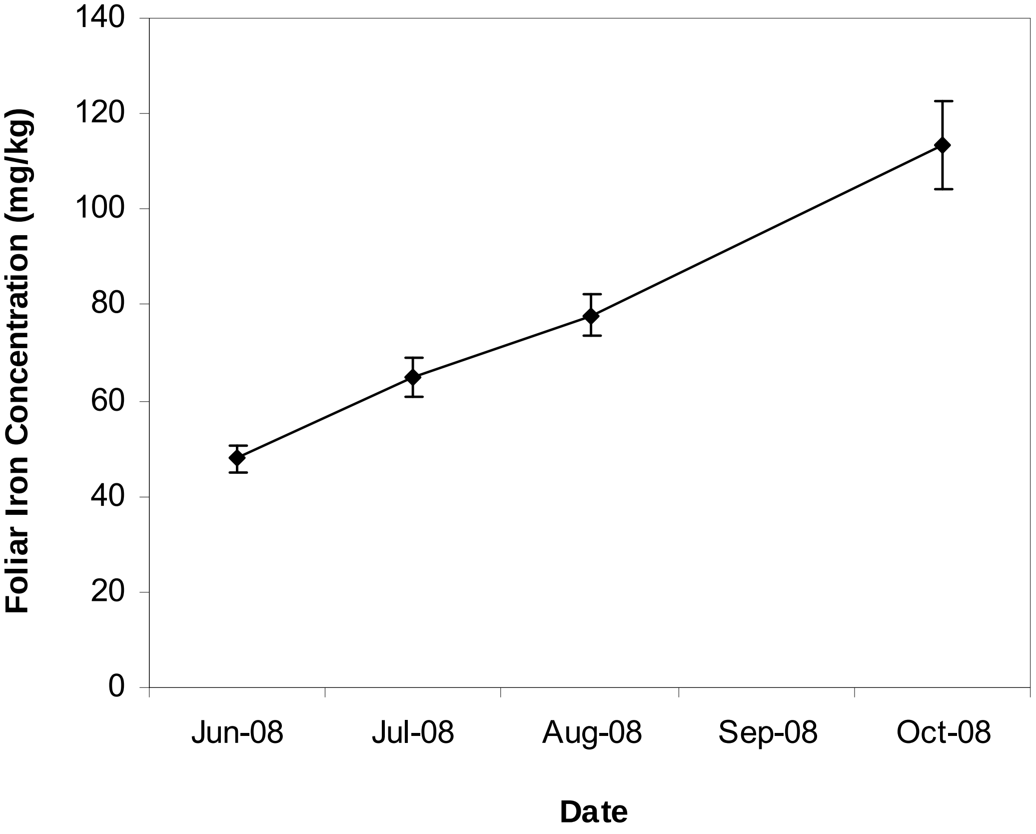

Figure 26. Foliar Fe concentration (± SE) averaged across pin oak and swamp white oak and four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

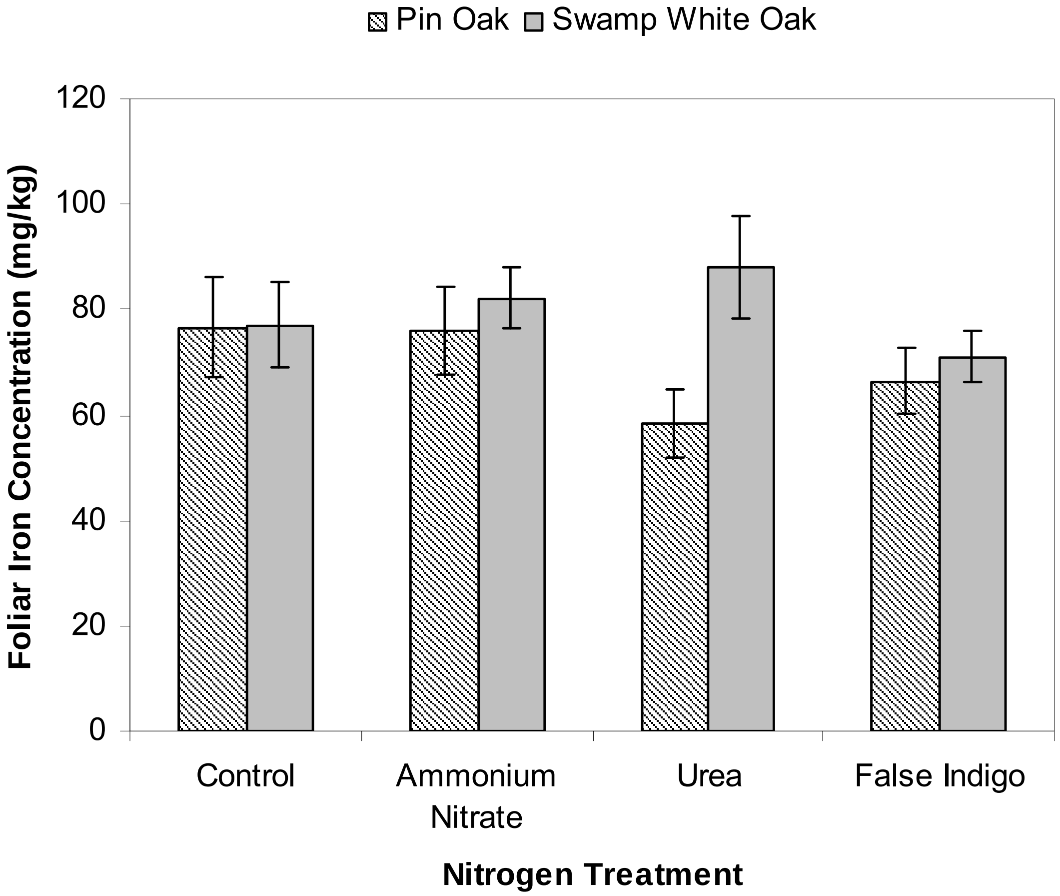

Figure 27. The relationship between oak species and N fertilizer treatment effect on foliar Fe concentration (± SE) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

