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# Relationships of Hydrological and Soil Conditions to Red Oak Acorn Yield in the Lower Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions

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By

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Red oak (*Quercus* spp.) acorns provide food for wildlife and are propagules for regeneration of these trees. Annual yield of acorns varies temporally and site-specifically. I examined acorn yield in relation to hydrology and soils of hardwood bottomlands at five sites in the Mississippi Alluvial Valley and a site in the Mississippi Interior Flatwoods Region during fall-winter 2012-2013. Acorn yield varied among sites (mean = 44.9 acorns/$m^2$; SE = 6.7; CV = 14.9%). Duration of flooding during the growing season differed among sites which influenced soil characteristics. Acorn yield varied inversely with number of days sites were inundated during the growing season ($R^2$ = 0.6725; $P$ = 0.0456; $n$ = 6) during 2012-2013. Managers should consider alleviating growing season flooding of red oaks, which may increase acorn yield and sustain red oaks and other bottomland hardwoods.

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# CHAPTER I

# INTRODUCTION

Bottomland hardwood forests were historically a dominant forest type in the eastern United States, particularly within the Mississippi Alluvial Valley (MAV) covering 10 million ha (Fredrickson et al. 2005). However, due to altered hydrology and harvesting of trees for timber and clearing land for agriculture and other human uses, only 2.8 million ha remain (King et al. 2005). Within bottomland hardwood forests in the MAV, hydrology is a major driver of ecosystem structure and function, and these forests are some of the most productive due to nutrient inputs from flood waters and abundant seasonal precipitation (Reinecke et al. 1989, Heitmeyer et al. 2005).

Of the tree species in MAV bottomland hardwood forests, red oak (*Quercus* spp.; Section *Erythrobalanus*) species are important economically and ecologically (Kaminski et al. 2003, Heitmeyer 2006). Five red oak species are commonly found in bottomland hardwood forests: cherrybark oak (*Q. pagoda*), Nuttall oak (*Q. texana*), pin oak (*Q. palustris*), water oak (*Q. nigra*), and willow oak (*Q. phellos*). These species vary in their flood tolerance and preferred soil characteristics, and thus are found in different locations within bottomland hardwood forests (Hodges 1997, Straub 2012).

Acorns of red oaks are a principal food source for several waterfowl species and other wildlife in the MAV (Dabbert and Martin 2000, Kaminski et al. 2003, Heitmeyer 2006). Kaminski et al. (2003) reported that red oak acorns provide true metabolizable energy (TME) of ~2.76 kcal (dry mass)/g for mallards (*Anas platyrhynchos*) and wood ducks (*Aix sponsa*), which is comparable to many moist-soil seeds consumed by waterfowl. Waterfowl biologists and conservationists assume that waterfowl forage for acorns and other seeds if at least 50 kg/ha exist (Reinecke et al. 1989, Greer et al. 2007). This value is known as giving up density (GUD) or food availability threshold (FAT; Reinecke et al. 1989, Hagy 2010). Multiple studies have reported that red oak acorn yield and on-ground abundance in the MAV exceed estimates of GUD or FAT (McQuilkin and Musbach 1977, Guttery 2006, Thornton 2009, Leach 2011, Straub 2012). This evidence demonstrates the importance of bottomland hardwood forests to provide waterfowl forage and cover.

Within bottomland hardwood forests, research has focused on greentree reservoirs (GTRs), which are forested areas impounded with a levee to provide consistent water for waterfowl use (Francis 1983, Frederickson et al. 2005). Development of GTRs has increased since late 1930's, with >100 having been created in the MAV (Wigley and Filer 1989). However, GTRs inhibit natural hydrologic dynamics of bottomland hardwood forests (Frederickson 2005). Additionally, other consequences of GTRs have been reported, such as decreased acorn yield by red oaks (Francis 1983), changes in species composition (Young et al. 1995, Guttery 2006), and decreased red oak regeneration (Gray and Kaminski 2005, Guttery 2006). Because GTRs comprise a small portion of the bottomland hardwood forested area in the MAV, estimating acorn yield and understanding the effects on yields in the more expansive, naturally, seasonally flooded bottomland forests of the MAV are important to sustain these forests.

Acorn yield varies temporally and spatially, with many acorns being produced by most trees in an area some years (i.e., masting), and few produced in other years (Sork et al. 1993, Kelly 1994, Sanchez-Humanes et al. 2011, Straub 2012). Masting events are extremely variable (Sork et al. 1993, Kelly 1994, Koenig and Knops 2005). Furthermore the spatial scale at which it occurs varies, with masting occurring in only one population some years and across entire regions in other years (Sork et al. 1993). There are conflicting hypotheses regarding causes for this inter-year and site variation (Salisbury 1942, Sharp and Sprague 1967, Sork 1993, Kelly 1994, Sullivan and Kelly 2000, Kelly and Sork 2002, Koenig and Knops 2005). However, many variables that may affect acorn yield, particularly site specific characteristics, have not been examined and an accurate method to predict acorn yield has not been formulated. Thus, our ability to understand inter-year and site variation in acorn yield is diminished.

Much research on acorn masting has been conducted in upland hardwood systems where the primary source of water is precipitation. Bottomland hardwood systems have two primary water sources, precipitation and riverine originated flooding. Therefore, the soil moisture regime is quite different from an upland hardwood system, possibly affecting the timing and size of masting events (Sork and Bramble 1993, Sork et al. 1993, Koenig et al. 1996, Pérez-Ramos et al. 2010). Research regarding the relationship of hydrology and masting has been primarily conducted in GTRs. The relationship of masting and soil characteristics has rarely been examined and may be important regulators of inter-year and site variability. Indeed, bottomland forests slow floodwater velocities, which allows suspended sediments to fall out of suspension and in turn deposit nutrients (Hupp et al. 1993, Hupp 2000). Additionally, hydroperiod, soils, and sedimentation have been recognized as potential drivers of masting events and acorn yield in bottomland hardwood systems (Straub 2012). However, the potential impacts of soils, soil nutrients, and hydrology on acorn yield has not been examined.

Thus, I undertook my study to evaluate effects of soils and hydrology on acorn yield in naturally flooded bottomland hardwood forests. The objectives of the study were to: 1) estimate red oak acorn yield in the MAV and Mississippi Interior Flatwoods (MIF) during fall-winter of 2012-2013, 2) evaluate the relationship of hydroperiod and acorn yield, and 3) evaluate the relationship of selected soil characteristics and acorn yield.

# CHAPTER II

# MATERIALS AND METHODS

## Study Areas

I studied at six sites in five states in the Mississippi Alluvial Valley (MAV) and Mississippi Interior Flatwoods (MIF) Regions (Figure 1, Table 1). All sites were located on federal lands (National Wildlife Refuges or a National Forest). These sites were used because: 1) all were dominated by bottomland hardwood forests, 2) geographic distribution was across the MAV, 3) and waterfowl habitat was a major goal in management of each site. Red oak species present varied across sites, with the two most northern sites (Chickasaw NWR [TN] and Mingo NWR [MO]) having pin oak, which was not present in the more southern sites. In total, there were five species studied: cherrybark oak, Nuttall oak, pin oak, water oak, and willow oak. Annual precipitation and mean annual temperature varied across the sites (Table 1).


Figure 1 Location of study sites in the Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions (Straub 2012).

