Soil Carbon and Nitrogen Dynamics across the Hillslope-Riparian Interface in Adjacent Watersheds with Contrasting Cellulosic Biofuel Systems

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ABSTRACT

Climate change resulting from emissions of fossil fuel combustion has sparked considerable interest in renewable energy and fuel production research, particularly energy derived from cellulosic ethanol, which is derived from biomass such as wood and grass. Cellulosic ethanol demonstrates a more promising future as a global energy source than corn-derived ethanol because it does not displace food crops, irrigation is not required, and chemical application rates are much lower than for annual crops, such as corn. Growing cellulosic biomass for energy can help reduce greenhouse gas emissions via carbon (C) sequestration and by reducing demand for fossil fuel production. The objective of this study was to investigate how land use change affects soil properties and selected soil C and nitrogen (N) dynamics among alternative cellulosic biofuel treatments at the Weyerhaeuser Alabama Cellulosic Biofuel Research site in west-central Alabama. Composite soils for characterization, along with forest floor, were collected at year 1 and year 2 after treatment establishment at 0-15cm and 15-30cm depths at six locations along three hillslope-riparian transects in five experimental watershed treatments. Decomposition of loblolly pine needles was assessed in each watershed using an *in situ* litter bag method. Seasonal *in situ* net nitrogen mineralization was measured using a sequential core method, and an anaerobic incubation for N mineralization potential of composite soils was performed in the laboratory. Results revealed high variability of soil properties and processes within these watersheds, along with no consistent treatment effects. This study provides baseline data for these watershed treatments for future studies.

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Table of Contents

List of Figures

List of Tables

Chapter 1 - Introduction and Background

Introduction

The rate at which emissions from fossil fuel combustion are accelerating climate change is of increasing concern. Consequently, interest in renewable energy and fuel production research, particularly energy derived from cellulosic ethanol, has increased in the last decade (Farrell *et al.*, 2006). This fuel source is derived from biomass such as wood, grass, and residual biomass following timber harvest and demonstrates a more promising future as a global energy source than corn because it does not displace food crops, irrigation is not required, and chemical application rates are an order-of-magnitude lower than for annual crops (Tilman *et al*., 2006). Growing cellulosic biomass for energy can help reduce greenhouse gas emissions via sequestration of carbon (C) and by reducing the demand for fossil fuel production.

In the southeastern U.S., traditional biomass harvest of competing understory vegetation in loblolly pine (*Pinus taeda*) plantations now has another crop being investigated as an energy source--switchgrass (*Panicum virgatum*). Switchgrass is a native perennial grass, which can grow under a wide range of conditions and shows great potential as an energy source (McLaughlin and Kszos, 2005; Schmer *et al*., 2008). Current research in this area is examining the environmental effects of growing cellulosic biofuels (e.g. Thy *et al*., 2013; Murphy *et al*., 2013; Wu *et al*., 2013), particularly focusing on establishment and sustainability of growing switchgrass between rows of trees in pine plantations (Albaugh *et al*., 2012; Loman *et al*., 2013).

The environmental impacts of changing land use to biofuel production have yet to be adequately assessed on multiple scales (Williams, *et al*., 2009). Evaluating a range of management strategies and the efficacy of preserving and promoting soil and water quality through riparian buffers at the small watershed scale will provide information needed to predict potential environmental effects of future bioenergy operations. These smaller, watershed-scale measurements will help inform large, regional-scale computer simulation models to predict environmental effects of different scenarios of converting forested lands to various types of alternative bioenergy crops for biofuels across the southeastern U.S.

I studied how land use affects selected soil C and nitrogen (N) dynamics in a novel setting of cellulosic biofuel treatments at the Weyerhaeuser Alabama Cellulosic Biofuel Research site in the Upper Coastal Plain of Alabama. The overall objective of this study was to compare the influence of establishment of different cellulosic biofuel treatments on soil properties and on selected C and N dynamics and how riparian buffers in each watershed may influence treatment effects.

Background

Climate Change

Changing of the global climate system is unequivocal. The atmosphere and ocean are warming, volumes of snow and ice are decreasing, sea level is rising, and concentrations of greenhouse gases continue to increase. Timing, frequency, and intensity of weather patterns are becoming more alarming and transforming the way society perceives its relationship with the environment. Enrichment of the earth's atmosphere with greenhouse gases from fossil fuel combustion is the primary driver of this global climate change (IPCC, 2007, 2013). Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unparalleled in nearly the last one million years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change (including deforestation) emissions. Roughly half of all C emissions to the atmosphere since pre-industrial times remain in the atmosphere, whereas sinks such as the ocean and undisturbed vegetation biomass and soils not affected by land use change store most of the rest (NRC, 2008). Continued emissions of greenhouse gases will cause further warming and changes in all facets of the climate system. Curbing climate change will necessitate extensive and continued reductions of greenhouse gas emissions (IPCC, 2013). Efforts to achieve reductions in greenhouse gas emissions are currently underway as governments, industry and academia are exploring alternative (non-fossil fuel) energy sources. Renewable, no-, or low-C extractions of energy sources including solar, wind, nuclear, hydroelectric, wave and tidal, geothermal, and biomass may all be viable options for the present and for the future to meet U.S. (and global) demand for fuel.

Biofuels

Energy derived from biomass is intriguing. Biomass conversion to ethanol is currently the most cost-effective means by which to produce renewable liquid fuels and presently contributes to more than 75% of total renewable energy worldwide (IEA, 2010). Grasses, such as elephantgrass (*Pennisetum purpureum* Schum.), kleingrass (*Panicum coloratum*), buffalograss (*Buchloe dactyloides* Nutt.), switchgrass (*Panicum virgatum* L.), miscanthus (*Miscanthus* spp.), reed canarygrass (*Phalaris arundeneacea* L.), tall fescue (*Fetusca arundinacea*), eastern gamagrass (*Tripsacum dactyloides*), and big bluestem (*Andropogon gerardii*) have been identified as promising species for biofuel production (Madakadze *et al*., 1999). Some biomass crops used for fuel are also used for food and feed, including corn and sugarcane, which leads to a concern of sustainability with global population expansion and the accompanying demand for food, feed, and other products these crops provide, in addition to the required land to produce these crops. Efforts are being made, however, to grow biomass crops on marginal lands generally considered unsuitable for food crop production (Liu *et al*., 2011; Zhuang *et al*., 2011).

Already, other countries are using biomass to provide a major source of their total fuel. For example, Brazil uses biofuels produced from sugarcane, which, in 2008, supplied more than 40% of the total volume of gasoline for the country (Somerville *et al*., 2010). Additionally, the Brazilian government passed legislation to allow for re-allocation of more than 60 million hectares of agricultural land for sugarcane growth. A 2005 joint study of the U.S. Department of Energy and the U.S. Department of Agriculture determined that the U.S. could produce 227 billion liters of ethanol by 2030, enough to substitute 30% of expected U.S. fuel demand (USDA/DOE, 2005). In the U.S. in 2011, about 49 billion liters of ethanol was produced for use as fuel additive on nearly 40% of the nation's 32 million hectares used for corn. Currently, liquid biofuels contribute roughly 1% to the total fuel source in the U.S. (USEIA, 2013). Other options for biofuels have been identified and are currently being investigated to determine their feasibility as a potential fuel source (Clark *et al*., 2013).

Many of these sources, including unused material left over after timber harvest, understory trees, and high-energy-yield grass crops (i.e. miscanthus and switchgrass) grown between rows of trees, may be well-suited for the longer growing season on the millions of hectares of pine plantations across the southeastern U.S. (Fox *et al*., 2007). Growing perennial grasses as a bioenergy crop between existing or new rows of trees grown for other purposes is a relatively new idea. It is known that grasses help provide erosion control and can improve soil infiltration upon establishment (Kort *et al*., 1998). Furthermore, forests and forest soils are generally net sinks for CO_2 and may help to reduce greenhouse gas emissions, so conversion of forests completely to grasses would result in a net C loss (Strickland *et al*., 2011).

Switchgrass is a hearty, native perennial grass, which proves to be both economically and environmentally promising as a fuel source (McLaughlin and Kszos, 2005) upon being converted into cellulosic ethanol (as opposed to a corn ethanol). Cellulosic ethanol is typically produced from biofuels such as wood, grass, and materials leftover following timber harvest. Cellulosic ethanol is a promising alternative to corn ethanol because food crops are not displaced, irrigation is not required, and chemical application rates are an order-of-magnitude lower than for many annual crops (Tilman *et al*., 2006).

In addition to research on enhancing the processing and refining of switchgrass to a readily available fuel, there is much research being conducted on development and improvement of growing (Nageswara-Rao *et al*., 2013; Ghimire and Craven, 2011) and harvesting (Sokhansanj *et al*., 2009) switchgrass. An adequate assessment of the environmental impact of growing switchgrass, both on its own and between rows in pine plantations, will help to understand the feasibility of growing switchgrass as a biofuel from an environmental standpoint (Albaugh *et al*., 2012; Murphy *et al*., 2013).

Management Impacts and Environmental Effects of Bioenergy Crops

The environmental impacts of changing land use to bioenergy crop production have yet to be adequately assessed (Williams *et al*., 2009). Environmental impacts need to be evaluated by monitoring 1) nutrients in surface and groundwater and in soils, 2) soil erosion, and 3) soil compaction. To understand treatment effects on soil and water resources in ‘new’ biofuel systems, evaluations will need to be made at the watershed scale, beginning before experimental treatments are initiated to document baseline conditions in order to understand watershed responses.

Switchgrass grown as an energy crop could help reduce atmospheric CO_2 accumulation by replacing fossil fuels to some degree and sequestering C in the soil. Belowground biomass of switchgrass is four to five times greater than that of corn (Lemus and Lal, 2005; Hartman *et al*., 2011). Through C sequestration, switchgrass can improve soil productivity and reduce nitrate contamination of water bodies by taking up N lost from fertilizer and other land management activities if planted as a buffer strip alongside water bodies (Bransby *et al*., 1998). Carbon sequestration benefits from the switchgrass farming industry will depend primarily on the type of crop it replaces (e.g. row crops, grazed pastureland).