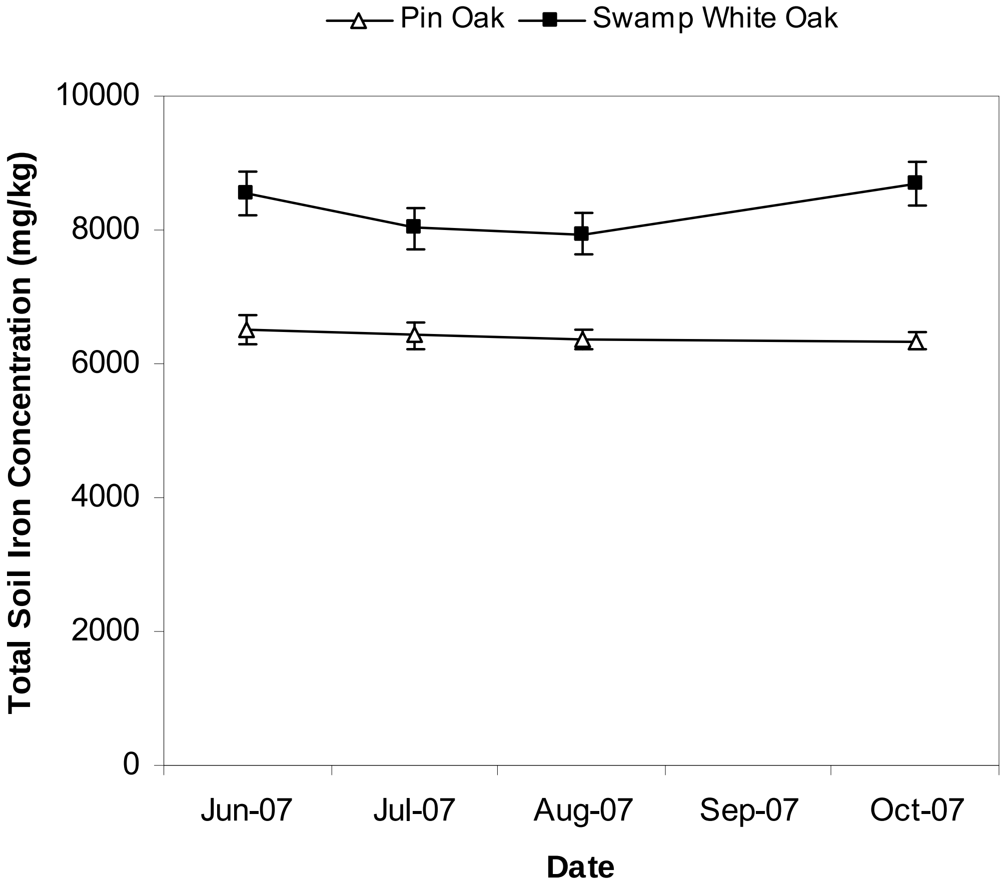

Figure 28. Soil Fe concentration (± SE) under pin oak and swamp white oak averaged across two sampling depths and four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Furthermore, ANOVA revealed a significant species*date interaction in the soil under swamp white oak and pin oak during the growing season. Swamp white oak had significantly higher soil Fe than pin oak (Figure 28). Soil pH under pin oak was significantly lower than the pH under swamp white oak. Gardiner and Miller (2004) conclude that Fe solubility decreases by a factor of 1000 per pH unit rise. Since soil under pin oak has significantly lower soil pH than soil under swamp white oak it might suggest that more of the Fe is in a soluble form and being taken up by the pin oak or surrounding vegetation resulting in less soil Fe.

Foliage and Soil Manganese

Analysis of variance for pin oak and swamp white oak foliar Mn revealed a significant species*treatment interaction ($p = 0.0155$) and a significant date effect ($p = 0.0001$). Separate ANOVAs for each species showed significant differences in N fertilizer treatment within the pin oaks but not swamp white oaks. Furthermore, statistical analysis for soil Mn revealed a significant date and species effect ($p = 0.0001$ for both). Analysis of variance showed no treatment effects for swamp white oak.

The foliar Mn sufficiency range reported by Mills and Jones (1996) is 121 to 633 mg/kg for swamp white oak and pin oak. The average foliar Mn concentration during the growing season in this study is 40 mg/kg for pin oak and 28 mg/kg for swamp white oak indicating a severe deficiency. When the determined tissue concentration for an essential nutrient falls close to or below the lower sufficiency value, one should assume that it is affecting plant growth and should be corrected (Mills and Jones, 1996).

However, even though foliar Mn is not within the sufficiency range, it did increase significantly at all four sampling periods during the growing season (Figure 29). The concentration in June was 22 mg/kg and had increased to 46 mg/kg by October. Bockheim and Leide (1991) and Woodwell (1974) reported that foliar Mn continued to increase in pin oak until leaf abscission occurred on a low-fertility soil in Wisconsin. This agrees with the findings of increasing foliar Mn concentration of pin oak at the low-fertility site at Plowboy Bend during the growing season.

Furthermore, a significant species*treatment effect occurred between swamp white oak and pin oak foliage and the N fertilizer treatments (Figure 30). Pin oak had significantly higher foliar Mn in the control, ammonium nitrate, and urea N treatments than swamp white oak. In addition, separate ANOVAs for each species showed pin oak foliar Mn expressed significant differences between N treatments, while N treatments within swamp white oak showed no significant differences (Table 7). The ammonium nitrate treatment resulted in significantly higher pin oak foliar Mn than the control, urea, and false indigo N treatments.

There was also a significant date effect on soil Mn concentration (Figure 31). Soil Mn was significantly higher in August than during any other sampling period. According to Mills and Jones (1996), Mn as the Mn^{2+} ion is easily leached from the soil. During the growing season of 2007, August received the least amount of rainfall (Figure 8). Since August was the driest month of sampling, less soil Mn would have leached, resulting in significantly greater Mn in the soil.

Furthermore, a significant species effect existed between swamp white oak and pin oak soil Mn concentration during the growing season (Figure 32). Pin oak had a significantly lower soil Mn concentration than swamp white oak. Through visual observation pin oak appeared to have a thin crown during much of the growing season, whereas, swamp white oak had a dense healthy crown (Figures 24 and 25). The dense crown of the swamp white oak allowed for less vegetation around the weed barrier mat due to the shading of the canopy, whereas pin oak had a thick mixture of forbs and grasses surrounding the weed mat that might have taken up more Mn resulting in less soil Mn. Also, rainfall could pass through the pin oak crown more easily and have a greater effect on leaching of Mn down through the soil horizons.

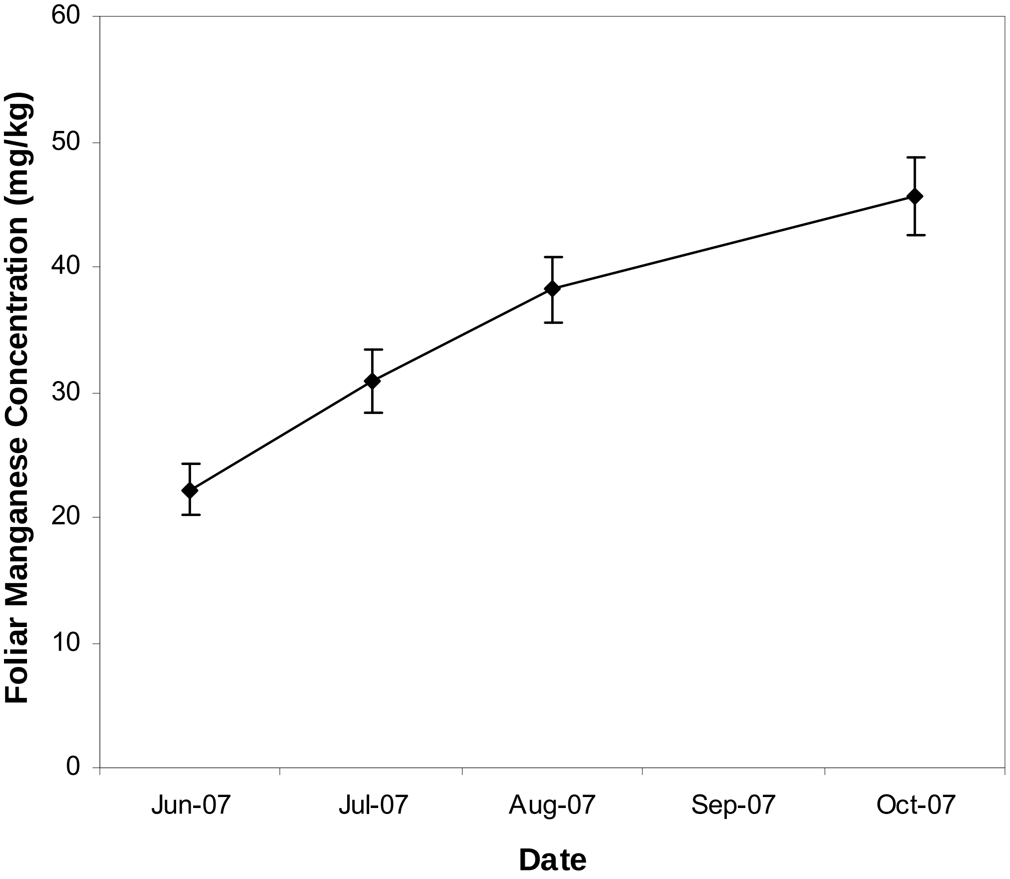

Figure 29. Foliar Mn concentration (± SE) averaged across pin oak and swamp white oak and across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