Table 1 Description of each study site located in the Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions.

| **Study Site** | **Size (ha)** | **Location (Latitude/ Longitude)** | **Major River** | **Dominant Soil Type(s) (Soil Survey Staff 2011)** | **2011 Annual Precipitation (cm) (National Climatic Data Center 2011)** | **2011 Mean Annual Temperature (°C) (National Climatic Data Center 2011)** | **Total red oak species and number located within plots** |
|---|---|---|---|---|---|---|---|
| Chickasaw NWR | 10,120 | 35°50’00” N<br>89°39’30” W | Mississippi River | Keyespoint (Vertic Epiaquepts)<br>Openlake (Vertic Epiaquepts)<br>Sharkey (Chromic Epiaquerts) | 188.7 | 14.6 | 51 NUO*<br>14 WAO*<br>4 CBO*<br>49 PIO* |
| Delta NF | 24,645 | 32°43’55” N<br>90°47’20” W | Sunflower and Little Sunflower Rivers | Sharkey (Chromic Epiaquerts)<br>Alligator (Vertic Endoaquepts)<br>Dowling (Chromic Dystraquerts) | 127.5 | 18.6 | 165 NUO*<br>54 WIO*<br>9 WAO* |
| Mingo NWR | 8,738 | 36°59’54” N<br>90°09’50” W | St. Francis River | Forrestdale (Typic Endoaqualfs) | 191.5 | 14.9 | 10 NUO*<br>118 WIO*<br>26 CBO*<br>196 PIO* |
| Noxubee NWR | 19,425 | 33°16’55” N<br>88°45’52” W | Noxubee River | Mathiston (Aeric Fluvaquents) | 147.6 | 17.6 | 42 WIO*<br>54 CBO* |
| Tensas River NWR | 30,756 | 32°12’40” N<br>91°23’45” W | Tensas River | Sharkey (Chromic Epiaquerts) | 118.4 | 19.0 | 41 NUO*<br>91 WIO*<br>100 WAO* |
| White River NWR | 64,750 | 34°10’27” N<br>91°07’19” W | White River | Kobel (Vertic Endoaquepts) | 106.9 | 17.0 | 172 NUO*<br>25 WIO* |

*CBO – cherrybark oak, NUO - Nuttall oak, PIO – pin oak, WAO – water oak, WIO – willow oak

## Sampling Design

Plots (0.2 ha) established in previous studies measuring red oak acorn yield were used for this study (Leach 2011, Straub 2012). At the MAV sites, there were a total of 20 plots per study site placed randomly 0.08-0.32 km from a vehicle accessible road within the study site. Plots were placed at this distance to reduce the impact of increased light along roadways and reduce the potential impact of roads acting as levees. At each plot, two seed traps were utilized to measure acorn yield. Because not all of Noxubee NWR, the MIF site, is forested in bottomland hardwoods a polygon was drawn around a bottomland hardwood stand, located between the Noxubee River and Bluff Lake, and 20 plots were randomly placed within this area. At each plot one seed trap was used to measure acorn yield. Within each plot of all sites the number of stems, DBH, and individual basal area for all red oaks was recorded. For tree(s) selected for acorn collection crown area were also recorded. One groundwater well was installed at each site. Soils were described to 50 cm, sedimentation was measured using sediment tiles, and root distribution using root cores (0-20 cm) on 20 plots at Noxubee NWR and ten plots at all other sites.

## Field Methods

### Acorn Collection

Seed traps were used to estimate acorn yield (Guttery 2006, Thornton 2009, Leach 2011, Straub 2012). Seed trap frames were made of 10 cm X 2.5 cm X 1 m treated lumber, or PVC frames. The frames were fastened to four 1.5 m sections of electrical conduit with screws. Funnel shaped nets were made from fiberglass window screen and fastened to the trap frame. A wide mouth bottle was attached to the bottom of each net to collect acorns and prevent animal predation. Legs of each trap were pushed into the soil 30-40 cm to provide stability while still keeping the trap frame elevated to prevent animal predation and damage from flooding. Seed traps were placed midway between the bole and the canopy dripline of two randomly selected red oaks per plot at the MAV sites and one randomly selected oak per plot at the MIF site using a randomly chosen cardinal direction (Figure 2). Minimum DBH of selected trees was 25 cm to ensure that trees were large enough to produce acorns. If the trap location chosen fell under the overlap of a red oak canopy other than the randomly selected tree a different cardinal direction was randomly selected.

Acorns were collected from 220 seed traps once monthly from October 2012-February 2013. In February 2013 it was determined visually that all acorns had dropped from sampled trees. The contents of each trap, minus leaf litter, were collected from each trap and placed in a labeled Ziploc bag. Acorns were then sorted in the laboratory.

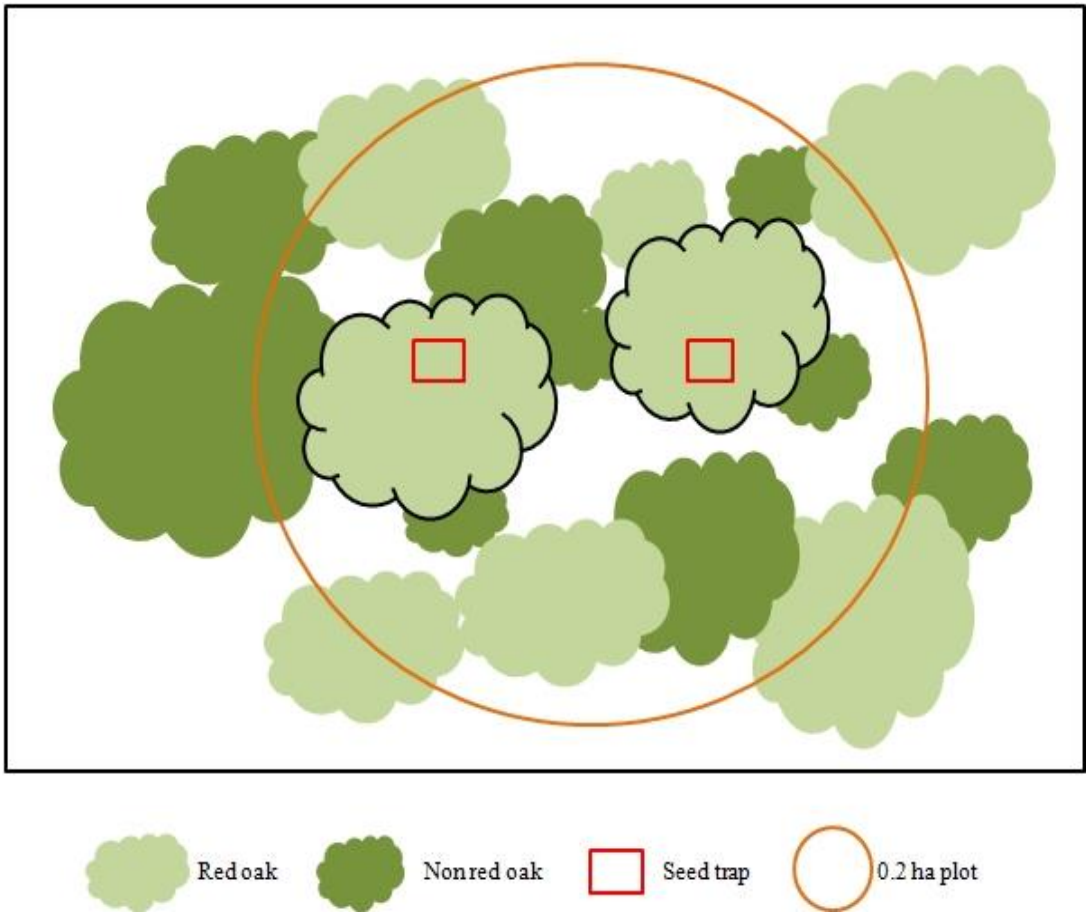


Figure 2 Diagram of trap placement in 0.2 ha plots of Mississippi Alluvial Valley sites.

## Hydroperiod

To measure the hydroperiod of sites it was important to measure both groundwater and flooding. Wells were placed in a plot as close to the center of the study sites as possible, but more importantly, in a plot that had undergone typical hydrological events for the study site during the previous three years (Straub 2011). This allowed for hydrological variation among sites to be measured. Wells were placed at plot center. To install the well, a 7.5 cm diameter hole was augered into the ground to a depth of 1.72 m.

A 5.1 cm PVC pipe with pre-drilled 0.3 cm holes along its length was placed in the augered hole. The pipe was cut at the top so that only 0.6 m was above ground. Bentonite pellets were placed between the pipe and side of the augered hole to a depth of 12 cm to prevent the well from floating. An In-Situ Inc. LevelTROLL 300 (hereafter known as pressure transducer) was attached to 1.83 m of rubber coated cable using aluminum ferrules. The pressure transducer was lowered into the well to a position 7.5 cm above the bottom of the augered hole and fastened to the well. The pressure transducer was set to record depth and pressure once daily. A PVC cap with a pre-drilled hole was then placed on top of the well to seal the PVC pipe and prevent leaves and debris from falling into the well. An In-Situ Inc. BaroTROLL (hereafter known as barotroll) was placed at each site to record atmospheric pressure. The barotroll was hung from a tree no more than ten meters from the well. The barotroll was set to record pressure and temperature once daily.