Switchgrass promises considerably greater energy returns than corn and is thought to possess many other environmental benefits, such as reduced nitrate losses (Powlson *et al*., 2005). Some studies have shown that perennial grasses left unfertilized and unharvested generate very little inorganic N leaching (Randall *et al*., 1997; Brye *et al*., 2001), but few studies have examined inorganic N losses via drainage waters under perennial grasses (miscanthus and switchgrass) that have been annually harvested for biomass (McIsaac *et al*., 2010). Other studies have investigated surface runoff of sediment, nitrate, and phosphorus (P) from switchgrass and only estimated losses by modeling (Powlson *et al*., 2005; Nelson *et al*., 2006) rather than actual measurement. McIsaac *et al*. (2010) observed greater soil moisture under switchgrass than under corn-soybean plots, and inorganic N leaching 50cm below unfertilized switchgrass was less than 14% of the magnitude leached from corn and unfertilized soybeans. One study (Sladden *et al*., 1991) found that certain varieties of switchgrass, Cave-in-Rock and Alamo, contained 150% and 335% of previously applied N based on total N contained in harvested aboveground biomass. Relative to other crops, switchgrass is believed to be superior in recovering applied N (Bransby *et al*., 1998).

Unfertilized perennial biomass crops will likely reduce nitrate movement to streams and influence the hydrologic cycle, which may have both advantages (e.g. flood reduction) and disadvantages (e.g. intensified and prolong low flows) (McIsaac *et al*., 2010). Several studies have shown yield responses of switchgrass to natural and fertilizer-induced variations in N, K, Ca, and P, but positive responses of productivity to fertilization have been found only with N (e.g. Muir *et al*., 2001.) The N nutrition of switchgrass is affected by many factors, including, but not limited to, timing and frequency of harvests, amount of plant biomass removed, and mineralization rates of soils (McLaughlin and Kszos, 2005). One management strategy to remove N from the system is to cut switchgrass during mid-season when most of the plant N is located in the aboveground biomass (Sanderson and Wolf, 1995), but typically switchgrass grown for biomass is harvested later in the growing season when most nutrients have been translocated into belowground biomass (Lemus, 2004).

In general, the best way of assessing changes in soil N-supplying capacity is to measure *in situ* rates of N mineralization (e.g. Raison *et al*., 1992). Sequential soil coring allows estimates of N mineralization, uptake and leaching in the field (Raison *et al*., 1987). Many studies (e.g. Adams *et al*., 1989; Adams and Attiwill, 1993; Jarvis *et al*., 1996; Verchot *et al*., 2001; Dicus and Dean, 2008; Moberg *et al*., 2013) have subsequently used these techniques or similar techniques adopted from the original Raison *et al.* (1987) study to assess availability of soil N for plants.

Increased management intensity will result in more equipment, potentially more fertilization, more water use, and more nutrient leaching and potential nutrient removal from the system. Site preparation for switchgrass-only fields can be done by V-shearing and root raking, but this will inevitably remove coarse woody debris and associated C and N contained within. Albaugh *et al*. (2012) found that using this site preparation type removed 9.6 Mg ha^{-1} of coarse woody debris that contained 4.6 Mg C ha^{-1} and 14.9 kg N ha^{-1}, compared to 6.1 Mg ha^{-1} of coarse woody debris containing 2.9 Mg C ha^{-1} and 9.5 kg N ha^{-1} in a pine-switchgrass intercropped system where biomass between pine tree rows was harvested. Approximately six times the amount of coarse woody debris and C and N was distributed on the soil surface where biomass was left in place than where biomass was removed. Management practices like V-shearing and root raking cause significant soil disturbance, which can lead to erosion if left unattended.

Reducing erosion can be achieved through various practices such as terracing, conservation tillage techniques such as no-till (crop residues left in place), and strip-till (leaves some crop residue between rows). Perennial grasses have an obvious advantage over corn, soybeans, and other annual crops grown for bioenergy. Reducing N and P in stream runoff and groundwater can be achieved by using enhanced-efficiency fertilizers that are matched to uptake rates and patterns of a specific crop, or injecting fertilizer below the soil surface to reduce runoff and volatilization (NRC, 2008).

There is a need to understand and be able to quantify water use and seasonal fluctuations and competition for water between trees grown for timber and plants grown for biomass. Water availability in inter-cropped, forested systems largely depends on soil physical properties. Forest soils can be highly heterogeneous. A review of the literature reveals that many studies identify different, and sometimes conflicting, results from similar management practices with similar environmental factors. In other words, an increase, a decrease, or no effect is observed in a specific parameter (e.g. N fertilization effects on C storage in mineral soil) (e.g. Shan *et al*., 2001; Johnson *et al*., 2002; Adams *et al*., 2005; McFarlane *et al*., 2009). Intensively managed forest systems may be at risk for both groundwater and surface water contamination. Groundwater contamination by nitrate correlates strongly with increased fertilizer loading and with unconsolidated aquifers overlain by well-drained surficial soils (Nolan *et al*., 2002). In general, N excess in watersheds is detrimental because of disruptions in plant-soil nutrient interactions, increased soil acidification, increased emissions of N-containing greenhouse gases from soil, decreased water quality, toxic effects on freshwater biota, and eutrophication of coastal marine waters (Fenn *et al*., 1998). Studies have found export of nitrate and other ions to increase with increasing stream flow (Jaworski *et al*. 1992; Hill 1993; Fenn *et al*., 1998). Such occurrences can lead to extreme levels of dissolved nutrient, which may exceed the tolerance threshold for many aquatic organisms and eventually result in eutrophication of a water body. Eutrophication can lead to toxic algal blooms, oxygen depletion, fish kills, and biodiversity loss (Vitousek *et al*., 1997).

Soil organic matter (or soil C) and porosity are generally the two most influential factors affecting soil quality and fertility (Powers *et al*., 1990). Soil C, a surrogate for soil organic matter, is a key component in soil process and function because of its influence on nutrient cycling and availability and soil water dynamics, and as a C source for heterotrophic organisms (Raison and Rab, 2001). According to Raison and Rab (2001), changes in soil function, which may impact other ecosystem dynamics, are likely due to factors such as: soil disturbance (profile mixing, change in soil strength); bulk density/porosity changes (aeration, hydraulic conductivity, root access); soil organic matter (nutrient availability, soil moisture, soil organisms), and soil acidity and base condition (C storage, nutrient availability, decomposition rate, root growth). Management practices can change belowground C pools by changing amount of litter inputs or by altering C loss (Franklin, 2003). Amount and retention of soil organic C from bioenergy crop residue is affected by soil texture (McConkey *et al.*, 2003). Coarse-textured soils with lower bulk density will have lower amounts of organic C than fine-textured soils with high bulk density because crop residues decompose at higher rates in sandy soils than in clayey soils (Lemus and Lal, 2005). Other properties such as cation exchange capacity and concentrations of aluminum, calcium, and iron can also influence potential C sequestration (Grigal and Berguson, 1998).

Properties of the forest floor also affect C sequestration. Forest floor is the part of the ‘soil’ that is most active and responsive to environmental changes (Townsend, 1995), and upon decomposition, returns nutrients from litter to the soil profile. Forest floor decomposition rate is influenced most by the climate and litter quality in terms of its susceptibility to being attacked by decomposers (Attiwill and Adams, 1993). Forest floor can also play a key role in a properly functioning riparian buffer by impeding overland flows and providing adherent surfaces for sediment and dissolved nutrients (Hickey and Doran, 2004). Use of a riparian buffer is often implemented to ameliorate upslope management effects that may directly or indirectly impact surface water quality Zhang *et al*., 2010).

Riparian Buffer Efficiency

Riparian buffers are, as the name implies, buffers between managed upslope areas and waters downslope. Riparian buffers can be highly effective in removing N and P in runoff from agricultural watersheds (e.g. Peterjohn and Correll, 1984; Hill, 1993; Hefting and de Klein, 1998; Schilling and Jacobson, 2014). Creating buffers of typical riparian vegetation can also be effective for managing and retaining nutrients in a N-saturated watershed, therefore helping protect stream water quality (Mayer *et al*., 2007; Christen and Dalgaard, 2013). Riparian buffers can function as a long-term nutrient filter and sink if older, larger trees are harvested occasionally to promote accelerated nutrient uptake by younger trees (Fenn *et al*., 1998).
The basic idea of how riparian buffers function is the following. Native or introduced trees and/or shrubs and herbaceous vegetation are left in place or purposely planted alongside a stream

channel to protect water quality. The vegetation and the forest floor litter tend to reduce water velocity, so sediment and associated nutrients will settle out as overland flow slows. Dissolved nutrients are adsorbed by soil particles, immobilized by microorganisms, and/or taken up by the riparian buffer plants. Buffer effectiveness depends on the ability of the buffer to intercept and attenuate nutrients traveling along surface or subsurface pathways (Mayer *et al*., 2007). Additionally, riparian buffers can contribute other ecosystem services such as stream bank stabilization, stream temperature regulation via shading, organic matter input to streams, and habitat structures (Hickey and Doran, 2004).

Functional efficacy of riparian buffers has been observed to be quite variable, depending upon expectations of the buffer, climate, location, time of year (growing season vs. dormant season) buffer width, slope, buffer area-to-upslope source ratio, type of upslope land management, pollutant type, soil type, vegetation type, etc. (Dillaha *et al*., 1989; Vought *et al*., 1994; Patty *et al*., 1997; Syversen, 2002, Zhang *et al*., 2010). Buffer widths range from <1 m to approximately 35 m on average, with slopes ranging from 2 to 16%. In a meta-analysis of 73 studies by Zhang *et al*. (2010), median removal effectiveness was highest for pesticides (88%), followed by sediment (86%), P (72%), and N (68%). Variability of effectiveness was lowest with sediment removal, whereas N removal had the widest range (2 to 100%). Phosphorous had a smaller range (22-96%) but had the same standard deviation as N. Pesticide removal also had high variation with a wide range in effectiveness (4 to 100%). Buffer slope was found to have a break point (between 8 to 12%) where its relationship with sediment removal efficiency changes from positive to negative. Vegetation type in riparian buffers appears to be a significant factor in ecosystem functioning. Buffers with trees remove more N and P than buffers with mixed trees and grasses or only grass (Zhang *et al*., 2010). Potentially, subsurface hydrology and biogeochemistry are important for N removal within buffers as well (Mayer *et al*., 2007).