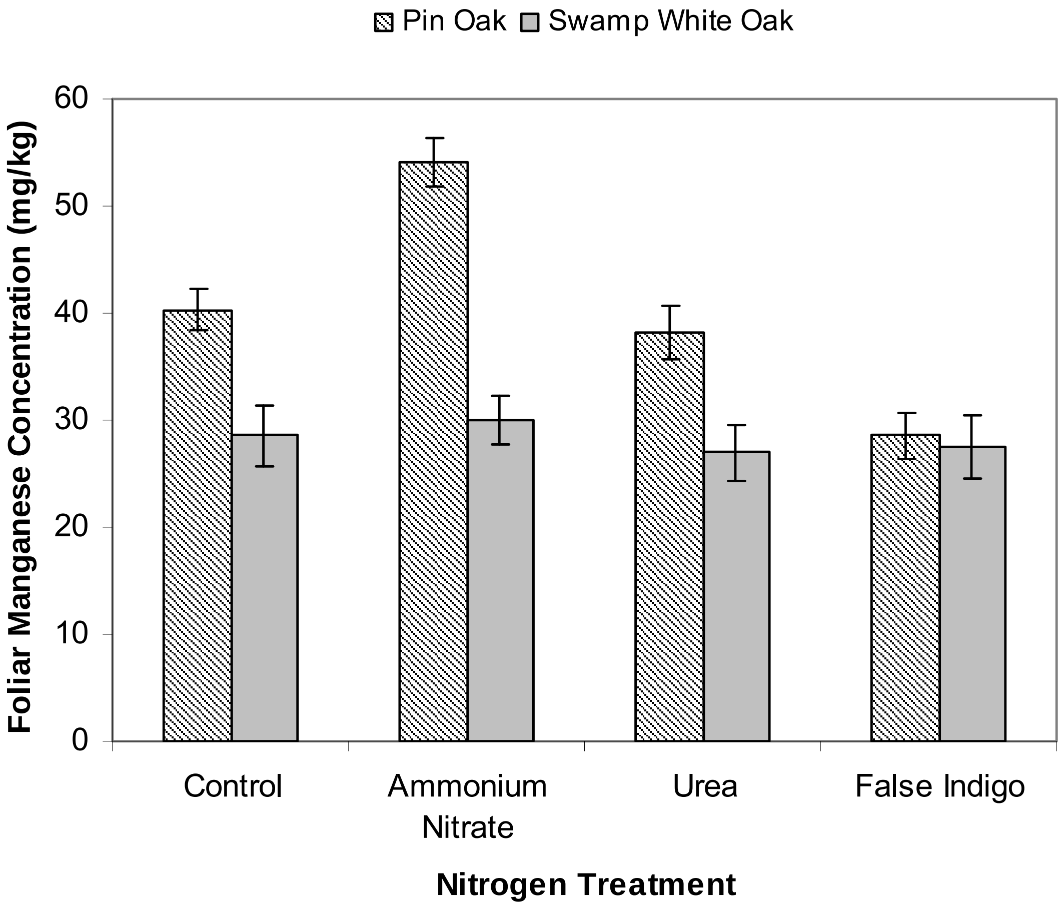

Figure 30. The relationship between oak species and N fertilizer treatment effect on foliar Mn concentration (± SE) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

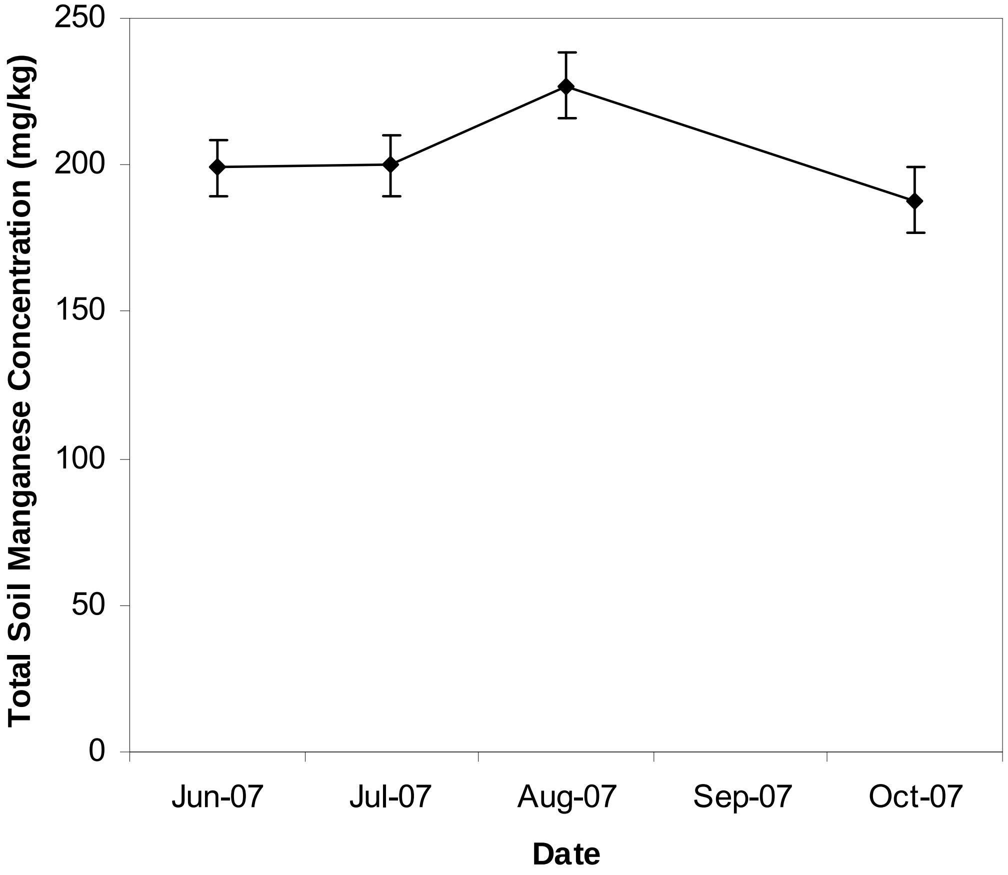

Figure 31. Soil Mn concentration (± SE) under pin oak and swamp white oak at a depth of 0-20 cm averaged across four N treatments during the 2007growing season at Plowboy Bend Conservation Area near Jamestown, MO.

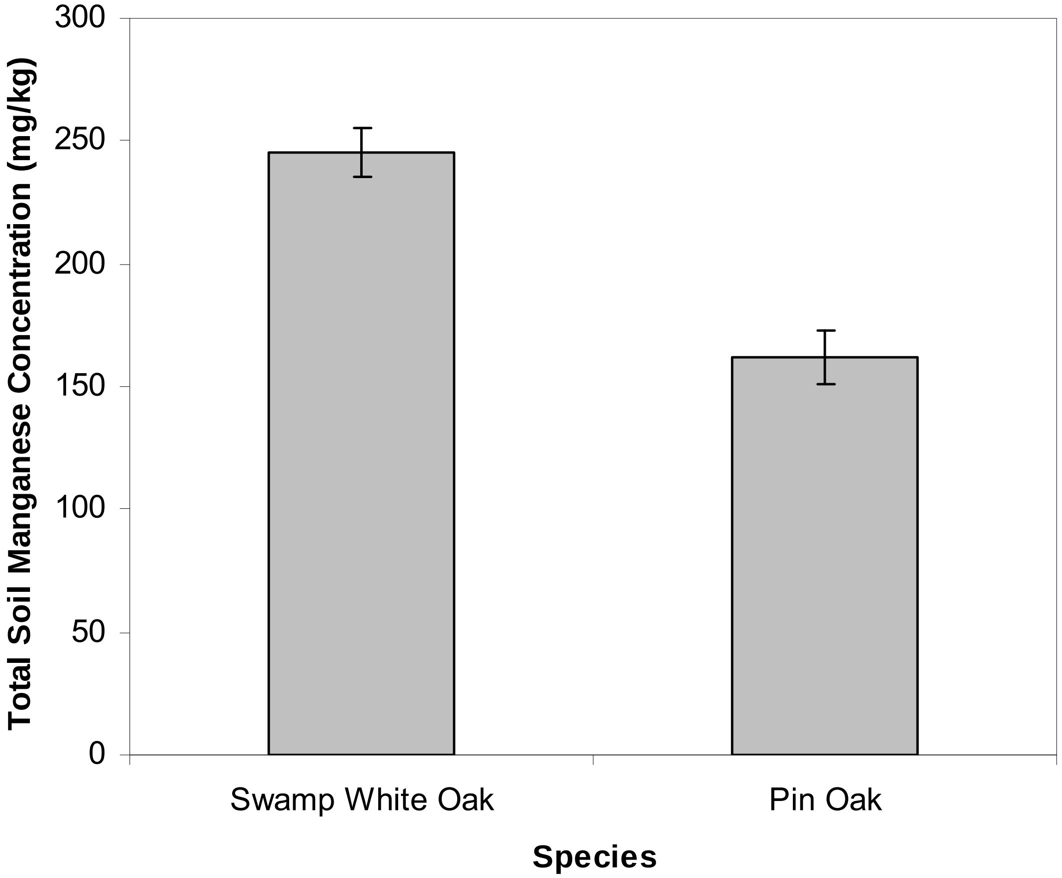

Figure 32. Soil Mn concentration (± SE) under pin oak and swamp white oak at a depth of 0-20 cm during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Foliage and Soil Zinc

Analysis of variance for foliar and soil Zn showed a significant species*date interaction ($p = 0.0001$ and $p = 0.0036$, respectively) between swamp white oak and pin oak during the growing season. No significant N treatment effects occurred for foliar or soil Zn.