In the laboratory, data from pressure transducers and barotrolls were downloaded onto a computer and atmospheric pressure measurements from the barotroll were subtracted from pressure measurements on the pressure transducer. The resulting differences were the pressure exerted by the depth of water. If the water table fell below the depth of well then the pressure measurements of the pressure transducer and barotroll would be equal.

**Sediment Tiles**

Sediment plays a role in nutrient input of bottomland hardwood forests that undergo flooding events, and these nutrients are a resource that could potentially impact acorn yield. Porcelain tiles (0.3m X 0.3m) were placed on the soil surface and used to measure sediment accumulation rates. One sediment tile was placed in each plot at Noxubee NWR and one sediment tile in 10 even numbered plots at each of the other study sites. On these plots an acorn trap was randomly selected and the tile was placed two meters south of the southern edge of the trap to ensure that the sediment tile would not be disturbed when removing acorns from the traps. The sediment tile was placed parallel to the soil surface after all leaf litter and vegetation were removed. A section of PVC pipe, 2.5 cm in diameter and one meter in length, was placed in the ground near the tile to mark its location. Sediment removed once in August 2012 and placed in Ziploc bags. In the lab sediment from each tile was placed in its own pre-weighed paper bag and dried in an oven at 60$^{o}$C for at least 24 hours and weighed. Mass of dried sediment was calculated by subtracting mass of the bag from total mass and g/m$^2$ of sediment was determined.

**Soil Pits**

Soil characteristics impact many aspects of site productivity but have not been examined extensively in relation to acorn yield. To examine soil characteristics, soil pits were dug to 50 cm in depth. Pits were dug at the same plots where sediment tiles were installed. Soil pits were three meters to the west of the western edge of the randomly selected acorn trap.

At each soil pit, depths of soil horizons were recorded. Color of matrix and mottles in each horizon were assessed using a Munsell Soil Color Chart and percentage of mottling in each horizon recorded. Soil structure was recorded for each horizon, as well as amount of roots in fine, medium, coarse, and very course categories (Soil Survey

Division Staff 1993). Texture of each horizon was determined using hand texture methods (Franzmeier and Owens 2008).

Two samples from each horizon were collected using a soil core sampler. One was used to calculate bulk density and the other used for chemical analysis. All soil samples were stored in a refrigerator at 2.8°C until processing occurred. Samples were oven dried at 60°C for at least 24 hours and mass measured within one month of collection.

### Root Cores

Because of the importance of roots in water and nutrient uptake, root density and distribution may impact acorn yield. A root core was collected from the location of the soil pit, prior to excavation, using a 10.16 cm diameter PVC pipe driven into the ground to a depth of 20 cm. Root cores were taken at the location of the soil pit (three meters from the seed trap) to standardize the location for each plot. The PVC pipe was removed from the ground and the core removed. The core was placed in a Ziploc bag and refrigerated until processing occurred.

## Laboratory Analyses

### Acorn Processing

All acorns, tips, and caps were stored in a freezer at -10°C at Mississippi State University until processed. Acorns were thawed and separated into sound and unsound categories using the float test (Allen and Kennedy 1989, Barras et al. 1996, Guttery 2006, Thornton 2009, Leach 2011, Straub 2012). Whole acorns that were unsound were placed in their own category because they provide wildlife forage value but float due to low moisture content in the acorn or air pockets (Allen and Kennedy 1989, Straub 2012). All of the partial sound, whole sound, and whole unsound acorns (with pericarp) were dried in an oven at 60$^{o}$C for five days (Leach 2011, Straub 2012). Mass of dried acorns was then measured. Number of partial unsound and whole unsound acorns as well as partial sound and whole sound acorns was also recorded as well as number of shriveled acorns, caps, tips, and immature acorns.

### Carbon and Nitrogen Analysis

A sub-sample of soil from each horizon and sediment from each tile was ground using a mortar and pestle to pass through a 500 micron sieve and stored in a glass vial until analysis. A sub-sample of 30-50 mg of soil and 3-6 mg of sediment from each sample was then measured and mass recorded to the nearest thousandth of a mg and the sub-sample was placed into a tin (Sn) capsule. Five atropine samples were used as calibrators on the CHN dry combustion analyzer (Costech ECS 4010). Accuracy of the calibration curve was judged using the $R^2$ of a linear fit of standard calibrants. A $R^2 >$ 0.99 was achieved for all carbon (C) and nitrogen (N) estimates. Blanks and standards (Leco Soil) were used to determine accuracy of the C and N runs. Runs were accepted when standards and blanks reproduced within 10% of the true nitrogen and carbon value. I calculated total carbon and nitrogen content (Mg/ha) by horizon and by pit using carbon and nitrogen concentrations, bulk density, and horizon depth.

### Bulk Density

A soil sample of known volume (cm$^3$) was collected from each horizon using a push probe inserted to a depth that was recorded and placed in its own pre-weighed paper bag and dried in an oven at 105$^{o}$C for at least 24 hours and mass measured. Mass of dried soil was calculated by subtracting the mass of the bag from total mass. Bulk density (BD) of each horizon was then calculated as the mass of dry soil divided by the volume of the soil sample (length of core X area of the soil corer).

**pH**

A second, unground sub-sample of soil from each horizon was dried at 60$^{o}$C and used in further analysis. Ten grams of each of these sub-samples was placed in a 30 ml beaker with a 2:1 deionized (DI) water to soil solution and stirred well. This solution sat for one half hour prior to pH being determined using a Fisher Scientific Accumet pH meter 915. The pH meter was calibrated with a pH 4.0 buffer and pH 7.0 buffer at the beginning of processing and every 50 samples thereafter. Duplicates reproduced within 5% of each other. Between each sample, all instruments were cleaned with methanol.

**Root Cores**

Each root core was washed to remove all soil and other non-root matter. Roots were washed with water in stacked sieves of five mm, three mm and one mm apertures, from top to bottom. Roots that did not pass a one mm sieve were placed in a pre-weighed paper bag and dried at 60$^{o}$C for five days. Total mass of roots from each sample was measured and mass recorded.

The mass of roots for each plot was calculated: total root mass (g) from the root core/1,621.5 $cm^3$. 1,621.5 $cm^3$ is the volume of the PVC pipe used to collect root cores.

## Data Analysis

Due to windthrow and lightening damage to sample trees and trap damage by black bears (*Ursus americana*) or tree limbs, not all traps were sampled throughout fall-winter 2012-2013. Thus, different numbers of trees were sampled among sites (Table 2).

Table 2 Number of trees sampled throughout fall-winter of 2012-2013 at each site.

| Site | Number of trees sampled |
|---|---|
| Chickasaw NWR | 40 |
| Delta NF | 40 |
| Mingo NWR | 40 |
| Noxubee NWR | 20 |
| Tensas River NWR | 32 |
| White River NWR | 20 |

### Estimating Red Oak Acorn Yield

A multi-stage sampling design was used to estimate red oak acorn yield because it is less biased than a simple random sample and is appropriate when examining natural resources on a large scale (Stafford et al. 2006, Leach 2011, Straub et al. 2012, Straub 2012). PROC SURVEYMEANS in SAS version 9.2 (SAS 2010) was used to incorporate sampling weights for three stages of sampling: 1) plot selection, 2) red oak tree selection within plot, and 3) sampled crown area selected. The probability of selecting a plot within the study area was calculated by dividing one by the total bottomland hardwood area in the study site. The probability of selecting a red oak tree within the plot was calculated by dividing two by the total number of red oak trees ≥ 25 cm DBH within the plot. The probability of selecting a one $m^2$ area of the canopy was calculated by dividing one by the estimated canopy area of the selected red oak tree. The inverse of the product of these three probabilities was used to determine the weight for each tree (Stafford et al. 2006, Leach 2011, Straub et al. 2012, Straub 2012).