Riparian zones can help decrease the amount of nutrients, particularly nitrate, entering streams and other water bodies. Some means of contributing to nitrate reduction in riparian areas are sediment trapping, vegetation uptake, microbial immobilization, and denitrification (Martin *et al*., 1999). Though riparian buffer zones reduce amount of sediment and nutrients entering waters, during large storm events, overland flow has the potential to override functions the riparian buffer zone would normally provide. Buffer width, slope, and vegetation type appear to be the main drivers of riparian buffer efficiency (Zhang *et al*., 2010). Based on previous studies (e.g. Haycock and Pinay, 1993; Mayer *et al*., 2007) the optimal buffer should be 20-30 m wide, have a slope of <10%, and contain predominantly trees, but ultimately success of a riparian buffer may depend on specific characteristics of the buffer strip (soil properties, vegetation type, successional stage), as well as the nutrients or pesticides involved and topography of upslope areas (Hickey and Doran, 2004).

The environmental impacts of changing land use to biofuel production have yet to be adequately assessed on multiple scales (Williams, *et al*., 2009). Evaluating a range of management strategies and the efficacy of preserving and promoting soil and water quality through riparian buffers at the small watershed scale will provide information needed to predict potential environmental effects of future bioenergy operations and to make good planning choices. These smaller, watershed-scale measurements will help to inform large, regional-scale computer simulation models to predict environmental effects of different scenarios of converting forested lands to various types of bioenergy crops for biofuels across the southeastern U.S.

Chapter 2 - Objectives and Hypotheses, Approach and Methods

Objectives and Hypotheses

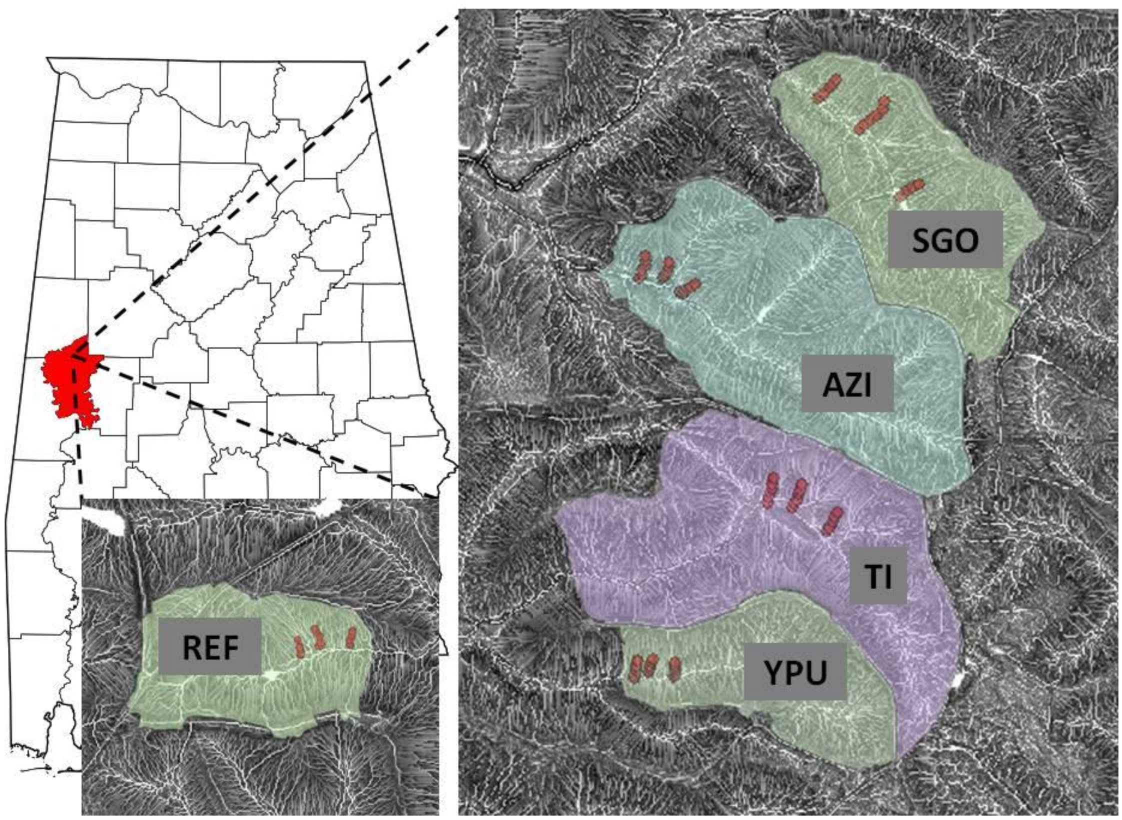
The overall objective of this study was to examine how land use (e.g. establishment practices, vegetation type) affects soil properties and selected soil C and N dynamics in a novel setting of cellulosic biofuel treatments at the Weyerhaeuser Alabama Cellulosic Biofuel Research site in the Upper Coastal Plain of Alabama. I examined selected soil physical and chemical characteristics during the first two years following switchgrass establishment within these watersheds receiving cellulosic biofuel treatments and observed how they compare with a reference watershed supporting an established loblolly pine stand. My hypotheses were that 1) bulk density and soil nutrient content at 0-15cm depth will be high compared to a mid-rotation reference loblolly pine stand because of increased decomposition and incorporation of organic matter and compaction during site preparation and switchgrass harvest, and 2) forest floor mass and nutrient content will be low compared to a mid-rotation reference loblolly pine stand because of increased decomposition and incorporation of organic matter into soil during site preparation and switchgrass harvest. I also explored the short-term treatment effects on selected C and N dynamics along hillslope-riparian transects and how they compare with a reference watershed supporting an established loblolly pine stand. My hypothesis was that litter decomposition, *in situ* net mineralization, and anaerobic N mineralization potential will be high compared to a mid-rotation reference loblolly pine stand because of increased decomposition and incorporation of organic matter into soil during site preparation and switchgrass harvest in areas of greatest disturbance. Furthermore, I investigated how selected soil physical and chemical properties along hillslope-riparian transects relate to soil C & N dynamics among watershed treatments and within watershed treatments based on slope position (i.e. upslope vs. riparian).

Approach and Methods

Study Sites and Treatments

Five watersheds with contrasting biofuel treatments within the Weyerhaeuser Alabama Cellulosic Biofuel Research site offer an opportunity for research to investigate how land cover/management (e.g. establishment practices, vegetation type) affects selected soil properties and C and N dynamics of soil. Four watersheds are adjacent, with similar soils and management histories, differing primarily by biofuel treatment. The fifth watershed (reference) is located approximately three kilometers southeast of the other four watersheds. Sites are located in the Upper Coastal Plain physiographic province near Aliceville, Alabama (Figure 1). Soils are mapped as Falaya (Entisol), Faceville, (Ultisol) Ochlockonee (Entisol) or Smithdale (Ultisol) (all fine sandy loams, differing primarily by slope). Soils generally trend from clay in the northernmost watershed (#4) to more sandy in the southernmost watershed (#1).

Figure 1. Study site locations in Greene County, Alabama.



Treatments include: 1) loblolly pine with understory (YPU) [tree age: 5 years]; 2) thinned loblolly pine with switchgrass intercropped between pine rows (TI) [tree age: 5 years], switchgrass planted in 2012 and again in May 2013; 3) age-zero loblolly pine-switchgrass intercropping (planted simultaneously in 2013) (AZI); 4) switchgrass-only, planted in 2012 and again in May 2013 (SGO); and 5) reference loblolly pine stand (control) (REF) [tree age: 19 years] [Table 1]. Each treatment is applied to an entire watershed (where applicable) with exception of streamside management areas along the channels where existing riparian vegetation was left in place. Riparian buffers are approximately 10 m wide on each side of the stream in each of the treated watersheds.

Table 1. Watershed cellulosic biofuel treatments in Greene County, Alabama.

Watershed	ha	Treatment	Tree Yr[1]	Grass Yr[1]
1	11.3	**Pine/Understory Removal**	2008	--
2	25.1	**Thinned/Intercropped**	2008	2012, 2013[2]
3	24.4	**Age-Zero Intercropped**	2013	2013
4	16.5	**Switchgrass-Only**	--	2012, 2013[2]
5	8.0	**Reference - Mid-Rotation Pine**	1994	--

[1]Year planted.

[2]Switchgrass was replanted in watersheds 2 and 4.

Site Preparation and Management History

Watershed 1 – Loblolly Pine (Vision Forestry)

2008: Planted in loblolly pine at 1.5 m x 6.1 m spacing (1,076 trees per ha).

2012: September – Release herbicide spray to remove competing hardwoods and understory.

Watershed 2 – Thinned Loblolly Pine – Switchgrass Intercropping

2008: Planted in loblolly pine at 1.5 m x 6.1 m spacing (1,076 trees/ha).

2012: March – Stand thinned and sheared. Trees planted in 2008 were thinned where slopes were less than 12% using a trackhoe mounted shredder to a 6.1 m x 6.1 m spacing (~247 trees/ha). Shearing was done with a D8 Bulldozer with a V-blade to clear row middles to along edge of planted rows.

April – Spray post-emergent herbicide. Glyphosate 2% in 93.5 liters/ha + 0.25% surfactant.

May – Disking and switchgrass planting. A rubber tire tractor was used to pull a disk. Disk ran ahead of a four-wheeler that had a spin spreader mounted on the front to broadcast seed and a steel bar with chains dragging on the back to incorporate seed approximately ~3 mm into soil. Variety: Alamo (seed harvested in 2011 in Texas, Johnson Seed Company), Planting Method: broadcast and covered, Time to Germination: Approximately 40 days.

2013: May – Switchgrass resown. A rubber tire tractor was used to pull a disk. Disk ran ahead of a four-wheeler that had a spin spreader mounted on the front to broadcast seed and a steel bar with chains dragging on the back to incorporate seed approximately 3 mm into soil. Variety: Alamo, Planting Method: broadcast and covered, Time to Germination: Approximately 40 days.

Watershed 3 – Age-Zero Pine - Switchgrass Intercropping Management Operations

2006: Planted in loblolly pine at 1.5 m x 6.1 m spacing (1,076 trees/ha).

2012: September – Release herbicide spray to remove competing hardwoods and understory.

October – Sheared and piled in windrows. Trees planted in 2006 were removed from site where slopes were less than 12%. Sheering was done with a D8 Bulldozer with a V-blade. Tree residue was piled into windrows 60 m apart between the edges of the cleared area running east to west using a D8 Bulldozer with a rake.

November – Tree treatment of offset rip and planting. A D8 tractor was used to pull an offset rip along proposed planting beds to loosen the soil. Offset rip is two blades that cut to a depth of 60cm. Blades are mounted, one blade is 20cm behind the other, in line on opposite sides of the draw bar.