Foliar Zn concentration for pin oak was significantly higher than for swamp white oak (Figure 33). The average foliar Zn concentration for pin oak was 52 mg/kg and 28 mg/kg for swamp white oak. Literature suggests that pin oak has a higher sufficiency range for Zn than swamp white oak (Tables 5 and 6). The significantly higher foliar Zn in pin oak could be a necessary requirement for healthy plant growth by that species.

Mills and Jones (1996) found that increasing the supply of N tends to increase plant Zn content. Pin oak seemed to respond after applying the ammonium fertilizers by taking up more Zn. However, foliar Zn concentration in swamp white oak decreased after the application of the N fertilizers, suggesting that there are inherent differences between species and their ability to take up nutrients from the soil (Goddard and Hollis, 1984).

Furthermore, calcareous soils have both a high pH and carbonates (typical of the soil found at the study site) to which Zn adsorbs (Gardiner and Miller, 2004). Mills and Jones (1996) report that Zn solubility increases about 100-fold for each unit that pH is lowered. Liu et al. (2004) found that two maize (*Zea mays* L.) genotypes differ in their ability to acidify the rhizosphere of a calcareous soil to allow P to become more available (Liu et al., 2004). Pin oak has a significantly lower rhizosphere pH (Figure 6), which might suggest it has the ability to acidify the rhizosphere and allow greater uptake of Zn over swamp white oak, resulting in greater Zn concentration in pin oak foliage.

A significant species*date interaction also occurred between swamp white oak and pin oak soil Zn concentration during the growing season (Figure 34). Swamp white oak exhibited significantly higher soil Zn than pin oak during every sampling period. Zinc concentration in the soil changed very little for both species after N treatments were applied.

Zinc concentration in pin oak foliage nearly doubles that of swamp white oak (Figure 33). As mentioned previously, pin oak had a significantly lower pH in the rhizosphere than swamp white oak (Figure 6). The high pH and sandy soils at Plowboy Bend could be forcing pin oak to adapt by releasing exudates from the roots in response to the harsh site conditions. These root exudates from pin oak might be facilitating Zn^{+2} diffusion to the roots (Havlin et al., 2005) allowing greater uptake of Zn through the tree resulting in less soil Zn. Furthermore, swamp white oak had dense healthy crowns, whereas, pin oak was the opposite (Figures 24, and 25), resulting in greater leaf litter at the end of the growing season. The greater quantity of leaf litter should increase organic matter and allow a greater amount of soil Zn to be bound (Gardiner and Miller, 2004) and not be as readily diffused to swamp white oak roots, resulting in less foliar Zn.

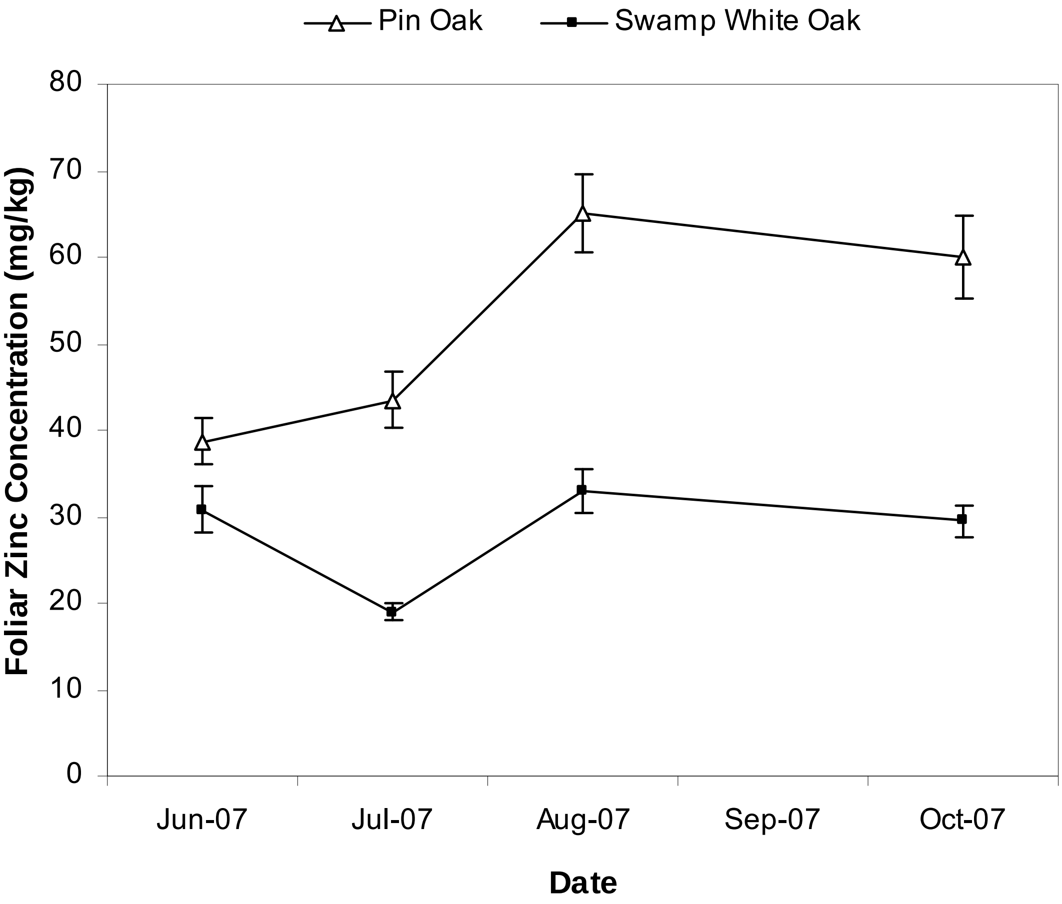

Figure 33. Foliar Zn concentration (± SE) for pin oak and swamp white oak averaged across four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