For each site mean number of acorns/m$^2$ was calculated. This allowed for direct comparison of relative density of yields among sites. I used number of acorns instead of mass because number and mass of acorns at each tree is positively correlated ($R^2$ = 0.7103; $P$ < 0.0001; $n$ = 172 trees; Leach 2011, Straub 2012). Number also provides an estimate that can be used when determining seed for regeneration. I calculated coefficients of variation (CV) for each site by the standard error of mean number of acorns divided by its mean, multiplied by 100 (Stafford et al. 2006, Straub 2012). This allowed for comparison of variation among sites. Due to multi-stage sampling weights being placed on each tree, individual trees that had a larger canopy, were in a plot with many other red oak trees, and were in a larger bottomland hardwood forest had a greater influence on the MAV-wide estimate of red oak acorn yield (Straub 2012).

**Modeling Red Oak Acorn Yield in the MAV and MIF Regions using Hydrological and Soil Conditions**

*Site Level*

Due to a small sample size ($n$ = 6 sites), all explanatory variables measured could not be used to model the impact of hydrological and soil relationships on red oak acorn yield at the site level because of a lack of degrees of freedom. For this reason, means of site nitrogen content [NITROGEN], pH [PH], and g/cm$^3$ of roots [ROOTS] were calculated for each site. Whole profile nitrogen content was calculated as the sum of nitrogen content of all horizons to 50 cm and mean nitrogen content for each site was calculated from this value and used in analysis. Mean pH between all horizons was calculated for each site and used in analysis. Number of days each site was inundated during the growing season (March 15, 2012 - October 15, 2012) was calculated [HYDROLOGY]. Growing season length was determined through National Climatic Data Center (2013) growing season data. This time period results in a 214 day growing season (Gardiner and Oliver 2005). These values were used as explanatory variables in modeling red oak acorn yields. Mean bulk density was not used in analysis because it was used to calculate nitrogen content and thus both would be correlated and not independent. Soil carbon content was not used as an explanatory variable due to the strong correlation with soil nitrogen content ($R^2 = 0.93$ and 0.98 for A and B horizons, respectively). Furthermore, soil nitrogen is a limiting factor in site productivity and therefore potentially more directly related to acorn yield than carbon. I used PROC ANOVA with the Waller K ratio test to determine if each explanatory variable differed among sites (SAS 2010). Waller K ratio tests were conducted for each horizon (A and B) independently.

I used a general linear model (SAS 2010) to model the relationships between measured hydrologic and soil characteristics with mean acorn yield (number/$m^2$) at each site, specifying the backwards selection procedure. This model is a backward stepwise multiple linear regression model. This procedure begins with a model that contains all variables with variables removed until all remaining explanatory variables have a probability ≤ alpha. Alpha was set a priori at 0.10.

### *Plot Level*

Due to soil factors being measured at the plot level, acorn yield was examined at this scale. This scheme also removed psuedoreplication between sampling units (the seed trap) within plots, because two traps from a given plot were not independent of one another. Relations between soil characteristics at plot level and acorn yield were examined for 61 trees within plots for which soil characteristics were measured and at least one seed trap was monitored throughout the sampling period. I used PROC GLIMMIX (SAS 2010) and specified a negative binomial distribution with the log link function. Because count data have a right skewed distribution and numerous zero values I utilized the negative binomial distribution (Zuur et al. 2009). The GLIMMIX model is a generalized linear mixed model that can account for random effects where the distribution of data is not required to be normal. I analyzed data from all sites and plots combined to test if the relationship between acorn yield and explanatory variables varied by site. Thus, my response variable was mean number of acorns/$m^2$ for each plot and explanatory variables were the fixed factor of site [SITE] and continuous variables total nitrogen concentration (%) [NITROGEN], total profile (A and B horizons) bulk density ($g/cm^3$) [BD], root mass for each plot ($g/m^2$) [ROOTS], and depth to mottling (cm) [MOTTLING]. Because depth to mottling is related to drainage class and is impacted by the hydrology of the site it should account for the hydrology at each plot (Faulkner and Patrick 1992). I did not use pH in the plot level analysis because of its correlation with nitrogen. Due to data loss from feral hogs (*Sus scrofa*), trees, and humans destroying or removing sediment tiles, sediment data were not used in analysis to prevent use of an unrepresentative sample. Alpha was set a priori at 0.10.

CHAPTER III

RESULTS

## Red Oak Acorn Yield in the MAV and MIF Regions

A total of 172 trees were sampled during the fall-winter 2012-2013. Acorn yield was right skewed (Figure 3), with 24 (14%) trees producing >50% of acorn yield. Across all sites and red oak species, mean acorn yield was 44.90 acorns/m$^2$ (SE = 6.70; CV = 14.92%). Mingo NWR in southeastern Missouri had the greatest yield of acorns in 2012-2013 ($\bar{x}$ = 74.97 acorns/m$^2$; SE = 13.49; CV = 17.99%), followed by nearby Chickasaw NWR in western Tennessee ($\bar{x}$ = 60.31 acorns/m$^2$; SE = 8.27; CV = 13.71%). White River NWR in eastern Arkansas had the least ($\bar{x}$ = 14.03 acorns/m$^2$; SE = 6.11; CV = 43.55%; Table 3). With the exception of Chickasaw NWR, variation within sites was greater than among sites. However, when estimating acorn yield across sites a CV of < 15% was achieved, thus, my estimate of acorn yield in the MAV and MIF Regions is precise (Straub 2012).

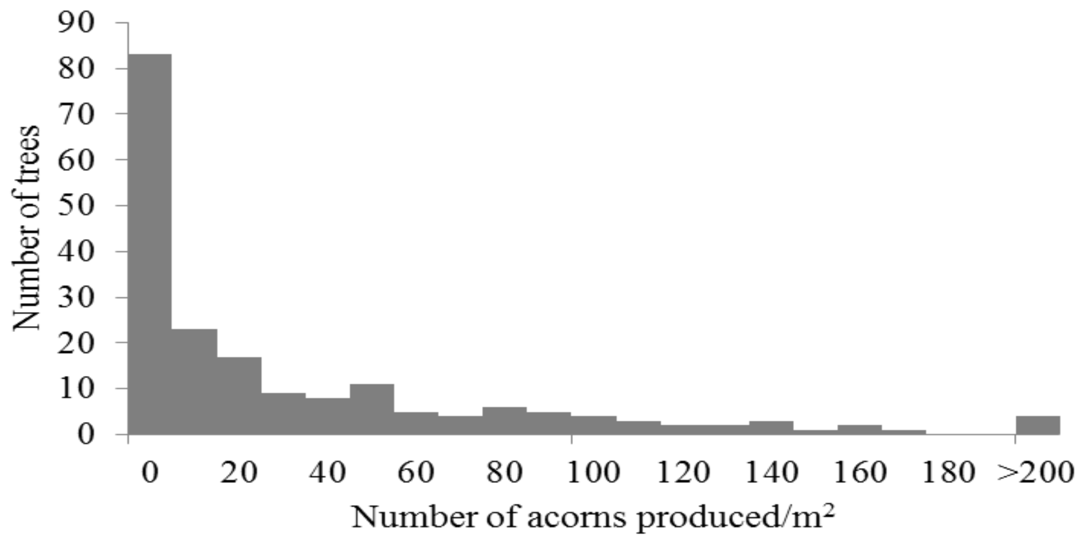


Figure 3 Distribution of the number of acorns produced per $m^2$ from red oak trees at six sites in the Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions, fall-winter 2012-2013.