2013: February – Trees were planted at 1.5 m x 6.1 m spacing (1,076 trees/ha).

May – Switchgrass resown. A rubber tire tractor was used to pull a disk. Disk ran ahead of a four wheeler that had a spin spreader mounted on the front to broadcast seed and a steel bar with chains dragging on the back to incorporate seed approximately 3 mm into soil. Variety: Alamo, Planting Method: broadcast and covered, Time to Germination: Approximately 40 days.

Watershed 4 – Switchgrass Only

2006: Planted in loblolly pine at 1.5 m x 6.1 m spacing (1,076 trees/ha).

2012: March – Sheared and piled in windrows. Trees planted in 2006 were removed from site where slopes were less than 12%. Sheering was done with a D8 Bulldozer with a V-blade. Tree residue was piled into windrows 60 m apart between the edges of the cleared area running east to west using a D8 Bulldozer with a rake.

April – Spray post-emergent herbicide. Glyphosate 2% in 93.5 liters/ha + 0.25% surfactant.

May – Disking and switchgrass planting. A rubber tire tractor was used to pull a disk. Disk ran ahead of a four wheeler that had a spin spreader mounted on the front to broadcast seed and a steel bar with chains dragging on the back to incorporate seed approximately 3 mm into soil. Variety: Alamo (seed harvested in 2011 in Texas, Johnson Seed Company), Planting Method: broadcast and covered, Time to Germination: Approximately 40 days.

2013: May – Switchgrass resown. Disking and switchgrass planting. A rubber tire tractor was used to pull a disk. Disk ran ahead of a four wheeler that had a spin spreader mounted on the front to broadcast seed and a steel bar with chains dragging on the back to incorporate seed approximately 3 mm into soil. Variety: Alamo, Planting Method: broadcast and covered, Time to Germination: Approximately 40 days.

Watershed 5 – Reference Loblolly Stand

1994: Planted in loblolly pine.

2008: April –Thinned. Trees were thinned.

2009: January – Pruned. Pruning operation removed lower and dead branches from trees. Stem Injection Fertilization.

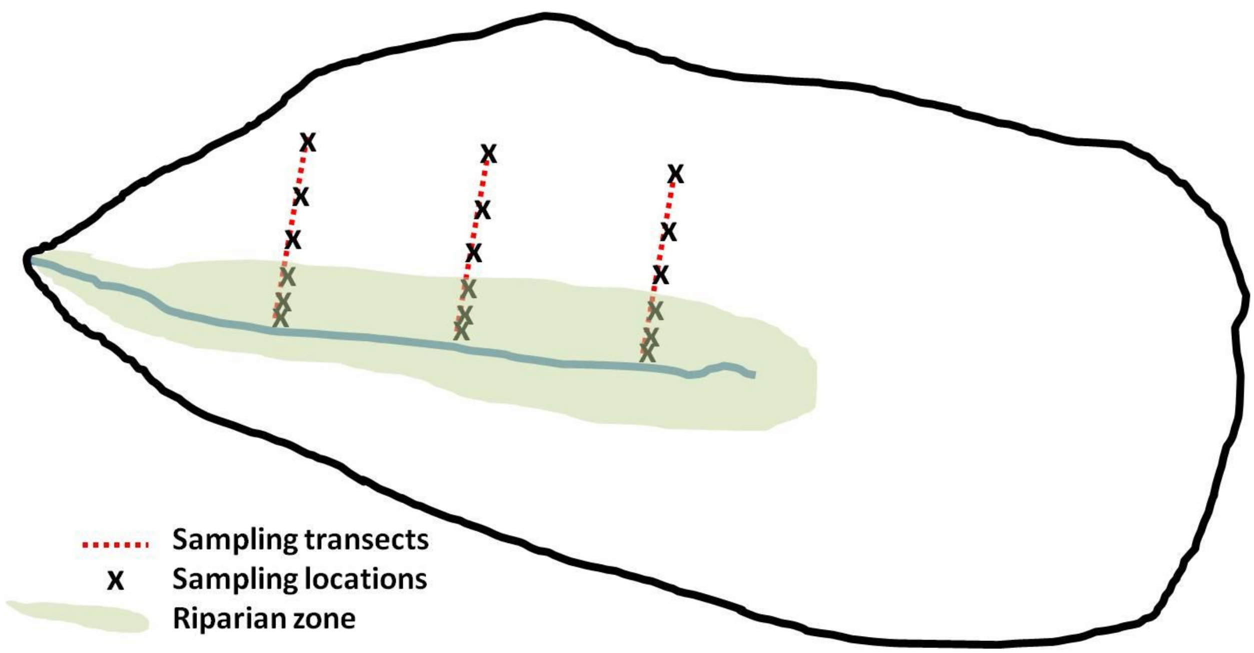
2011: April – Fertilized. Fertilization was conducted as a broadcast dry fertilizer.

Data Collection

Sampling Location Selection

Areas of potentially higher saturation were identified through a topographic wetness index assessment (System for Automated Geoscientific Analyses), along with a visual assessment of topographic features, and were targeted initially as “wet spots” and assumed to be potential locations of dissolved C and N transport to the stream. Topographic wetness indices were calculated from 2m-resolution digital elevation models as $ln(\alpha/\tan\beta)$, where α is the upslope contributing area and β is the surface slope at a given point (Hornberger, 1998). Within each watershed, three transects (A-farthest upstream, B, C-farthest downstream) [Figure 2] were established along a hillslope based on results from the topographic wetness index assessment and visual topographic features. Each transect passed through areas of likely saturation and spanned from the stream channel perpendicularly to approximately 40 m upslope. Aspect was kept consistent for all transects in the five watersheds. The goal of this approach was to establish transects along a hillslope-riparian-stream continuum to assess potential movement of dissolved C and N. Six locations were sampled along each transect—three within the riparian zone (1,2,3) and three upslope from the riparian zone (4,5,6). Distances of sampling locations from stream channel within the riparian zone ranged from 1 m to approximately 10 m at the outer edge of the riparian zone, with one sample mid-way between them at approximately 5 m. Upslope from the riparian zone, samples were collected at increasingly further distances (e.g. 8, 17, 27 m) from the previous samples (Figure 2).

Figure 2. Diagram of transect and sampling locations within a watershed, with riparian area shown in green.



Soil Physical Properties

Bulk density was measured at year 1. Samples for measuring bulk density were collected using a hammer-driven core sampler and a core length of 10cm at each sampling location within the center of each of the two depth increments (0-15cm and 15-30cm). Cores were capped in the field and returned to Virginia Tech, where they were dried at 105 °C and weighed. Because no coarse fragments were observed, bulk density was calculated by dividing mass of soil by volume of sample core.

Soil particle-size analysis was performed on the composite soil samples described below. Twenty ml of Calgon solution was added to 10.0 g of soil and soaked for 10-15 minutes, stirred, then washed into a large graduated cylinder with a hydrometer. Another cylinder containing only deionized water and 20 ml of Calgon was set up as a blank to account for effect of Calgon on the viscosity of water. The cylinder containing the soil was shaken vigorously for one minute, and then left to sit as time was immediately noted. Three drops of octanol were added and the hydrometer was quickly placed in suspension and a reading was taken at 40 seconds, which gives the silt + clay reading (sand has settled out). The hydrometer was removed and the temperature of the suspension was recorded. After two hours, the hydrometer was reinserted and a reading and temperature measurement was made. This reading measures the clay in suspension (silt + sand have settled out). The suspension was then be passed through a 270 mesh sieve and the sand was transferred to a drying tin, dried at 105 °C, and then weighed as total sand. The remaining was considered silt and clay. Clay fraction was determined by dividing the corrected hydrometer reading at 2 hr by the oven-dry weight of the soil, and silt fraction was calculated as 100 – (% sand + % clay).

Soil Chemical Properties

Composite soil samples for chemical analysis were collected at year 1 (2012) and at year 2 (2013) at two depth increments (0-15 and 15-30cm) at each sampling point along each transect within each watershed. Soils were sampled at closer intervals in the riparian zone to assess the effect the riparian zone has on selected N and C dynamics. All soils were brought to Virginia Tech where they were air-dried and sieved at 2 mm. Approximately one gram of soil for each year-1 and each year-2 composite soil sample were weighed into small crucibles and combusted at 550 °C. N_2 and CO_2 gases were be measured by CNS elemental analyzer (Elementar Vario MAX CNS, Hanau, Germany) and reported as percent total C and total N. Another subsample of each composite soil sample was sent to Virginia Tech Soil Testing Lab for analysis of soil pH (Kalra, 1995), Mehlich-1 extractable nutrients [potassium, calcium, magnesium (Mehlich, 1953), zinc (Alley *et al*., 1972), manganese (Cox, 1968), copper, iron, and boron (Soil Analysis Handbook of Reference Methods, 1999), and extractable P (Kuo, 1996)], along with an estimate of cation exchange capacity. Mean values from year 1 and year 2 soil chemical properties were used to evaluate treatment and slope position effects on soil chemical properties and for evaluation of relationships between soil chemical properties and selected C and N dynamics.

Soil Nitrogen Mineralization Potential

Using mineral composite soils collected at year 2 as described above, soil N mineralization potential was measured via anaerobic incubation in the laboratory according to methods described by Bremner (1965), Geist (1977), and Shumway (1978). For each sample, 5.0 g of soil was placed in a vial, filled with distilled water, and shaken to disperse soil. Vials were incubated at 40 °C for seven days then transferred quantitatively to a centrifuge tube using 3 M KCl. The total weight of the soil and solution was brought to 55.0 g using 3 M KCl then shaken for one hour, filtered through a Whatman #1 filter paper into 20 mL scintillation vials and frozen until NH_4-N levels were measured by an auto-analyzer (Bran-Luebbe TRAACS 2000, Nordersted, Germany). Differences in NH_4-N between lab-incubated sample and initial sample were considered net N mineralization potential.

Forest Floor

Forest floor samples were collected in January 2013 and January 2014 using 50cm x 50cm (0.25m^2) sampling frames at each of the six sampling locations along each of the three transects described above and characterized by oven-dry weight, total C, total N, and C:N measured by CN elemental analyzer as described for mineral soil. All materials < 5cm diameter were included in the forest floor samples.