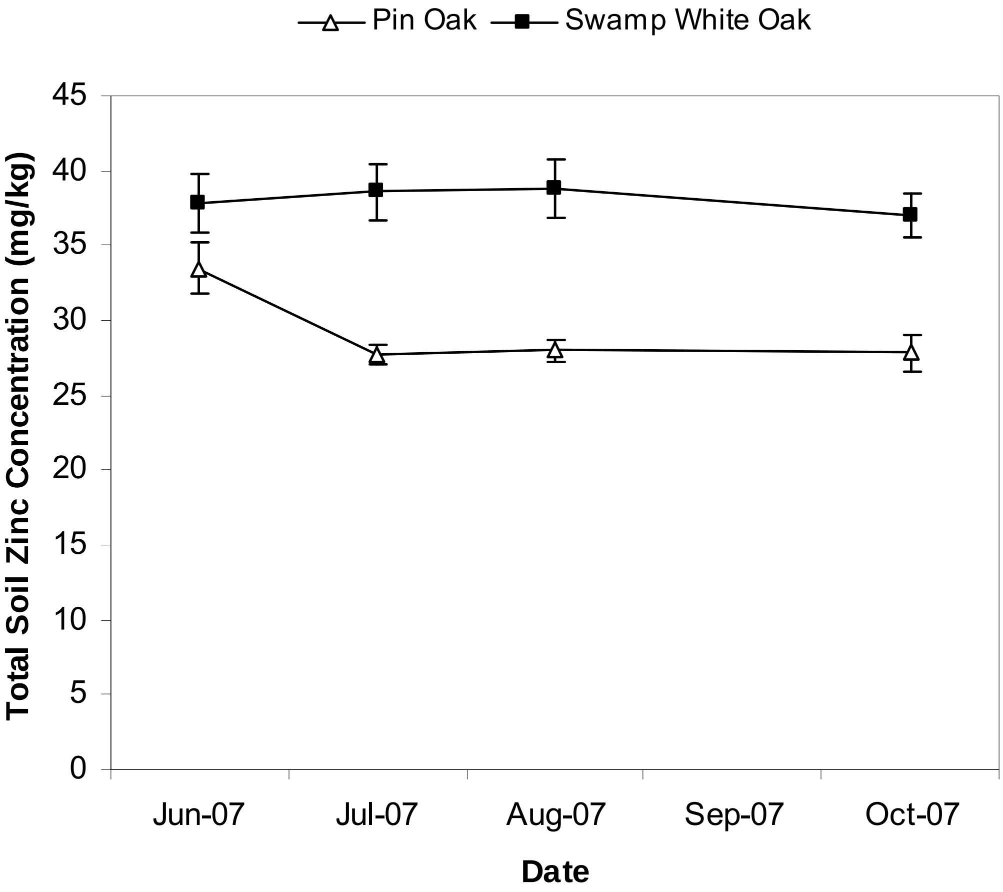

Figure 34. Soil Zn concentration (± SE) under pin oak and swamp white oak averaged across two sampling depths and four N treatments during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

CHAPTER 4

CONCLUSION

The results of this study showed that major problems exist in reforesting agricultural floodplains along the Missouri River including, depletion of soil nutrients following row cropping, high soil pH, lack of natural seed sources, and animal damage, just to name a few. This study was established to evaluate methods of enhancing tree growth by increasing foliar N content using slow-release N fertilizers or N-fixing shrubs.

The study took place during the 2007 growing season from June through October in which seasonal foliage and soil concentrations were determined for pin oak and swamp white oak saplings. Leaf and soil samples were collected prior to fertilization in June and then again after fertilization in July, August, and October. It was concluded that despite fertilization, pin oak and swamp white oak were still deficient in K, S, Ca, Mn, and Cu. Furthermore, pin oak was deficient in P and swamp white oak was deficient in N. Soil pH values above 8 can greatly affect solubility of these nutrients leaving them in an unavailable form. Our findings are consistent with those reported in the literature that high pH can be a limiting factor in many nutrient transformations in soil and plant uptake.

The N treatments had some significant effects within each species. Pin oaks showed significant differences between N treatment effects on foliar N, K, Mg, Fe, Cu, and Mn. Swamp white oaks showed significant differences between N treatment effects on foliar N, P, Mg, Fe, and Cu. Three species*treatment interactions occurred between pin oak and swamp white oak for foliar Fe, Cu, and Mn. Also, the slow-release urea had a significant effect on lowering soil pH shortly after application. Significant species*date interactions occurred between soil nutrients under swamp white oak and soil nutrients under pin oak for pH, P, K, Fe, and Zinc. Furthermore, significant species*date interactions occurred between foliage nutrients of pin oak and foliage nutrients of swamp white oak including N, P, K, S, Mg, Cu, and Zn. In addition, many significant species and date effects occurred as well. It can be suggested that pin oak is not a suitable species for this sandy, high pH site since it is better suited to acidic or low pH soils.

This study has provided useful information on the effects of fertilization on bottomland trees on a high pH site along the Missouri River. Perhaps in future studies a different selection of hard-mast trees might be beneficial on these bottomland sites, where productivity was almost destroyed by the great flood of 1993. Future research in bottomland hardwood plantings is vital to ensure adequate plant and animal diversity and to sustain these bottomlands in a productive manner, both economically and aesthetically, for future generations to come.

CHAPTER 5

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Appendix

A-1. Basic statistics from analysis of pin oak foliage during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO. Macronutrients (**bold**) are in percent, micronutrients (*italics*) are in mg/kg, and remaining nutrients are in mg/kg.

Element	N	Distribution	Mean*	SD*	Min*	Max*	# of undetected**	# Outliers***
N	80	normal	1.90	0.30	1.00	2.80	0	2
P	80	normal	0.14	0.04	0.08	0.25	0	3
K	80	normal	0.64	0.22	0.17	1.21	0	0
S	80	normal	0.12	0.02	0.07	0.18	0	0
Ca	80	normal	0.32	0.03	0.26	0.41	0	0
Cu	80	normal	6.30	2.10	1.10	13.10	0	0
Fe	80	normal	69.30	33.80	25.90	168.70	0	5
Mg	80	normal	0.15	0.03	0.09	0.23	0	0
Mn	80	normal	40.10	18.20	9.80	87.90	0	1
Al	80	normal	84.70	66.70	14.00	304.30	0	3
Zn	80	normal	51.70	7.70	14.40	120.20	0	3
Na	80	skewed to 0	96.70	63.40	35.90	297.30	0	2
Se	80	skewed to 0	0.50	0.80	0.00	2.90	49	0
Mo	80	skewed to 0	1.40	1.20	0.00	5.60	10	2
Ba	80	normal	42.30	19.90	11.00	113.10	0	0
Co	80	below detection	0.70	0.70	0.00	3.40	13	0
Cr	80	below detection	7.20	17.30	0.00	148.20	1	0
Ag	80	below detection	0.00	0.00	0.00	0.20	72	0
Cd	80	below detection	0.40	0.20	0.00	1.10	7	0
Ni	80	skewed to 0	26.30	23.30	4.20	144.10	0	0
Pb	80	below detection	0.90	1.00	0.00	4.00	18	0
Sb	80	below detection	0.20	0.30	0.00	1.00	68	0
Be	80	below detection	0.00	0.00	0.00	0.10	76	0
Sn	80	below detection	0.40	0.60	0.00	2.30	48	0
V	80	below detection	0.10	0.30	0.00	2.30	68	0
As	80	below detection	0.30	0.50	0.00	1.80	55	0

*After outliers were removed

**Total number of sample elements not dected with ICP

***Data beyond 3.5* IQR (Interquartile Range) from the mean is considered an outlier and the probability of these values occurring within the indicated population is less than 0.001 percent after ‘PROC UNIVARIATE PLOT NORMAL FREQUENCY’ analysis for that element (McClave and Sincich, 2000)

A-2. Basic statistics from analysis of swamp white oak foliage during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO. Macronutrients (**bold**) are in percent, micronutrients (*italics*) are in mg/kg, and remaining nutrients are in mg/kg.