Table 3 Multi-stage sampling means, standard errors (SE), and coefficients of variation (CV[a]) for number of red oak acorns per $m^2$ collected during the fall-winter 2012-2013 in the Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions.

| Site | Mean | SE | CV[a] (%) |
|---|---|---|---|
| Chickasaw NWR | 60.31 | 8.27 | 13.71 |
| Delta NF | 26.55 | 11.97 | 45.08 |
| Mingo NWR | 74.97 | 13.49 | 17.99 |
| Noxubee NWR | 42.72 | 7.30 | 17.09 |
| Tensas River NWR | 15.77 | 3.89 | 24.67 |
| White River NWR | 14.03 | 6.11 | 43.55 |
| All Sites | 44.90 | 6.70 | 14.92 |

[a]CV (%) = (SE/mean) X 100

## Hydrologic and Soil Characteristics Related to Red Oak Acorn Yield in the MAV and MIF Regions

### Site Level

Number of days each site was inundated (i.e., water at or above soil surface) during the growing season (March 15-October 15, 2012) ranged from 0-33 days, with Chickasaw NWR never being inundated and White River NWR being inundated most days (Figure 4). These values represent one year of hydrology data, and thus have no variance associated with them. Although White River NWR was inundated the greatest period of time, it did not have the lowest depth to mottling (Table 4). Mean mass of roots differed significantly among sites ($F = 2.87$; $P = 0.0227$; $n = 6$) and ranged from 3,010.2-6,478.6 g/$m^3$, with White River NWR and Noxubee NWR having greater masses than other sites (150% and 125% greater than the overall mean, respectively; Figure 5). Mean A horizon pH differed significantly among sites ($F = 29.06$; $P < 0.0001$; $n = 6$), with Chickasaw NWR having greater pH values in the A horizon (117% greater than the overall mean). Mean B horizon pH differed significantly among sites ($F = 9.21$; $P < 0.0001$; $n = 6$), with Chickasaw NWR having a greater pH value in the B horizon (115% greater than the overall mean; Figure 6). pH values only varied a small amount between A and B horizons within a site (Figure 6). The B horizon had more nitrogen (Mg/ha) than the A horizon at all sites due to greater horizon depth and higher bulk densities in B horizons (Figure 7, Table 4). A horizon nitrogen content differed significantly among sites ($F = 7.11$; $P < 0.0001$; $n = 6$). B horizon nitrogen content also differed significantly among sites ($F = 6.32$; $P < 0.0001$; $n = 6$). Chickasaw NWR had the greatest mean amount of nitrogen in the A horizon with 3.71 Mg/ha and in the B horizon with 5.41 Mg/ha, while Noxubee NWR had the smallest mean amount of nitrogen in the A and B horizons (1.26 Mg/ha and 2.54 Mg/ha, respectively; Figure 7). The three sites with lowest nitrogen all underwent inundation for greater than 15 days. (Table 4).

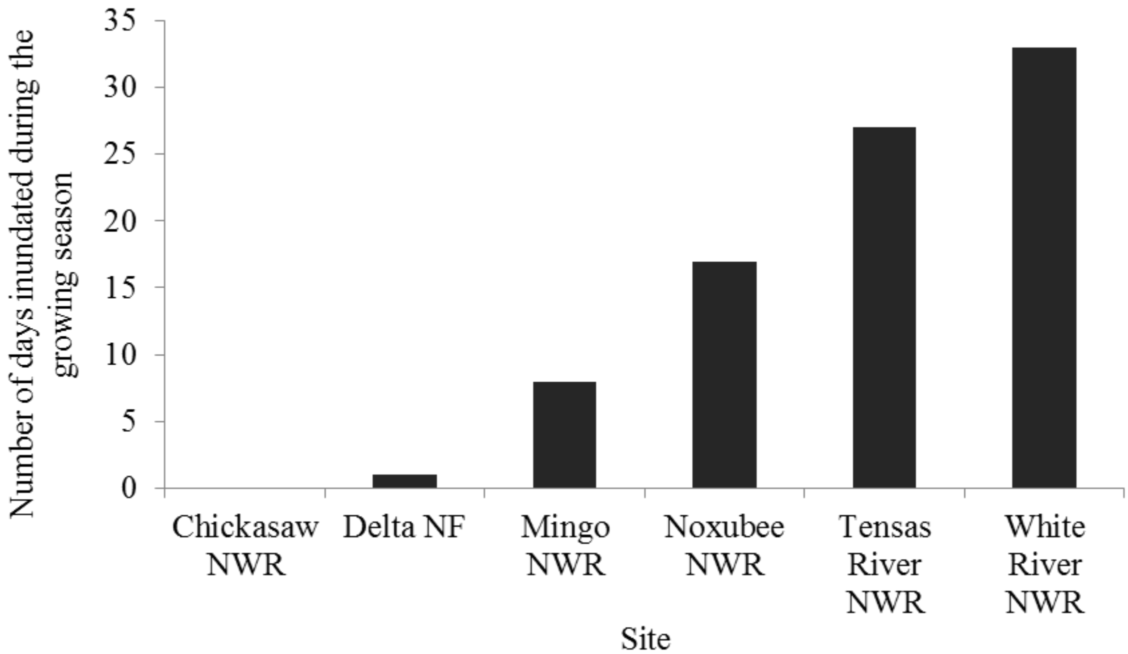


Figure 4 Number of days each site was inundated during the growing season (March 15-October 15) during 2012.

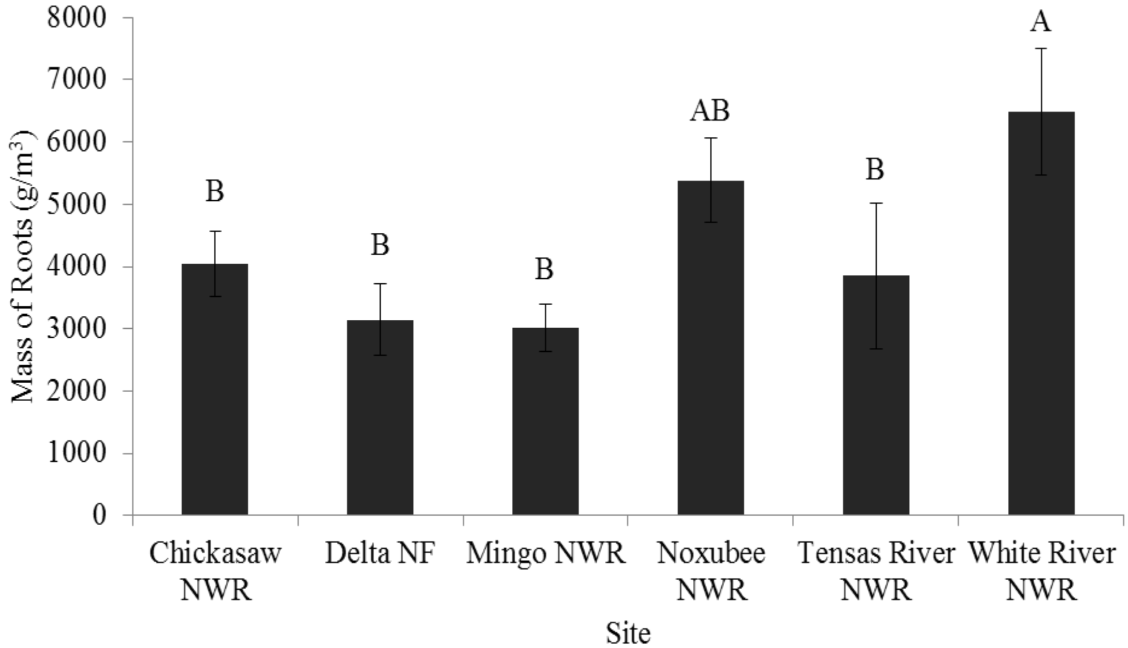


Figure 5 Mean dry root mass (to 20 cm) of each site, with standard error bars and Waller grouping.[a]

[a]Values with the same letter do not differ at $\alpha = 0.10$.