Litter Decomposition

Rate of litter decomposition was assessed using a method adapted from Kelly and Beauchamp (1987). Fresh loblolly pine needles were collected on site at one common location adjacent to treatment watersheds in August 2012. Needles were oven-dried and placed in 30cm x 30cm mesh bags. The bottom of the bags had 1-mm openings to prevent litter loss by gravity, and the top of the bags had 13-mm openings to allow access for larger soil fauna. Approximately 10 g of oven-dry loblolly needles was inserted into each bag. Nine bags were placed at sampling points 1, 3, and 5 along each transect in each watershed (n=45). Bags were collected seasonally at roughly 3-month intervals beginning in January 2013 and ending in January 2014. One bag was collected at each sampling location, and foreign debris was removed from the bag. Each litter bag was secured into a Ziploc bag for transport back to laboratory where litter bag contents were emptied into a paper bag and oven-dried at 65 °C, weighed, then ground and passed through a 2 mm sieve for chemical analysis. Samples were analyzed for total C and N by CNS elemental analyzer (Elementar Vario MAX CNS, Hanau, Germany). Decomposition rate (*k*) was calculated for each sampling location by plotting the natural log of percent mass remaining versus time (yrs), then taking the slope of that line as k (yr^{-1}).

In situ net N ammonification, nitrification and mineralization

In situ net N ammonification, nitrification, and mineralization rates (Raison *et al*., 1987) were measured at ~3-month, seasonal intervals (August 2012-January 2013, January 2013-March 2013, March 2013-June 2013, June 2013-September 2013, September 2013-January 2014) at six sampling points along transects described above to determine if they were influenced by biofuel treatments. Two intact soil cores (0-15cm) were collected at the six sampling sites along soil sampling transects described above within each watershed. One core was returned to the laboratory for measurement of initial soil inorganic N concentrations, and the second core was capped and remained in the field for approximately three-months for an *in situ* incubation study. Replicate soil cores were taken at each sampling site within each transect. Soils were air-dried, ground, and passed through a 2 mm sieve. A KCl extraction was done on each core sample (Bremner, 1965). Approximately 5.0 g of soil was weighed into a centrifuge tube and 50 mL of 2 M KCl was added then shaken for one hour, filtered through a Whatman #42 filter paper into 20 mL scintillation vials and frozen until concentrations of NH_4-N and NO_3-N could be measured by an auto-analyzer (Bran-Luebbe TRAACS 2000, Nordersted, Germany). Differences in NH_4-N between field-incubated sample and initial sample were considered net N ammonification, and differences in NO_3-N between incubated and initial samples were considered net nitrification. Net N mineralization was calculated as the sum of net ammonification and net nitrification. Incubations were done four times per year (seasonally) for approximately one and a half years starting in August 2012 and ending in January 2014.

Statistical Analysis

Soil chemical and physical data, along with forest floor, litter composition, net N mineralization, and N mineralization potential data were analyzed using analysis of variance (ANOVA) (JMP, version 11) to determine if there were watershed treatment effects, slope position (upslope vs riparian) effects, or interaction effects on soil chemical and physical properties or on soil C and N dynamics. Sample points along the three sampling transects in each watershed were grouped as either riparian or upslope to determine effects of riparian zone (sample locations 1-3) versus the actual treatment area upslope (sample locations 4-6) from the riparian zone. Treatment means for each slope position (riparian, upslope) in each watershed were calculated from nine upslope and nine riparian sampling locations in each watershed. Most soil chemical data were log transformed, and percent data were arcsine transformed, to achieve normality before running an ANOVA. Additionally, correlations between each of the soil chemical and physical properties at 0-15 cm and soil C and N dynamics were examined by multiple comparisons run by slope position (upland, riparian) across all watershed treatments. Based on p-values of these results and Spearman's correlation ρ, the variables with highest correlations were selected for evaluation in linear regression models in an effort to examine how the most influential soil chemical and physical properties at 0-15cm are related to selected soil C and N dynamics.

Chapter 3 - Results

Soil Physical Properties

Bulk Density

There was a significant interaction between watershed treatment and slope position for bulk density at 0-15cm depth (Table 2). Within each watershed treatment, bulk density at 0-15cm for each slope position (upslope, riparian) was similar for the young-pine-with-understory, age-zero intercropped, and switchgrass-only treatments but differed significantly for the thinned-intercropped [1.06 Mg/m^3 (riparian) and 1.60 Mg/m^3 (upslope); p=0.0001] and mid-rotation reference [1.40 Mg/m^3 (riparian) and 1.53 Mg/m^3 (upslope); p=0.0418] treatments. Bulk density at 0-15cm in riparian positions was similar among watershed treatments (1.40-1.43 Mg/m^3) with the exception of the thinned-intercropped treatment, which was significantly lower (1.06 Mg/m^3; p=0.0007). There was no significant difference (p=0.2061) in bulk density at 0-15cm in upslope positions among watershed treatments. Among watershed treatments, bulk density at 15-30cm was significantly greater (p=0.0131) in the switchgrass-only and mid-rotation reference treatments than in the age-zero intercropped treatment (Table 3). Bulk density at 15-30cm was greater (p=0.0004) in the upslope position than in the riparian position across all treatments.

Table 2. Effects of watershed treatments and slope position on bulk density at 0-15cm.[1]

Treatment	Slope Position	Bulk Density (Mg/m^3)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	1.47	0.06	A[2]	**NSD[3]**	
Young-pine-with-understory	Riparian	1.43	0.07	A		a
Thinned - Intercropped	Upslope	1.60	0.04	A		
Thinned - Intercropped	Riparian	1.06	0.09	B		b
Age-zero - Intercropped	Upslope	1.38	0.08	A		
Age-zero - Intercropped	Riparian	1.40	0.04	A		a
Switchgrass-only	Upslope	1.53	0.08	A		
Switchgrass-only	Riparian	1.41	0.06	A		a
Mid-rotation Reference	Upslope	1.53	0.05	A		
Mid-rotation Reference	Riparian	1.40	0.03	B		a

[1]A significant interaction between watershed treatment and slope position is present.
[2]For each watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.
[3]For each slope position, watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Table 3. Effects of watershed treatments and slope position on bulk density at 15-30cm.

Treatment	Mean Bulk Density (Mg/m^3)	SE	Tukey
Young-pine-with-understory	1.60	0.04	AB[1]
Thinned - Intercropped	1.53	0.06	AB
Age-zero - Intercropped	1.49	0.04	B
Switchgrass-only	1.65	0.04	A
Mid-rotation Reference	1.66	0.03	A
Slope Position	**Mean Bulk Density (Mg/m^3)**	SE	t-test
Upslope	1.65	0.03	A[2]
Riparian	1.52	0.03	B

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

Particle-Size Distribution

There was a significant interaction between watershed treatment and slope position for percent sand at both 0-15cm and 15-30cm depths (Table 4). Within each watershed treatment, % sand at 0-15cm for each slope position (upslope, riparian) was similar for all treatments except for the age-zero intercropped treatment [67% (riparian) and 53% (upslope); p=0.0124]. There was no significant difference (p=0.1873) in % sand at 0-15cm in riparian positions among watershed treatments (64%-77%). % sand at 0-15cm in upslope positions was significantly greater (p<0.0001) in the thinned-intercropped and young-pine-with-understory treatments than in the other three watershed treatments. Within each watershed treatment, % sand at 15-30cm for each slope position (upslope, riparian) was similar for the thinned-intercropped, switchgrass-only, and mid-rotation reference treatments, but differed significantly between riparian and upslope positions in the young-pine-with-understory [82% (riparian) and 73% (upslope); p=0.0017] and age-zero intercropped treatments [61% (riparian) and 46% (upslope); p=0.0074] (Table 4). Percent sand at 15-30cm in the upslope position was significantly greater (p<0.0001) in the young-pine-with-understory treatment than the age-zero intercropped and mid-rotation reference treatments. Percent sand at 15-30cm in the riparian position was significantly greater (p=0.0010) in the young-pine-with-understory treatment than the thinned-intercropped, age-zero intercropped, and mid-rotation reference treatments.

There was a significant interaction between watershed treatment and slope position for percent silt at both 0-15cm and 15-30cm depths (Table 4). Within each watershed treatment, % silt at 0-

15cm for each slope position (upslope, riparian) was similar for young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments, but differed significantly for the age-zero intercropped [10% (riparian) and 26% (upslope); p=0.0005] and the switchgrass-only intercropped [5% (riparian) and 10% (upslope); p=0.0111] treatment. Percent silt at 0-15cm in the riparian position was significantly greater (p=0.0423) in the age-zero intercropped treatment than in the thinned-intercropped treatment. Percent silt at 0-15cm in the upslope position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the other four watershed treatments. Within each watershed treatment, % silt at 15-30cm for each slope position (upslope, riparian) was similar for young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments, but differed significantly for the age-zero intercropped [19% (riparian) and 34% (upslope); p=0.0042] and the switchgrass-only [5% (riparian) and 11% (upslope); p=0.0455] treatments (Table 4). Percent silt at 15-30cm in the upslope position was significantly greater (p=0.0002) in the age-zero intercropped treatment than all other treatments. % silt at 15-30cm in the riparian position was significantly greater (p=0.0002) in the age-zero intercropped treatment than the thinned-intercropped, age-zero intercropped, and switchgrass-only treatments.

There was a significant interaction between watershed treatment and slope position for percent clay at both 0-15cm and 15-30cm depths (Table 4). Within each watershed treatment, % clay at 0-15cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the thinned-intercropped [31% (riparian) and 15% (upslope); p=0.0066] treatment. % clay at 0-15cm in the upslope position was significantly greater (p<0.0001) in the switchgrass-only and mid-rotation reference treatments than in the other three watershed treatments. There was no significant difference (p=0.0683) in % clay at 0-15cm in the riparian position among treatments. Within each watershed treatment, % clay at 15-30cm for each slope position (upslope, riparian) was similar for the age-zero intercropped, switchgrass-only, and mid-rotation reference treatments, but differed significantly for the young-pine-with-understory [13% (riparian) and 18% (upslope); p=0.0237] and the thinned-intercropped [31% (riparian) and 16% (upslope); p=0.0256] treatments (Table 4). Percent clay at 15-30cm in the upslope position was significantly greater (p=0.0076) in the switchgrass-only treatment than in the young-pine-with-understory and the thinned-intercropped treatments. Percent clay at 15-30cm in the riparian position was significantly greater (p=0.0111) in the thinned-intercropped and mid-rotation reference treatments than in the young-pine-with-understory treatment.