Element	N	Distribution	Mean*	SD*	Min*	Max*	# of undetected**	# Outliers***
N	80	normal	1.70	0.20	1.20	2.10	0	0
P	80	normal	0.16	0.03	0.11	0.25	0	2
K	80	normal	0.71	0.11	0.41	1.07	0	0
S	80	normal	0.11	0.01	0.09	0.16	0	0
Ca	80	normal	0.32	0.03	0.27	0.41	0	0
Cu	80	normal	6.30	2.20	1.70	12.10	0	2
Fe	80	normal	79.70	32.00	35.90	176.80	0	4
Mg	80	normal	0.19	0.03	0.11	0.29	0	1
Mn	80	normal	28.30	12.00	7.70	54.60	0	0
Al	80	normal	75.90	46.70	0.00	247.80	0	3
Zn	80	normal	28.10	10.80	13.60	60.20	0	0
Na	80	skewed to 0	121.60	76.80	26.80	358.50	0	3
Se	80	skewed to 0	0.30	0.50	0.00	1.70	57	2
Mo	80	skewed to 0	1.20	0.70	0.00	3.30	8	5
Ba	80	normal	105.60	55.10	14.70	246.60	0	0
Co	80	below detection	0.10	0.20	0.00	0.90	41	6
Cr	80	below detection	1.90	1.40	0.00	6.10	8	2
Ag	80	below detection	0.00	0.00	0.00	0.20	66	0
Cd	80	below detection	0.00	0.10	0.00	0.40	61	0
Ni	80	skewed to 0	10.20	4.20	3.50	21.60	0	2
Pb	80	below detection	0.80	0.90	0.00	3.80	25	0
Sb	80	below detection	0.10	0.20	0.00	1.00	66	0
Be	80	below detection	0.00	0.00	0.00	0.00	78	2
Sn	80	below detection	0.40	0.60	0.00	2.80	52	0
V	80	below detection	0.10	0.10	0.00	0.50	40	0
As	80	below detection	0.10	0.20	0.00	1.10	73	0

*After outliers were removed

**Total number of sample elements not dected with ICP

***Data beyond 3.5* IQR (Interquartile Range) from the mean is considered an outlier and the probability of these values occurring within the indicated population is less than 0.001 percent after 'PROC UNIVARIATE PLOT NORMAL FREQUENCY' analysis for that element (McClave and Sincich, 2000)

A-3. Basic statistics from analysis of false indigo foliage during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO. Macronutrients (**bold**) are in percent, micronutrients (*italics*) are in mg/kg, and other nutrients are in mg/kg.

Element	N	Distribution	Mean*	SD*	Min*	Max*	# of undetected**	# Outliers***
N	40	normal	2.70	0.30	2.10	3.40	0	0
P	40	normal	0.19	0.04	0.12	0.27	0	1
K	40	normal	0.90	0.18	0.48	1.22	0	0
S	40	normal	0.14	0.02	0.09	0.19	0	1
Ca	40	normal	0.32	0.03	0.27	0.39	0	0
Cu	40	normal	10.80	3.40	4.60	20.00	0	0
Fe	40	normal	90.60	23.80	50.50	141.40	0	0
Mg	40	normal	0.16	0.04	0.09	0.25	0	0
Mn	40	normal	31.90	12.90	12.70	69.80	0	0
Al	40	normal	62.60	30.60	16.70	139.10	0	0
Zn	40	normal	24.20	8.90	12.60	52.90	0	0
Na	40	skewed to 0	101.00	88.40	20.70	360.20	0	0
Se	40	skewed to 0	0.90	1.00	0.00	3.40	19	0
Mo	40	skewed to 0	3.50	2.20	0.00	10.40	1	2
Ba	40	normal	47.70	24.20	16.10	120.60	0	0
Co	40	below detection	0.30	0.50	0.00	2.90	16	0
Cr	40	below detection	1.70	1.00	0.00	4.50	2	0
Ag	40	below detection	0.00	0.00	0.00	0.20	35	0
Cd	40	below detection	0.00	0.00	0.00	0.20	37	0
Ni	40	skewed to 0	8.90	4.90	3.40	25.10	0	0
Pb	40	below detection	0.60	0.60	0.00	1.80	14	1
Sb	40	below detection	0.10	0.30	0.00	1.20	32	0
Be	40	below detection	0.00	0.00	0.00	0.10	37	0
Sn	40	below detection	0.40	0.70	0.00	2.50	25	0
V	40	below detection	0.00	0.00	0.00	0.20	31	2
As	40	below detection	0.30	0.50	0.00	1.70	28	0

*After outliers were removed

**Total number of sample elements not dected with ICP

***Data beyond 3.5* IQR (Interquartile Range) from the mean is considered an outlier and the probability of these values occurring within the indicated population is less than 0.001 percent after ‘PROC UNIVARIATE PLOT NORMAL FREQUENCY’ analysis for that element (McClave and Sincich, 2000)

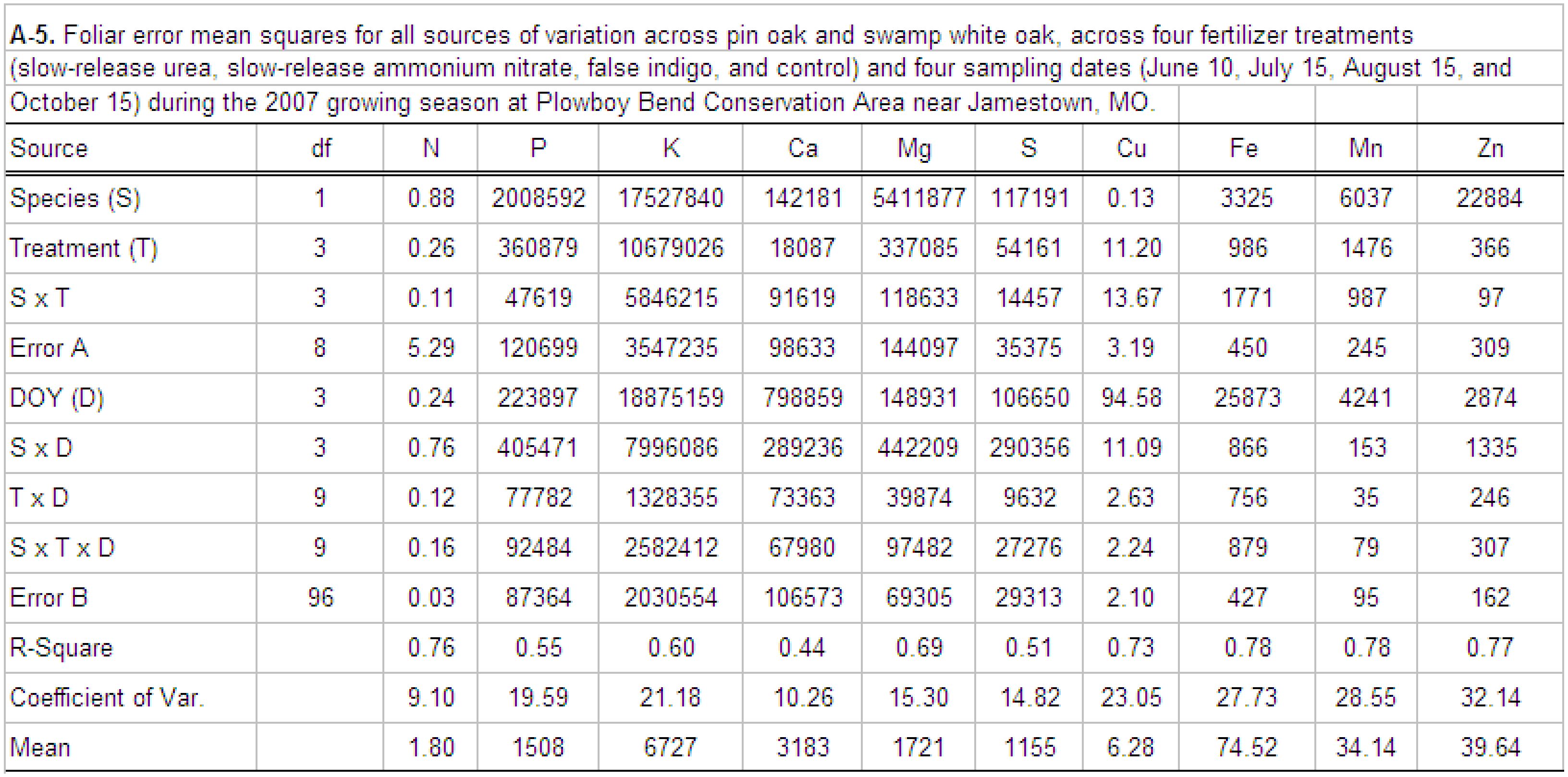
A-4. Basic statistics from soil analysis under swamp white oak, pin oak, and false indigo across four sampling dates (June 10, July 15, August 15, and October 15) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO. All nutrients are in mg/kg.