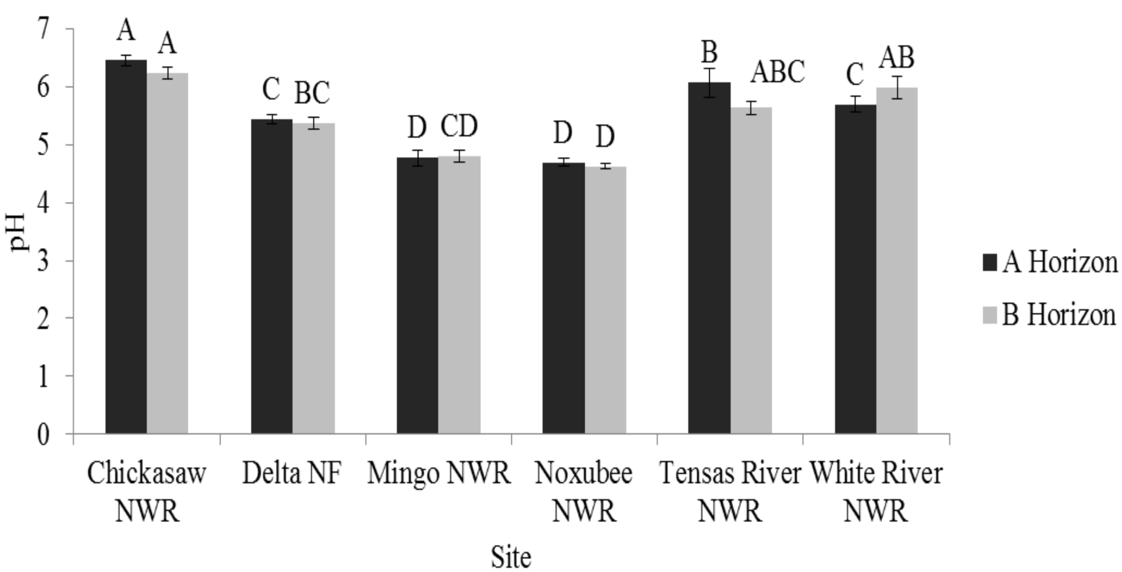


Figure 6 Mean pH of each site for horizons A and B, with standard error bars and Waller grouping[a] comparing each horizon among sites.

[a]Values with the same letter do not differ at $\alpha = 0.10$.

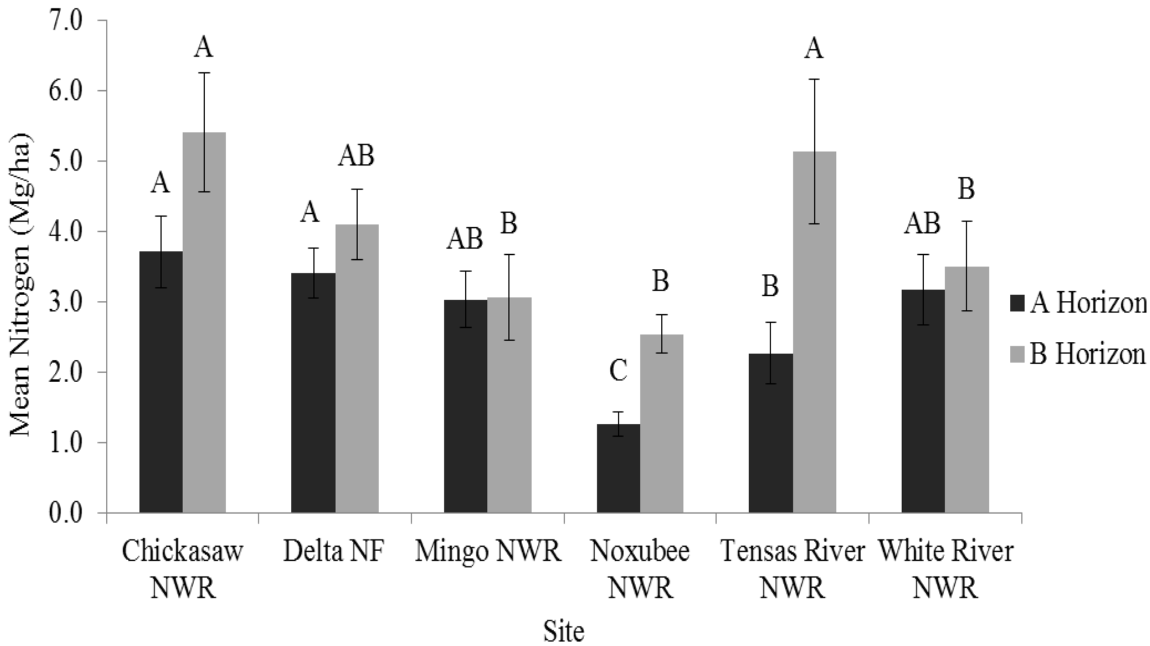


Figure 7 Weighted mean soil nitrogen (Mg/ha) of each site for horizons A and B, with standard error bars and Waller grouping[a] comparing each horizon among sites.

[a]Values with the same letter do not differ at $\alpha = 0.10$.

Table 4 Plot level red oak acorn yield and soil factors, with standard error (SE) below each factor, measured at six sites in the Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions.

| | Site | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | Chickasaw NWR | Delta NF | Mingo NWR | Noxubee NWR | Tensas River NWR | White River NWR |
| Acorn Yield ($n$/m$^2$) | 54.0 | 36.5 | 62.7 | 39.1 | 15.7 | 11.5 |
| SE | 7.8 | 19.4 | 13.2 | 7.4 | 4.5 | 3.3 |
| Bulk Density (g/cm$^3$) | | | | | | |
| A Horizon | 1.10 | 1.14 | 1.08 | 1.15 | 0.92 | 1.19 |
| SE | 0.05 | 0.03 | 0.04 | 0.06 | 0.07 | 0.04 |
| B Horizon | 1.28 | 1.23 | 1.32 | 1.46 | 1.21 | 1.39 |
| SE | 0.03 | 0.04 | 0.06 | 0.05 | 0.03 | 0.03 |
| Nitrogen Concentration (%) | | | | | | |
| A Horizon | 0.225 | 0.174 | 0.178 | 0.134 | 0.386 | 0.160 |
| SE | 0.035 | 0.015 | 0.021 | 0.016 | 0.089 | 0.016 |
| B Horizon | 0.132 | 0.112 | 0.076 | 0.067 | 0.146 | 0.079 |
| SE | 0.009 | 0.007 | 0.009 | 0.006 | 0.016 | 0.010 |
| Nitrogen Content (Mg/ha) | | | | | | |
| A Horizon | 3.71 | 3.42 | 3.04 | 1.26 | 2.27 | 3.17 |
| SE | 0.50 | 0.35 | 0.41 | 0.18 | 0.43 | 0.50 |
| B Horizon | 5.41 | 4.11 | 3.06 | 2.54 | 5.14 | 3.51 |
| SE | 0.84 | 0.50 | 0.61 | 0.27 | 1.03 | 0.63 |
| Depth to Mottling (cm) | 25.7 | 7.2 | 7.3 | 29.5 | 13.3 | 15.1 |
| SE | 5.8 | 3 | 2.5 | 4.7 | 5.7 | 3.9 |
| pH | | | | | | |
| A Horizon | 6.46 | 5.45 | 4.77 | 4.69 | 6.06 | 5.69 |
| SE | 0.09 | 0.08 | 0.14 | 0.06 | 0.24 | 0.14 |
| B Horizon | 6.23 | 5.37 | 4.81 | 4.63 | 5.64 | 5.98 |
| SE | 0.09 | 0.10 | 0.10 | 0.05 | 0.12 | 0.19 |
| Root Mass (g/m$^3$) | 4048.1 | 3146.5 | 3010.2 | 5385.1 | 3853.2 | 6478.6 |
| SE | 525.5 | 579.3 | 379.1 | 676.4 | 1168.6 | 1013.6 |
| Topographic Position of Soil Pit | 10 Flats | 9 Flats; 1 Terrace | 9 Flats; 1 Ridge | 10 Flats; 2 Ridges; 3 Fronts; 2 Sloughs | 6 Flats; 2 Ridges; 2 Terraces | 9 Flats; 1 Ridge |

Using the above parameters with the backward selection procedure specified resulted in a significant model with HYDROLOGY being the only remaining variable ($R^2$ = 0.6725; $P$ = 0.0456; $n$ = 6) when modeling red oak acorn yield. Acorn yield decreased by 1.21359 acorns/$m^2$ (SE = 0.42341; 90% CI = -2.30227, -0.56057) for every additional day of inundation.

**Plot Level**

Plot level factors varied among and within sites, with much of the variation caused by the topographic position of the soil pit (Table 4). Analyzing all plots and sites together, only SITE varied with acorn yield ($P < 0.10$). NITROGEN, ROOTS, BD, and MOTTLING were not related to acorn yield ($P \geq 0.60$).