Soil Texture

Soils in the young-pine-with-understory and thinned-intercropped treatments were comprised chiefly of loamy sand and sandy loam. The majority of soils in the age-zero intercropped treatment consisted of sandy loam or sandy clay loam. Soils in the switchgrass-only and the mid-rotation reference treatments were dominated (>60%) by sandy loam. Overall, distribution of soil textures were ~50% sandy loam, 25% loamy sand, 13% sandy clay loam, with lesser amounts of other loams and clays.

Soil Chemical Properties

Total Carbon

There was a significant interaction between watershed treatment and slope position for total C concentration at both 0-15cm and 15-30cm depths (Table 5). Within each watershed treatment, total C concentration at 0-15cm for each slope position (upslope, riparian) was similar for all watershed treatments except for the thinned-intercropped treatment [27.0 g/kg (riparian) and 7.1 g/kg (upslope); p<0.0001]. Total C concentration at 0-15cm in the upslope position was significantly greater (p<0.0001) in the age-zero intercropped and mid-rotation reference treatments than in the thinned-intercropped and switchgrass-only treatments. Total C concentration at 0-15cm in the riparian position was significantly greater (p=0.0067) in the thinned-intercropped treatment than in the switchgrass-only treatment. Within each watershed treatment, total C concentration at 15-30cm for each slope position (upslope, riparian) was similar for all watershed treatments except for the thinned-intercropped treatment [6.4 g/kg (riparian) and 3.9 g/kg (upslope); p=0.0033]. Total C concentration at 15-30cm in the upslope position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in all other watershed treatments. Total C concentration at 15-30cm in the riparian position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments.

Table 4. Effects of watershed treatments and slope position on particle-size distribution.[1]

0-15cm		% Sand			Watershed Treatment		% Silt			Watershed Treatment		% Clay			Watershed Treatment	
Treatment	Slope Position	Mean	SE	SP	Upslope	Riparian	Mean	SE	SP	Upslope	Riparian	Mean	SE	SP	Upslope	Riparian
Young-pine-with-understory	Upslope	74	3	A[2]	a[3]		8	2	A	b		18	1	A	b	
Young-pine-with-understory	Riparian	77	2	A		**NSD**	6	0	A		ab	18	2	A		**NSD**
Thinned - Intercropped	Upslope	77	3	A	a		8	2	A	b		15	1	B	b	
Thinned - Intercropped	Riparian	64	6	A			5	1	A		b	31	5	A		
Age-zero - Intercropped	Upslope	53	4	B	b		26	3	A	a		21	1	A	b	
Age-zero - Intercropped	Riparian	67	3	A			10	2	B		a	24	3	A		
Switchgrass-only	Upslope	62	2	A	b		10	1	A	b		29	2	A	a	
Switchgrass-only	Riparian	68	4	A			5	1	B		ab	26	4	A		
Mid-rotation Reference	Upslope	64	2	A	b		8	2	A	b		28	2	A	a	
Mid-rotation Reference	Riparian	64	4	A			6	1	A		ab	30	4	A		
15-30cm		**% Sand**			**Watershed Treatment**		**% Silt**			**Watershed Treatment**		**% Clay**			**Watershed Treatment**	
Young-pine-with-understory	Upslope	73	2	B	a		9	2	A	b		18	2	A	b	
Young-pine-with-understory	Riparian	82	1	A		a	5	0	A		b	13	1	B		b
Thinned - Intercropped	Upslope	70	4	A	ab		14	4	A	b		16	3	B	b	
Thinned - Intercropped	Riparian	60	7	A		b	9	2	A		b	31	5	A		a
Age-zero - Intercropped	Upslope	46	4	B	c		34	3	A	a		20	2	A	ab	
Age-zero - Intercropped	Riparian	61	3	A		b	19	3	B		a	20	2	A		ab
Switchgrass-only	Upslope	61	3	A	ab		11	3	A	b		28	3	A	a	
Switchgrass-only	Riparian	68	4	A		ab	5	1	B		b	28	3	A		ab
Mid-rotation Reference	Upslope	56	4	A	bc		18	5	A	b		25	3	A	ab	
Mid-rotation Reference	Riparian	58	6	A		b	12	3	A		ab	30	6	A		a

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth, particle-size fraction, and watershed treatment, slope position (SP) means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth, particle-size fraction, and slope position, watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Table 5. Effects of watershed treatments and slope position on soil total carbon.[1]

Treatment	Slope Position	C (g/kg) Mean	C (g/kg) SE	C (g/kg) Slope Position	Watershed Treatment Upslope	Watershed Treatment Riparian	C (Mg/ha) Mean	C (Mg/ha) SE	C (Mg/ha) Slope Position	Watershed Treatment Upslope	Watershed Treatment Riparian
0-15cm											
Young-pine-with-understory	Upslope	13.1	1.8	A[2]	ab[3]		29.2	4.1	A	ab	**NSD**
Young-pine-with-understory	Riparian	16.2	2.7	A		ab	33.9	4.2	A		
Thinned - Intercropped	Upslope	7.1	1.3	B	c		17.3	3.3	B	b	
Thinned - Intercropped	Riparian	27.0	4.0	A		a	41.1	5.5	A		
Age-zero - Intercropped	Upslope	19.4	1.7	A	a		40.8	4.2	A	a	
Age-zero - Intercropped	Riparian	15.5	1.3	A		ab	33.2	3.1	A		
Switchgrass-only	Upslope	10.0	1.9	A	bc		21.8	3.6	A	b	
Switchgrass-only	Riparian	13.1	2.4	A		b	27.8	5.0	A		
Mid-rotation Reference	Upslope	18.4	1.8	A	a		42.8	4.4	A	a	
Mid-rotation Reference	Riparian	17.1	1.3	A		ab	36.4	2.8	A		
15-30cm											
Young-pine-with-understory	Upslope	3.7	0.4	A	c		9.5	0.9	A	c	
Young-pine-with-understory	Riparian	3.6	0.3	A		d	8.3	0.7	A		c
Thinned - Intercropped	Upslope	3.9	0.6	B	c		9.5	1.0	A	c	
Thinned - Intercropped	Riparian	6.4	0.5	A		bc	13.6	1.2	A		b
Age-zero - Intercropped	Upslope	15.9	1.2	A	a		36.4	3.5	A	a	
Age-zero - Intercropped	Riparian	12.7	1.1	A		a	28.4	2.3	A		a
Switchgrass-only	Upslope	9.1	1.2	A	b		23.6	2.8	A	b	
Switchgrass-only	Riparian	9.6	1.5	A		ab	22.7	2.9	A		a
Mid-rotation Reference	Upslope	7.4	0.6	A	b		19.3	1.5	A	b	
Mid-rotation Reference	Riparian	6.1	0.7	A		c	14.7	1.4	B		b

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth and watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth and slope position, watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

There was a significant interaction between watershed treatment and slope position for total C content at both 0-15cm and 15-30cm depths. Within each watershed treatment, total C content at 0-15cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the thinned-intercropped treatment [41,060 kg/ha (riparian) and 17,253 kg/ha (upslope); p=0.0009]. Total C content at 0-15cm in the upslope position was significantly greater (p<0.0001) in the mid-rotation reference and age-zero intercropped treatments than in the thinned-intercropped and switchgrass-only treatments. There was no significant difference (p=0.1579) in total C content at 0-15cm in the riparian position among watershed treatments. Within each watershed treatment, total C content at 15-30cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the mid-rotation reference treatment [14,715 kg/ha (riparian) and 19,288 kg/ha (upslope); p=0.0037]. Total C content at 15-30cm in the upslope position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in all other watershed treatments. Total C content at 15-30cm in the riparian position was significantly greater (p<0.0001) in the age-zero intercropped and switchgrass-only treatments than in the other three watershed treatments.

Total Nitrogen

There was a significant interaction between watershed treatment and slope position for total N concentration at both 0-15cm and 15-30cm depths (Table 6). Within each watershed treatment, total N concentration at 0-15cm for each slope position (upslope, riparian) was similar for the young-pine-with-understory, switchgrass-only, and mid-rotation reference watershed treatments, but differed four-fold for the thinned-intercropped [1,822 mg/kg (riparian) and 425 mg/kg (upslope); p<0.0001] and by 32 % for the age-zero intercropped [905 mg/kg (riparian) and 1,196 mg/kg (upslope); p=0.0483] treatment. Total N concentration at 0-15cm in the upslope position was nearly twice higher (p<0.0001) in the age-zero intercropped and mid-rotation reference treatments than in the thinned-intercropped and switchgrass-only treatments. Total N concentration at 0-15cm in the riparian position was more than twice as high (p=0.0018) in the thinned-intercropped treatment than in the age-zero intercropped and switchgrass-only treatments. Within each watershed treatment, total N concentration at 15-30cm for each slope position (upslope, riparian) was similar for the young-pine-with-understory, switchgrass-only, and mid-rotation reference watershed treatments but differed significantly for the thinned-intercropped (p=0.0294) and the age-zero intercropped (p=0.0201) treatments, where total N concentration was 48% higher and 30% lower, respectively, in the riparian position than in the upslope position. Total N concentration at 15-30cm in the upslope position was at least 75% greater ($p<0.0001$) in the age-zero intercropped treatment than in all other watershed treatments. Total N concentration at 15-30cm in the riparian position was from two- to more than three-fold greater ($p<0.0001$) in the age-zero intercropped treatment than in the young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments.

There was a significant interaction between watershed treatment and slope position for total N content at both 0-15cm and 15-30cm depths (Table 6). Within each watershed treatment, total N content at 0-15cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the thinned-intercropped treatment [2,768 kg/ha (riparian) and 1,025 kg/ha (upslope); $p=0.0004$]. Total N content at 0-15cm in the upslope position was two times higher ($p<0.0001$) in the age-zero intercropped and mid-rotation reference treatments than in the thinned-intercropped and switchgrass-only treatments. There was no significant difference ($p=0.0612$) in total N content at 0-15cm in the riparian position among watershed treatments. Within each watershed treatment, total N content at 15-30cm for each slope position (upslope, riparian) was similar, except for the age-zero intercropped [1,708 kg/ha (riparian) and 2,241 kg/ha (upslope); $p=0.0358$] and mid-rotation reference [929 kg/ha (riparian) and 1,386 kg/ha (upslope); $p=0.0171$] treatments. Total N content at 15-30cm in the upslope position was 55-390% greater ($p<0.0001$) in the age-zero intercropped treatment than in all other watershed treatments. Total N content at 15-30cm in the riparian position was 84-348% higher ($p<0.0001$) in the age-zero intercropped than in the young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments.