Element	N	Distribution	Mean*	SD*	Min*	Max*	# of undetected**	# outliers***
pH	320	normal	8.30	0.20	7.70	8.60	0	1
P	320	normal	419	69	263	611	0	1
K	320	normal	11762	1183	8191	15350	0	10
S	320	normal	175	33	111	271	0	0
Ca	320	normal	1017	579	201	2710	0	3
Cu	320	normal	8.50	3.10	3.60	17.10	0	0
Fe	320	normal	7360	1561	4535	11875	0	1
Mg	320	normal	68	62	4	280	0	10
Mn	320	normal	204	72	84	419	0	0
Al	320	normal	2978	614	1817	5219	0	14
Zn	320	normal	33.70	8.70	17.70	66.20	0	4
Na	320	normal	5776	840	3308	9023	0	0
Se	320	normal	1.90	1.30	0.00	5.50	79	0
Mo	320	normal	0.90	0.50	0.00	2.70	17	30
Ba	320	normal	173	50	42	374	0	0
Co	320	normal	2.50	0.50	1.50	4.10	0	3
Cr	320	normal	21.70	5.60	12.30	34.30	0	1
Ag	320	below detection	0.20	0.10	0.00	0.70	68	3
Cd	320	below detection	0.60	0.10	0.30	0.90	0	3
Ni	320	normal	14.70	2.80	9.90	22.60	0	2
Pb	320	normal	12.90	1.80	9.30	19.00	0	4
Sb	320	below detection	0.90	0.70	0.00	3.00	93	0
Be	320	bimodal	0.60	0.30	0.00	1.10	65	0
Sn	320	below detection	1.20	0.90	0.00	3.80	81	0
V	320	normal	41.70	11.30	25.20	68.60	0	0
As	320	bimodal	10.50	8.30	1.50	28.60	0	1

*After outliers were removed

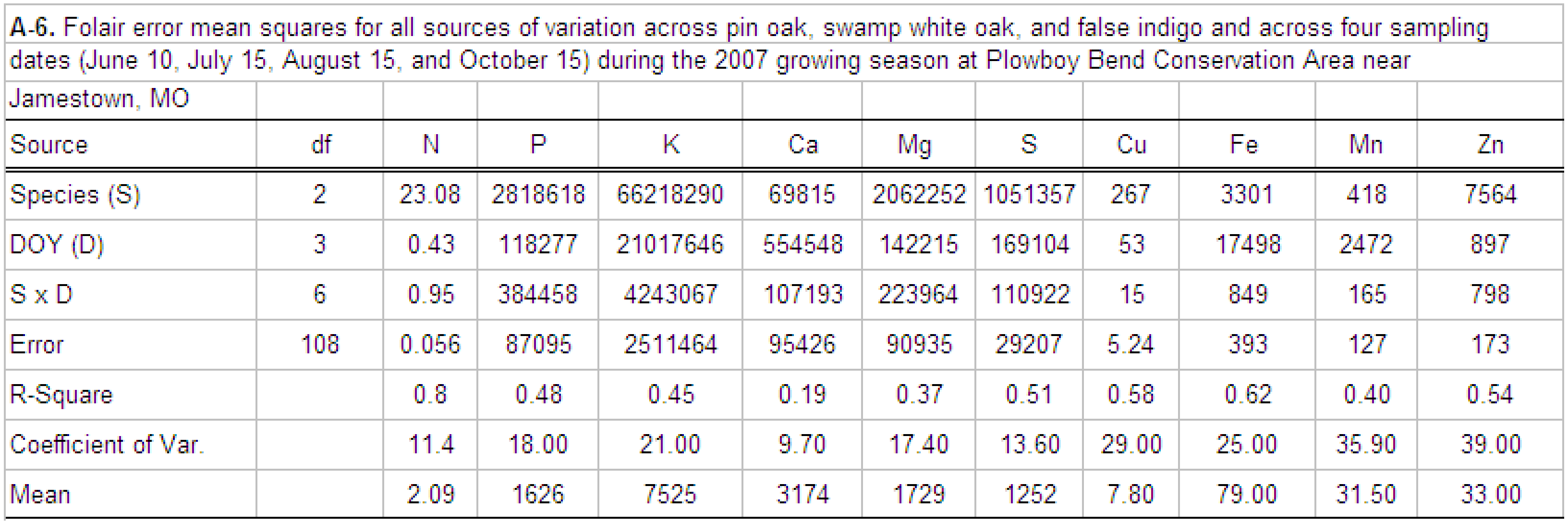
**Total number of sample elements not dected with ICP

***Data beyond 3.5* IQR (Interquartile Range) from the mean is considered an outlier and the probability of these values occurring within the indicated population is less than 0.001 percent after ‘PROC UNIVARIATE PLOT NORMAL FREQUENCY’ analysis for that element (McClave and Sincich, 2000)



A-5. Foliar error mean squares for all sources of variation across pin oak and swamp white oak, across four fertilizer treatments (slow-release urea, slow-release ammonium nitrate, false indigo, and control) and four sampling dates (June 10, July 15, August 15, and October 15) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

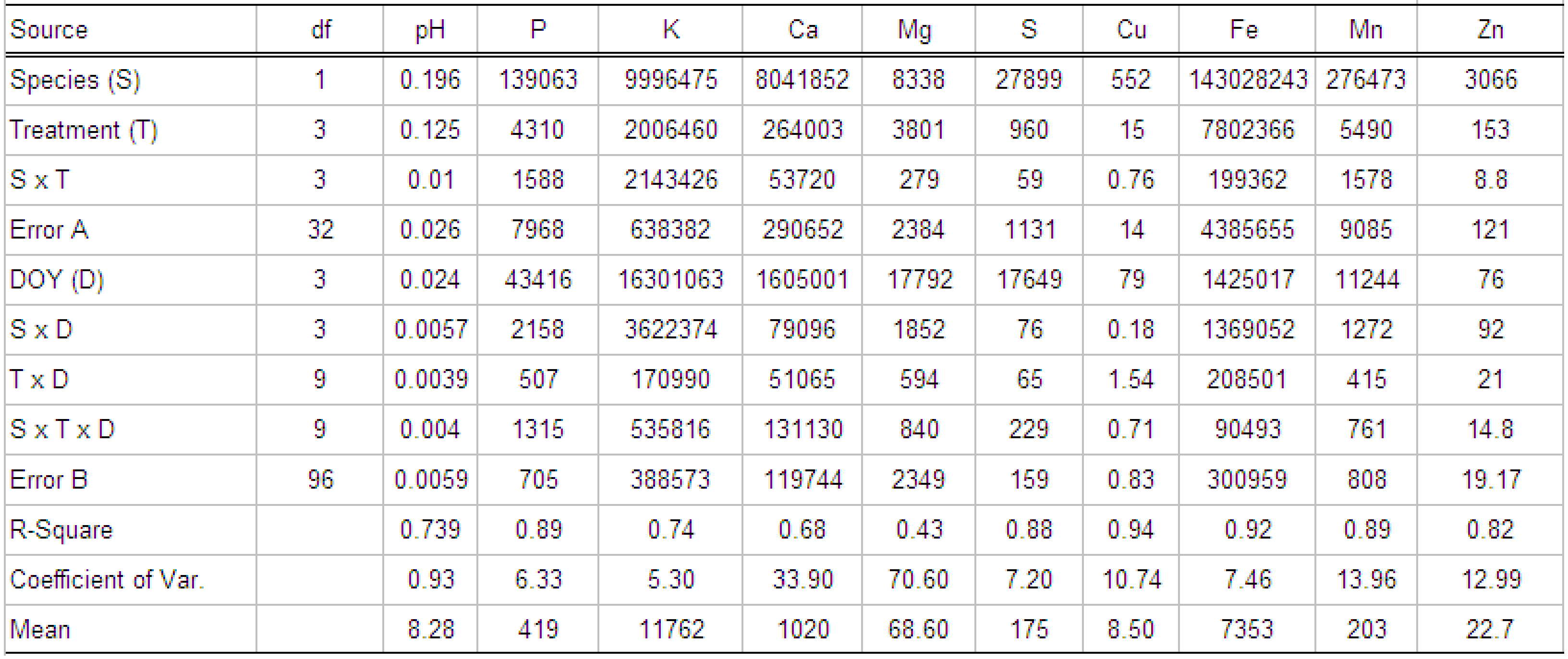
Source	df	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Species (S)	1	0.88	2008592	17527840	142181	5411877	117191	0.13	3325	6037	22884
Treatment (T)	3	0.26	360879	10679026	18087	337085	54161	11.20	986	1476	366
S x T	3	0.11	47619	5846215	91619	118633	14457	13.67	1771	987	97
Error A	8	5.29	120699	3547235	98633	144097	35375	3.19	450	245	309
DOY (D)	3	0.24	223897	18875159	798859	148931	106650	94.58	25873	4241	2874
S x D	3	0.76	405471	7996086	289236	442209	290356	11.09	866	153	1335
T x D	9	0.12	77782	1328355	73363	39874	9632	2.63	756	35	246
S x T x D	9	0.16	92484	2582412	67980	97482	27276	2.24	879	79	307
Error B	96	0.03	87364	2030554	106573	69305	29313	2.10	427	95	162
R-Square		0.76	0.55	0.60	0.44	0.69	0.51	0.73	0.78	0.78	0.77
Coefficient of Var.		9.10	19.59	21.18	10.26	15.30	14.82	23.05	27.73	28.55	32.14
Mean		1.80	1508	6727	3183	1721	1155	6.28	74.52	34.14	39.64