Within most sites, however, acorn yield varied among plots (Table 5). At Delta NF, acorn yield varied positively with NITROGEN ($P$ = 0.0165; β = 3.8417; SE = 1.0837; 90% CI = 1.6580 - 6.0254; $n$ = 10) and BD ($P$ = 0.0605; β = 15.7437; SE = 6.5190; 90% CI = 2.6077 - 28.8798; $n$ = 10); however, acorn yield varied inversely with MOTTLING ($P$ = 0.0090; β = -0.3917; SE = 0.0945; 90% CI = -0.5821, -0.2013; $n$ = 10), and ROOTS had no significant effect on acorn yield. At Mingo NWR, acorn yield varied positively with ROOTS ($P$ = 0.0805; β = 777.56; SE = 355.73; 90% CI = 60.7593 - 1494.37; $n$ = 10) and no other factors had a significant relationship. At Tensas River NWR, acorn yield varied inversely with NITROGEN ($P$ = 0.0074; β = -0.5281; SE = 0.0811; 90% CI = -0.7191, -0.3372; $n$ = 8) and ROOTS ($P$ = 0.0183; β = 117.33; SE = 25.0204; 90% CI = 58.4516 - 176.2200; $n$ = 8); however, acorn yield varied positively with MOTTLING ($P$ = 0.0052; β = 0.1251; SE = 0.0170; 90% CI = 0.0852 - 0.1650; $n$ = 8), and ROOTS ($P$ = 0.0183; β = 117.33; SE = 25.0204; 90% CI = 58.4516 - 176.2200; $n$

= 8). BD did not have a significant relationship. At White River NWR, acorn yield varied inversely with NITROGEN (*P* = 0.0998; β = -0.7920; SE = 0.2710; 90% CI = -1.5833, -0.0007; *n* = 7) and all other factors were insignificant. At Chickasaw NWR and Noxubee NWR, no explanatory variables had a significant relationship with acorn yield.

Table 5 Effects of soil variables on red oak acorn yield at six sites in the Mississippi Alluvial Valley and Mississippi Interior Flatwoods Regions, fall-winter 2012-2013.

| | Soil Variable β* | | | |
|---|---|---|---|---|
| Site | NITROGEN | ROOTS | BD | MOTTLING |
| Chickasaw NWR | | | | |
| Delta NF | 3.8417 | | 15.7437 | -0.3917 |
| Mingo NWR | | 777.56 | | |
| Noxubee NWR | | | | |
| Tensas River NWR | -0.5281 | 117.33 | | 0.1251 |
| White River NWR | -0.7920 | | | |

*Only significant effects ($P \leq 0.10$) presented.

# CHAPTER IV

# DISCUSSION

## Red Oak Acorn Yield in the MAV and MIF Regions

Red oak acorn yield varied among sites during fall 2012 and winter 2013. My study was conducted at a landscape scale with red oak trees of five species, DBHs, crown sizes, and crown classes, and the estimate of red oak acorn yield accrues variation from these sources (Straub 2012). Also, acorn yield has been shown to be related to climate and resource variables; at a landscape scale, these variables have greater variation than at local scales (Sork et al. 1993, Kelly 1994, Kelly and Sork 2002).

Greenberg and Parresol (2002) outlined criteria to compare acorn yields as: 1) poor (i.e., <60% of mean annual yield), 2) moderate (i.e., >60% and up to the mean), and 3) good acorn yield (i.e., > the mean). Using these criteria, three sites had good acorn yield (Chickasaw NWR, Mingo NWR, and Noxubee NWR), one site had moderate yield (Delta NF), and two sites had poor yield (White River NWR and Tensas River NWR). In a three year MAV-wide study by Straub (2012), who monitored the same sites and trees as during my study, he reported that acorn yield was never all good, moderate, or poor in the same year at his five study sites. Straub (2012) stated that "all sites had at least one year of good and poor yield except Tensas River NWR which had 2 poor years followed by a moderate year, which was the only site-year combination classified as moderate in my study". I found that Tensas NWR had poor acorn yield in fall 2012 – winter 2013, which is similar to Straub's findings. I classified each of the other sites as poor or good, with the exception of Delta NF. Thus, red oak trees apparently have asynchronous acorn yield across the MAV (Straub 2012).

The timing and quantity of acorn yield can have important implications on wildlife and regeneration of red oak species in bottomland forests. Because acorn yields in my study varied by site, highly mobile species, such as ducks (*Anatinae*), may be able to move among lowlands and exploit flooded areas with increased mast or other forage crops. Less mobile species, such as white-tail deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*), may not have same opportunities unless improved foraging patches exist within their home range.

For natural regeneration of oak species to be successful there must be production of viable acorns. Spatial variation observed in yields, as well as spatial and temporal variation observed in Straub's study (2012), suggests that partial harvest treatments utilized to change conditions, such as light resources, for regeneration need to be timed to ensure that sufficient seed is available after thinning. Merz and Brakhage (1964) reported that one of every 26 pin oak acorns produced will establish a seedling in unflooded areas and only one of every 2,100 pin oaks will establish in flooded areas. The six sites in my study varied in their growing season hydroperiod and species present, but even with these variations, it is critical for bottomland hardwood regeneration that there is seed to achieve regeneration. One should note that other factors, such as deer browse, can also reduce oak regeneration and growing season hydroperiod is not the only factor reducing successful regeneration (Rooney and Waller 2003).

### Site Level Variables Influencing Red Oak Acorn Yield

At the site level, number of days a site was inundated during the growing season was the only factor that had a significant relationship to red oak acorn yield, with acorn yield decreasing as number of days inundated increased. This inverse relationship is likely due to stress placed on the trees by being under anaerobic soil conditions during the growing season (Francis 1983, King 1995). This greater stress may result in individual trees placing more resources into survival rather than production of seed. In a five year study of Nuttall oak in GTRs and non-flooded areas, Francis (1983) found that acorn yield was significantly lower in flooded GTR areas. However, extended flooding in GTRs has also been reported to appear to have no negative effect, with red oak acorn yields being classified as good (Merz and Brakhage 1964, McQuilkin and Musbach 1977, Guttery 2006, Thornton 2009, Leach 2011). One should note that these studies were conducted in GTRs. Although GTRs are flooded annually for waterfowl use, this flooding occurs primarily during the dormant season. To my knowledge this is the only study that has measured acorn yield and growing season flooding in naturally flooded bottomland hardwood forests. Such flooding may be the primary driver of differences between acorn yields in my study compared to these studies from GTRs.

Although nitrogen is a limiting factor in forest productivity it was not shown to have a significant impact on acorn yield at the site level in fall 2012 – winter 2013. Roots are important for the uptake of water and nutrients and are a measurement of below ground productivity. This variable also did not have a significant impact on acorn yield at the site level in 2012-2013. pH is a factor that varies throughout a bottomland, depending on topographic location and deposited sediment among other things, and influences oak species that are present. I thought that pH may also influence acorn yield but this was not supported at the site level during 2012-2013. Although each of these variables are important to site productivity they were not strongly correlated with acorn yield in the MAV and MIF sites during 2012-2013. Each of these soil factors are relatively stable annually, particularly nitrogen and pH, and take many years to change (Brady and Weil 1999). Because these soil factors are relatively stable it suggests that they might not cause large variations that are seen temporally or spatially with acorn yields. However, this dataset was limited to only one year of acorn yield and because soils and hydrology are more stable on an annual basis, relative to acorn yield, I may not be able to make the most robust comparison of acorn yield and these site level variables. Greater temporal and spatial replication of annual hydroperiod, soil characteristic changes, and acorn yield may reveal a stronger relationship between these soil characteristics and acorn yield and demonstrate more support of the relationship that hydroperiod has with acorn yield. However, because of the large landscape scale that was studied these results give insight as to how these bottomlands function and the impact of site level variables on acorn yield.

## Plot Level Variables Influencing Red Oak Acorn Yield

At the plot level, only SITE explained a significant portion of variation in red oak acorn yield during fall 2012 – winter 2013 when analyzing plots from all sites together. This suggests that measured factors varied in the relationship with acorn yield at each site.