Carbon:Nitrogen

There was a significant interaction between watershed treatment and slope position for C:N at 0-15cm depth (Table 7). Within each watershed treatment, C:N at 0-15cm for each slope position (upslope, riparian) was similar for the age-zero intercropped, switchgrass-only, and mid-rotation reference treatments, but differed significantly for the young-pine-with-understory [16 (riparian) and 18 (upslope); $p=0.0009$] and thinned-intercropped [15 (riparian) and 17 (upslope); $p=0.0463$] treatments. C:N at 0-15cm in upslope positions was greater ($p=0.0440$) in the young-pine-with-understory treatment than the age-zero intercropped treatment. There was no significant

Table 6. Effects of watershed treatments and slope position on soil total nitrogen.[1]

Treatment	Slope Position	N (mg/kg)			Watershed Treatment		N (kg/ha)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian	Mean	SE	Slope Position	Upslope	Riparian
0-15cm											
Young-pine-with-understory	Upslope	741	105	A[2]	ab[3]		1648	237	A	ab	
Young-pine-with-understory	Riparian	1033	165	A		ab	2164	261	A		**NSD**
Thinned - Intercropped	Upslope	425	78	B	b		1025	193	B	b	
Thinned - Intercropped	Riparian	1822	290	A		a	2768	421	A		
Age-zero - Intercropped	Upslope	1196	113	A	a		2508	256	A	a	
Age-zero - Intercropped	Riparian	905	89	B		b	1945	218	A		
Switchgrass-only	Upslope	548	94	A	b		1209	174	A	b	
Switchgrass-only	Riparian	777	155	A		b	1656	323	A		
Mid-rotation Reference	Upslope	1100	111	A	a		2563	270	A	a	
Mid-rotation Reference	Riparian	1019	79	A		ab	2182	180	A		
15-30cm											
Young-pine-with-understory	Upslope	227	26	A	c		576	56	A	c	
Young-pine-with-understory	Riparian	211	14	A		c	491	47	A		d
Thinned - Intercropped	Upslope	279	42	B	c		676	75	A	c	
Thinned - Intercropped	Riparian	412	45	A		b	870	101	A		c
Age-zero - Intercropped	Upslope	980	58	A	a		2241	188	A	a	
Age-zero - Intercropped	Riparian	756	63	B		a	1708	148	B		a
Switchgrass-only	Upslope	561	85	A	b		1447	214	A	b	
Switchgrass-only	Riparian	548	74	A		ab	1303	146	A		ab
Mid-rotation Reference	Upslope	537	64	A	b		1386	148	A	b	
Mid-rotation Reference	Riparian	385	42	A		b	929	82	B		bc

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth and watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth and slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

difference (p=0.4721) among watershed treatments in C:N at 0-15cm in riparian positions (Table 7). C:N at 15-30cm was higher (p=0.0075) among watershed treatments in the young-pine-with-understory treatment (18) than in the thinned-intercropped (16) and mid-rotation reference (15) treatments (Table 8). C:N at 15-30cm was significantly higher (p=0.0169) in the riparian position than in the upslope position across all treatments.

Table 7. Effects of watershed treatments and slope position on soil C:N at 0-15cm.[1]

Treatment	Slope Position	C:N			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	18	0.4	A[2]	a[3]	
Young-pine-with-understory	Riparian	16	0.4	B		**NSD**
Thinned - Intercropped	Upslope	17	0.6	A	ab	
Thinned - Intercropped	Riparian	15	0.6	B		
Age-zero - Intercropped	Upslope	16	0.5	A	b	
Age-zero - Intercropped	Riparian	17	0.8	A		
Switchgrass-only	Upslope	17	0.6	A	ab	
Switchgrass-only	Riparian	17	0.6	A		
Mid-rotation Reference	Upslope	17	0.6	A	ab	
Mid-rotation Reference	Riparian	17	0.5	A		

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth and watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth and slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Table 8. Effects of watershed treatments and slope position on soil C:N at 15-30cm.

Treatment	Mean	SE	Tukey
Young-pine-with-understory	18	0.6	A[1]
Thinned - Intercropped	16	0.6	B
Age-zero - Intercropped	16	0.4	AB
Switchgrass-only	17	0.6	AB
Mid-rotation Reference	15	0.7	B
Slope Position	Mean	SE	t-test
Upslope	16	0.4	B[2]
Riparian	17	0.4	A

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

pH

Among watershed treatments, soil pH at 0-15cm was significantly lower (p=0.0004) in the young-pine-with-understory treatment than in the other four watershed treatments (Table 9). pH at 0-15cm was greater (p=0.0052) in the upslope position (5.34) than in the riparian position (5.18) across all treatments. There was a significant interaction between watershed treatment and slope position for pH at 15-30cm (Table 10). Within each watershed treatment, pH at 15-30cm for each slope position (upslope, riparian) was similar for the age-zero intercropped and switchgrass-only treatments but different for the young-pine-with-understory [5.10 (riparian) and 5.33 (upslope); p=0.0101], the thinned-intercropped [5.15 (riparian) and 5.55 (upslope); p<0.0001], and mid-rotation reference [5.27 (riparian) and 5.47 (upslope); p=0.0138] treatments. At 15-30cm in upslope positions pH was greater (p=0.0369) in the thinned-intercropped treatment than in the young-pine-with-understory treatment. At 15-30cm in riparian positions pH was greater (p=0.0193) in the switchgrass-only treatment than in the young-pine-with-understory treatment.

Table 9. Effects of watershed treatments and slope position on soil pH at 0-15cm.

Treatment	Mean	SE	Tukey
Young-pine-with-understory	5.01	0.04	B[1]
Thinned - Intercropped	5.25	0.04	A
Age-zero - Intercropped	5.33	0.03	A
Switchgrass-only	5.40	0.04	A
Mid-rotation Reference	5.33	0.04	A
Slope Position	Mean	SE	t-test
Upslope	5.34	0.02	A[2]
Riparian	5.18	0.03	B

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

Table 10. Effects of watershed treatments and slope position on soil pH at 15-30cm.[1]

Treatment	Slope Position	pH			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	5.33	0.05	A[2]	b[3]	
Young-pine-with-understory	Riparian	5.10	0.05	B		b
Thinned - Intercropped	Upslope	5.55	0.04	A	a	
Thinned - Intercropped	Riparian	5.15	0.05	B		ab
Age-zero - Intercropped	Upslope	5.38	0.07	A	ab	
Age-zero - Intercropped	Riparian	5.32	0.06	A		ab
Switchgrass-only	Upslope	5.47	0.04	A	ab	
Switchgrass-only	Riparian	5.38	0.11	A		a
Mid-rotation Reference	Upslope	5.47	0.06	A	ab	
Mid-rotation Reference	Riparian	5.27	0.05	B		ab

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Extractable Phosphorus

Among watershed treatments, soil extractable P concentration at 0-15cm was significantly greater (p=0.0018) in the young-pine-with-understory [2.9 mg/kg] and thinned-intercropped treatments [2.8 mg/kg], than in the age-zero intercropped [2.1 mg/kg], and switchgrass-only [2.1 mg/kg]. treatments (Table 11). No significant difference (p=0.0507) was observed in extractable P concentration at 0-15cm between upslope position [2.3 mg/kg] and riparian positions [2.6 mg/kg]. Among watershed treatments, soil extractable P concentration at 15-30cm was 38% greater (p=0.0130) in the thinned-intercropped treatment than in the switchgrass-only and mid-rotation reference treatments. At 15-30cm, extractable P was 20% greater (p=0.0104) in the upslope position than in the riparian position across all treatments.

Among watershed treatments, soil extractable P content at 0-15cm was 35% and 42% greater (p=0.0137) in the young-pine-with-understory than in the age-zero intercropped and switchgrass-only treatments, respectively (Table 11). No significant difference was observed in P content at 0-15cm between upslope position and riparian positions at either depth. No significant difference (p=0.1684) was observed in soil P content at 15-30cm among watershed treatments.

Table 11. Effects of watershed treatments and slope position on soil extractable phosphorus.

Treatment	P (mg/kg)			P (kg/ha)		
	Mean	SE	Tukey	Mean	SE	Tukey
0-15cm						
Young-pine-with-understory	2.9	0.2	A[1]	6.4	0.5	A
Thinned - Intercropped	2.8	0.2	A	5.5	0.3	AB
Age-zero - Intercropped	2.1	0.1	B	4.5	0.1	B
Switchgrass-only	2.1	0.1	B	4.8	0.3	B
Mid-rotation Reference	2.4	0.1	AB	5.5	0.3	AB
15-30cm						
Young-pine-with-understory	2.1	0.1	AB	5.1	0.4	**NSD**
Thinned - Intercropped	2.4	0.3	A	5.6	0.6	
Age-zero - Intercropped	2.1	0.1	AB	4.7	0.3	
Switchgrass-only	1.8	0.1	B	4.3	0.2	
Mid-rotation Reference	1.8	0.1	B	4.5	0.3	
0-15cm						
Slope Position	Mean	SE	t-test	Mean	SE	t-test
Upslope	2.3	0.1	**NSD**[2]	5.3	0.2	**NSD**
Riparian	2.6	0.1		5.4	0.2	
15-30cm						
Upslope	1.9	0.1	B	4.6	0.2	**NSD**
Riparian	2.2	0.1	A	5.1	0.3	

[1]For each depth, watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]For each depth, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

Exchangeable Potassium

There was a significant interaction between watershed treatment and slope position for exchangeable K concentration at both 0-15cm and 15-30cm depths (Table 12). Within each watershed treatment, exchangeable K concentration at 0-15cm for each slope position (upslope, riparian) was similar for the switchgrass only and mid-rotation reference treatments, but differed significantly for the young-pine-with-understory [35 mg/kg (riparian) and 43 mg/kg (upslope); p=0.0325], thinned-intercropped [27 mg/kg (riparian) and 42 mg/kg (upslope); p=0.0288] and the age-zero intercropped [45 mg/kg (riparian) and 80 mg/kg (upslope); p<0.0001] treatments. Exchangeable K concentration at 0-15cm in the upslope position was 67% greater (p<0.0001) in the age-zero intercropped than in the other four treatments. Exchangeable K concentration at 0-15cm in the riparian position was 67% greater (p=0.0036) in the age-zero intercropped treatment than in the thinned-intercropped treatment.