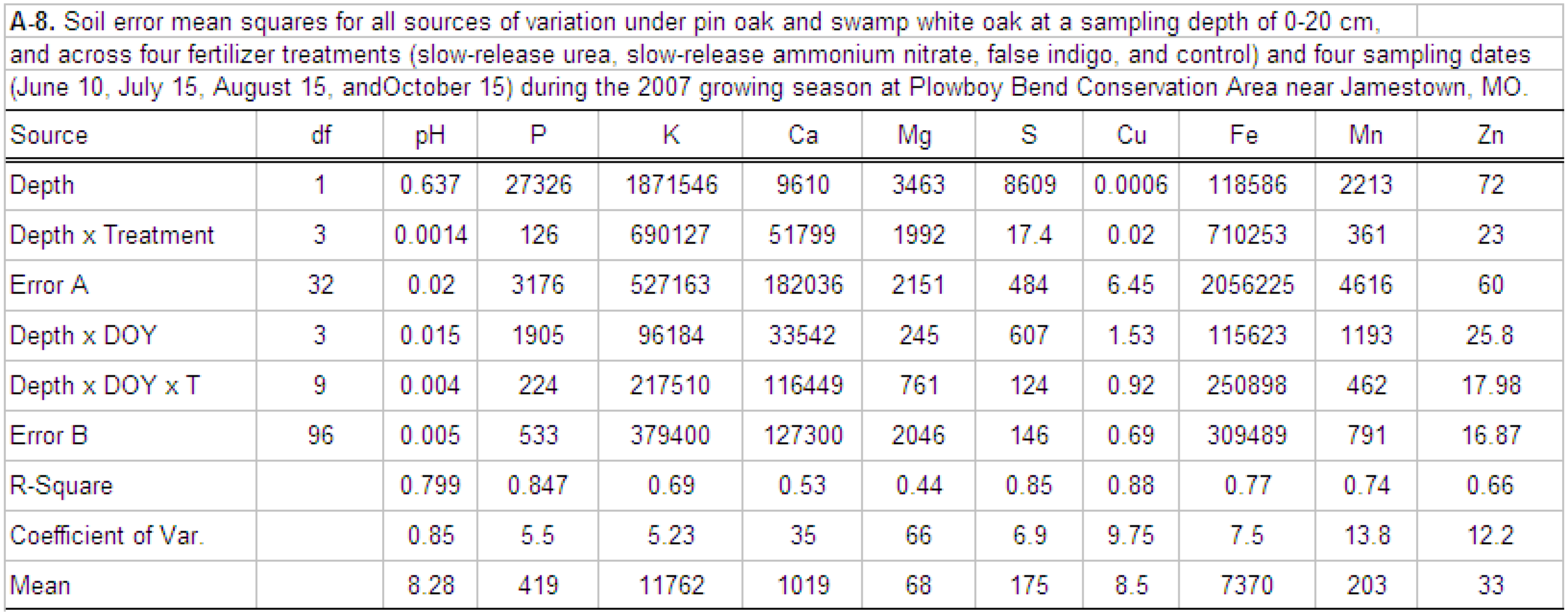
A-6. Folair error mean squares for all sources of variation across pin oak, swamp white oak, and false indigo and across four sampling dates (June 10, July 15, August 15, and October 15) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO

Source	df	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Species (S)	2	23.08	2818618	66218290	69815	2062252	1051357	267	3301	418	7564
DOY (D)	3	0.43	118277	21017646	554548	142215	169104	53	17498	2472	897
S x D	6	0.95	384458	4243067	107193	223964	110922	15	849	165	798
Error	108	0.056	87095	2511464	95426	90935	29207	5.24	393	127	173
R-Square		0.8	0.48	0.45	0.19	0.37	0.51	0.58	0.62	0.40	0.54
Coefficient of Var.		11.4	18.00	21.00	9.70	17.40	13.60	29.00	25.00	35.90	39.00
Mean		2.09	1626	7525	3174	1729	1252	7.80	79.00	31.50	33.00

A-7. Soil error mean squares for all sources of variation under pin oak and swamp white oak at a sampling depth of 0-20 cm, and across four fertilizer treatments (slow-release urea, slow-release ammonium nitrate, false indigo, and control) and four sampling dates (June 10, July 15, August 15, andOctober 15) during the2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.



Source	df	pH	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Species (S)	1	0.196	139063	9996475	8041852	8338	27899	552	143028243	276473	3066
Treatment (T)	3	0.125	4310	2006460	264003	3801	960	15	7802366	5490	153
S x T	3	0.01	1588	2143426	53720	279	59	0.76	199362	1578	8.8
Error A	32	0.026	7968	638382	290652	2384	1131	14	4385655	9085	121
DOY (D)	3	0.024	43416	16301063	1605001	17792	17649	79	1425017	11244	76
S x D	3	0.0057	2158	3622374	79096	1852	76	0.18	1369052	1272	92
T x D	9	0.0039	507	170990	51065	594	65	1.54	208501	415	21
S x T x D	9	0.004	1315	535816	131130	840	229	0.71	90493	761	14.8
Error B	96	0.0059	705	388573	119744	2349	159	0.83	300959	808	19.17
R-Square		0.739	0.89	0.74	0.68	0.43	0.88	0.94	0.92	0.89	0.82
Coefficient of Var.		0.93	6.33	5.30	33.90	70.60	7.20	10.74	7.46	13.96	12.99
Mean		8.28	419	11762	1020	68.60	175	8.50	7353	203	22.7



A-8. Soil error mean squares for all sources of variation under pin oak and swamp white oak at a sampling depth of 0-20 cm, and across four fertilizer treatments (slow-release urea, slow-release ammonium nitrate, false indigo, and control) and four sampling dates (June 10, July 15, August 15, andOctober 15) during the 2007 growing season at Plowboy Bend Conservation Area near Jamestown, MO.

Source	df	pH	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
Depth	1	0.637	27326	1871546	9610	3463	8609	0.0006	118586	2213	72
Depth x Treatment	3	0.0014	126	690127	51799	1992	17.4	0.02	710253	361	23
Error A	32	0.02	3176	527163	182036	2151	484	6.45	2056225	4616	60
Depth x DOY	3	0.015	1905	96184	33542	245	607	1.53	115623	1193	25.8
Depth x DOY x T	9	0.004	224	217510	116449	761	124	0.92	250898	462	17.98
Error B	96	0.005	533	379400	127300	2046	146	0.69	309489	791	16.87
R-Square		0.799	0.847	0.69	0.53	0.44	0.85	0.88	0.77	0.74	0.66
Coefficient of Var.		0.85	5.5	5.23	35	66	6.9	9.75	7.5	13.8	12.2
Mean		8.28	419	11762	1019	68	175	8.5	7370	203	33