When analyzing plots by site the above statement was found to be supported, with the relationship of measured factors to acorn yield varying by site. Not only did plots at each site vary in which factors had a significant relationship, they also varied in the relationship of that factor to acorn yield (positive or negative).

Depth to mottling (to 50 cm) had a positive relationship to acorn yield at one of the six sites (Tensas River NWR), an inverse relationship at one site (Delta NF), and no significant relationship at all other sites. Mottling is a redoximorphic feature that is a result of anoxic conditions during the growing season, when soil microbes are active (Brady and Weil 1999). Thus, the higher the water table is in the growing season the closer mottling will be to the soil surface. The relationship I found at Tensas River NWR suggests that as depth to mottling increases (water table farther from soil surface during growing season) acorn yield increases. This further supports the relationship at site level with acorn yield increasing with fewer days inundated during the growing season. The negative relationship at Delta NF and the lack of a significant relationship at all other sites could be due to the fact that mottling is a long term hydric soil indicator more so than an annual hydric soil indicator (Brady and Weil 1999). During the growing season of 2012 Tensas River NWR was inundated longer than Delta NF (27 days and 1 day respectively). Thus, during the growing season of 2012 Delta NF was a dry site while Tensas NWR was a wet site. For sites that are inundated for long periods of time, and have mottling close to the soil surface, hydrology may be the most significant factor impacting acorn yield, while at drier sites (Delta NF) hydrology (i.e., mottling) may influence acorn yield less. When an area has little, or no, growing season inundation another factor may influence acorn yield. This was supported at Delta NF, where nitrogen had a significant influence on acorn yield. The hydroperiod observed at Delta NF may not have been typical and the lack of growing season inundation may have resulted in a greater acorn yield. If the 2012 growing season hydroperiod was atypical for Delta NF, depth to mottling would not reflect this. Tensas River NWR is also the most southern site in this study so, soil temperatures are likely to be higher driving higher rates of microbe activity (> ≈ 5°C) for a longer period of time than more northern sites and this may result in an increase in mottling.

Nitrogen (Mg/ha to 50 cm) varied greatly in the relationship it had to acorn yield at plots in each site. It had a positive relationship at one site (Delta NF), an inverse relationship at two sites (Tensas River NWR and White River NWR), and no significant relationship at all other sites. The impact that nitrogen had at Delta NF was large (β = 3.8417) while β was much smaller at Tensas River NWR and White River NWR (β = -0.5281 and -0.7920 respectively). The inconsistency in these relationships leads me to reason that nitrogen is not a primary control of acorn yield and that some other variable, potentially hydrology or a soil variable not measured, has a greater impact and nitrogen is secondary to this. As discussed above, Delta NF was a dry site during the growing season of 2012 while Tensas River NWR and White River NWR were both wet during the growing season 2012, being inundated 27 and 33 days respectively. If hydroperiod is the major influence on acorn yield and nitrogen is secondary, the irregular (inverse) relationship could be explained by Tensas River NWR and White River NWR being inundated longer than Delta NF.

Root mass (to 20 cm) was found to be significant and have a large positive impact on acorn yield at Mingo NWR (β = 777.56) and Tensas River NWR (β = 117.33). Root mass did not have a significant relationship to acorn yield at plots in any other site. Mingo NWR also had smallest mean root mass of all sites ( $\bar{x}$ = 3010.18 $g/m^3$) and Tensas

River NWR had the third smallest mean root mass ( $\bar{x}$ = 3853.22 $g/m^3$). These relationships suggest that there may be a threshold of root mass where the tree is able to uptake water and nutrients sufficiently and above this threshold root mass becomes less important. However, root mass may be a secondary control and be responding to a more primary control and thus the reason a significant relationship was not seen at the site with the second lowest root mass (Delta NF). Greater temporal and spatial replication is needed to test this hypothesis.

Total profile bulk density (A and B horizons) had a significant positive relationship with acorn yield at Delta NF and was not significant at any other site. At high bulk densities drainage is decreased, thus more water is held between soil particles, while at low bulk densities drainage is increased, as water can easily move between the soil particles. The bulk density at Delta NF is neither the greatest nor smallest (Table 4). Because it is near the middle this bulk density may allow the soil to hold water better than at the other sites, but not enough water to place stress on the root system. This would result in a positive effect in acorn yield because decreased available water during the growing season has been reported to negatively impact acorn yield (Pérez-Ramos et al. 2010). The other sites may drain too quickly, or hold too much water during the growing season, and caused no relationship to be found between acorn yield and bulk density. Greater temporal and spatial replication would allow for greater acorn yield and bulk density variation to be measured and this hypothesis to be tested.

At plots within two sites (Chickasaw NWR and Noxubee NWR) no measured variables were found to have a significant relationship to acorn yield. These sites are located on the smallest river (Noxubee NWR) and largest river (Chickasaw NWR) in this study which may cause them to be extremes with respect to how the bottomland forests at these sites function. Because Noxubee NWR is located along a minor stream bottomland forest more of the variation in soil characteristics in a bottomland hardwood forest may have been observed, and resulted in more complicated hydrology and soil interactions. More variation may have been observed due to plots being on a wider array of topographic positions in the floodplain than other sites (Table 4). Chickasaw NWR is located along the Mississippi River and although growing season inundation in 2012 was lacking this is not always true (Straub 2011). When Chickasaw NWR does flood there are many inputs because it is a very large river system. Because of this, I suggest that more soil measurements be taken at this site, measuring other variables that impact productivity. By increasing the number of soil measurements (pits) in a plot more precise means of soil characteristics would be reached and variations observed.

As stated in the site level discussion section, my dataset is limited, with only one year of measurements. Greater spatial and temporal replication will allow for a better assessment of the relationships of soil and hydrology to acorn yield. However, based on plot level results it was shown that soil characteristics did impact 2012-2013 acorn yields at some sites, with the relationship varying by days of inundation. These results also give insight into the variation that is seen in soils across and among bottomland hardwood forests and that there is a greater need to study and understand the hydrological and soil variables that influence acorn yields. Also, bottomland forests are known to have productive soils and nutrients are typically not limiting. Thus, soil factors, such as nitrogen, may not have a large impact on acorn yields if it is not limiting to trees.

Alternatively, perhaps variables not measured, such as ambient temperature during the flowering period, influenced the relationship with acorn yield.

# CHAPTER V

# MANAGEMENT IMPLICATIONS

Even with only one year of hydroperiod and acorn yield data I can make several recommendations to forest managers. As stated previously, it is crucial to have seed during regeneration operations. Determining acorn yield through seed traps can be time consuming if a sufficient number of traps are placed, and management budgets may not allow for construction materials to be purchased. Thus, for forest managers seed traps are not an efficient and economical way to determine acorn yield. However, acorns can be visually assessed while seed is still in trees, through hard mast indices (HMIs) (Koenig et al. 1994b, Straub 2012). While HMIs do not estimate acorn yield, they do determine relative acorn abundance (Straub 2012). These methods allow for an assessment of potential seed and planning of regeneration operations to coincide with a large seed drop. Because HMIs are conducted in late summer or early fall, before seed drop, there is time to assess acorn abundance and plan regeneration operations (Gysel 1956, Koenig et al. 1994b, Straub 2012). Due to variation, temporally and spatially, in acorn yield it is important to carry out this assessment.

Based upon my results of growing season inundation and acorn yield I recommend that managers and landowners do all they can to reduce, or eliminate, flooding during the growing season. Although draining floodwaters in a naturally flooded system can be extremely difficult, there are sites that have strategically placed water control structures, levees, and ditches to assist with removal of water. Use of these features can be effective to reduce growing season flooding. Although this study was not conducted in GTRs, I believe results would be the same, with increasing growing season inundation having a negative impact on acorn yield. This could result in greater acorn yields in red oaks and not conflict with waterfowl hunting opportunities.

Due to the variation observed in acorn yields, and my limited dataset, I strongly suggest that further research be conducted to assess acorn yield in the MAV and MIF as well as the impact that hydrology and soil characteristics have on yield. In addition, I also suggest that other environmental factors, such as mean annual precipitation and temperatures during the flowering period, be examined as well.

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