Within each watershed treatment, exchangeable K concentration at 15-30cm for each slope position (upslope, riparian) was similar for the switchgrass only and mid-rotation reference treatments, but was on average 52% greater ($p<0.0001$) in the upslope position than in the riparian position for the young-pine-with-understory, the thinned-intercropped, and the age-zero intercropped treatments (Table 12). Exchangeable K concentration at 15-30cm in the upslope position was two-fold greater ($p<0.0001$) in the age-zero intercropped treatment than in all other watershed treatments. Exchangeable K concentration at 15-30cm in the riparian position was 71% greater ($p<0.0001$) in the age-zero intercropped treatment than in the thinned-intercropped, switchgrass only and mid-rotation reference treatments.

There was a significant interaction between watershed treatment and slope position for exchangeable K content at both 0-15cm and 15-30cm depths (Table 12). Within each watershed treatment, exchangeable K content at 0-15cm for each slope position (upslope, riparian) was similar for the switchgrass only and mid-rotation reference treatments, but differed significantly for the young-pine-with-understory [75 kg/ha (riparian) and 95 kg/ha (upslope); $p=0.0423$], thinned-intercropped [46 kg/ha (riparian) and 100 kg/ha (upslope); $p=0.0022$] and the age-zero intercropped [97 kg/ha (riparian) and 167 kg/ha (upslope); $p=0.0001$] treatments. Exchangeable K content at 0-15cm in the upslope position was 52-194% greater ($p<0.0001$) in the age-zero intercropped than in the other four treatments. Exchangeable K content at 0-15cm in the riparian position was at least 59% less ($p=0.0003$) in the thinned-intercropped treatment than in the other four watershed treatments.

Within each watershed treatment, exchangeable K content at 15-30cm for each slope position (upslope, riparian) was similar for the switchgrass-only and mid-rotation reference treatments, but was 86, 271, and 181% greater in the upslope position than in the riparian position for the young-pine-with-understory, the thinned-intercropped, and the age-zero intercropped treatments, respectively (Table 12). Exchangeable K content at 15-30cm in the upslope position was two-fold greater ($p<0.0001$) in the age-zero intercropped treatment than in all other watershed treatments. Exchangeable K content at 15-30cm in the riparian position was 63% greater ($p<0.0001$) in the age-zero intercropped treatment than in the other four watershed treatments.

Table 12. Effects of watershed treatments and slope position on soil exchangeable potassium.[1]

Treatment	Slope Position	K (mg/kg)			Watershed Treatment		K (kg/ha)			Watershed Treatment	
		Mean	SE	SP	Upslope	Riparian	Mean	SE	SP	Upslope	Riparian
0-15cm											
Young-pine-with-understory	Upslope	43	2	A[2]	b[3]		95	6	A	b	
Young-pine-with-understory	Riparian	35	2	B		ab	75	7	B		a
Thinned - Intercropped	Upslope	42	5	A	b		100	11	A	b	
Thinned - Intercropped	Riparian	27	3	B		b	46	7	B		b
Age-zero - Intercropped	Upslope	80	4	A	a		167	8	A	a	
Age-zero - Intercropped	Riparian	45	4	B		a	97	10	B		a
Switchgrass-only	Upslope	48	5	A	b		110	12	A	b	
Switchgrass-only	Riparian	37	3	A		ab	79	7	A		a
Mid-rotation Reference	Upslope	38	3	A	b		86	6	A	b	
Mid-rotation Reference	Riparian	35	2	A		ab	73	4	A		a
15-30cm											
Young-pine-with-understory	Upslope	32	2	A	b		80	6	A	b	
Young-pine-with-understory	Riparian	19	1	B		bc	43	3	B		bc
Thinned - Intercropped	Upslope	38	4	A	b		92	7	A	b	
Thinned - Intercropped	Riparian	16	2	B		c	34	4	B		c
Age-zero - Intercropped	Upslope	87	2	A	a		197	10	A	a	
Age-zero - Intercropped	Riparian	48	5	B		a	109	12	B		a
Switchgrass-only	Upslope	39	6	A	b		97	12	A	b	
Switchgrass-only	Riparian	28	4	A		b	67	9	A		b
Mid-rotation Reference	Upslope	34	4	A	b		87	9	A	b	
Mid-rotation Reference	Riparian	28	3	A		b	67	7	A		b

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth and watershed treatment, slope position (SP) means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth and slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Exchangeable Calcium

There was a significant interaction between watershed treatment and slope position for exchangeable Ca concentration at both 0-15cm and 15-30cm depths (Table 13). Within each watershed treatment, exchangeable Ca concentration at 0-15cm for each slope position (upslope, riparian) was similar for the young-pine-with-understory, thinned-intercropped, and switchgrass treatments, but differed significantly for the age-zero intercropped [492 mg/kg (riparian) and 742 mg/kg (upslope); $p=0.0033$] and mid-rotation reference [254 mg/kg (riparian) and 492 mg/kg (upslope); $p=0.0010$]. Exchangeable Ca concentration at 0-15cm in the upslope position was two-fold greater ($p<0.0001$) in the age-zero intercropped than in the young-pine-with-understory, the thinned-intercropped, and the switchgrass-only treatments. Exchangeable Ca concentration at 0-15cm in the riparian position was two-fold greater ($p=0.0009$) in the age-zero intercropped treatment than in the young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments. Within each watershed treatment, exchangeable Ca concentrations at 15-30cm for each slope position (upslope, riparian) were different for all watershed treatments, except for the switchgrass-only treatment ($p=0.7839$) (Table 13). Exchangeable Ca concentration at 15-30cm in the upslope position was two-fold and three-fold greater ($p<0.0001$) in the age-zero intercropped treatment than in the young-pine-with-understory and mid-rotation reference treatments, respectively, and also significantly higher than the thinned-intercropped and switchgrass-only treatments. Exchangeable Ca concentration at 15-30cm in the riparian position was 429, 298, and 269% greater ($p<0.0001$) in the age-zero intercropped treatment than in the young-pine-with-understory, the thinned-intercropped, and the mid-rotation reference treatments, respectively.

There was a significant interaction between watershed treatment and slope position for exchangeable Ca content at both 0-15cm and 15-30cm depths (Table 13). Within each watershed treatment, exchangeable Ca content at 0-15cm for each slope position (upslope, riparian) were different for all watershed treatments, except for the switchgrass-only treatment ($p=0.9326$). Exchangeable Ca content at 0-15cm in the upslope position was two-fold greater ($p<0.0001$) in the age-zero intercropped than in the young-pine-with-understory, the thinned-intercropped, and the switchgrass-only treatments. Exchangeable Ca content at 0-15cm in the riparian position was

Table 13. Effects of watershed treatments and slope position on soil exchangeable calcium.[1]

Treatment	Slope Position	Ca (mg/kg)			Watershed Treatment		Ca (kg/ha)			Watershed Treatment	
		Mean	SE	SP	Upslope	Riparian	Mean	SE	SP	Upslope	Riparian
0-15cm											
Young-pine-with-understory	Upslope	301	28	A[2]	bc[3]		672	63	A	bc	
Young-pine-with-understory	Riparian	231	25	A		b	495	48	B		bc
Thinned - Intercropped	Upslope	293	57	A	c		704	134	A	c	
Thinned - Intercropped	Riparian	236	41	A		b	386	84	B		c
Age-zero - Intercropped	Upslope	742	33	A	a		1570	128	A	a	
Age-zero - Intercropped	Riparian	492	61	B		a	1065	146	B		a
Switchgrass-only	Upslope	344	46	A	bc		776	100	A	bc	
Switchgrass-only	Riparian	347	32	A		ab	755	90	A		ab
Mid-rotation Reference	Upslope	492	41	A	ab		1143	99	A	ab	
Mid-rotation Reference	Riparian	254	40	B		b	540	81	B		bc
15-30cm											
Young-pine-with-understory	Upslope	200	20	A	c		510	46	A	c	
Young-pine-with-understory	Riparian	109	10	B		c	250	25	B		c
Thinned - Intercropped	Upslope	338	50	A	bc		818	87	A	bc	
Thinned - Intercropped	Riparian	157	31	B		c	337	78	B		c
Age-zero - Intercropped	Upslope	727	33	A	a		1681	141	A	a	
Age-zero - Intercropped	Riparian	468	63	B		a	1070	156	B		a
Switchgrass-only	Upslope	286	62	A	bc		716	131	A	bc	
Switchgrass-only	Riparian	277	32	A		ab	673	80	A		ab
Mid-rotation Reference	Upslope	375	40	A	b		965	93	A	b	
Mid-rotation Reference	Riparian	174	21	B		bc	429	55	B		bc

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth and watershed treatment, slope position (SP) means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth and slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

two-fold greater (p=0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, the thinned-intercropped, and the mid-rotation reference treatment.

Ca content at 15-30cm for each slope position (upslope, riparian) were different for all watershed treatments, except for the switchgrass-only treatment (p=0.9915) (Table 13). Ca content at 15-30cm in the upslope position was 329, 206, 235, and 174% greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, the thinned-intercropped, the switchgrass-only, and mid-rotation reference treatments, respectively. Ca content at 15-30cm in the riparian position was 428, 318, and 249% greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, the thinned-intercropped, and mid-rotation reference treatments.

Exchangeable Magnesium, Manganese, and Iron

Among watershed treatments, exchangeable Mg concentration at 0-15cm was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments (Table 14). Exchangeable Mg concentration at 0-15cm was significantly greater (p<0.0001) in the upslope position (130 mg/kg) than in the riparian position (79 mg/kg) across all treatments. Among watershed treatments, exchangeable Mg concentration at 15-30cm was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, switchgrass only, and mid-rotation reference treatments. Exchangeable Mg concentration at 15-30cm was significantly greater (p<0.0001) in the upslope position (148 mg/kg) than in the riparian position (77 mg/kg) across all treatments.

Among watershed treatments, exchangeable Mg content at 0-15cm was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory, thinned-intercropped, and mid-rotation reference treatments (Table 14). Exchangeable Mg content at 0-15cm was significantly greater (p<0.0001) in the upslope position (285 kg/ha) than in the riparian position (165 kg/ha) across all treatments. Among watershed treatments, exchangeable Mg content at 15-30cm was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory and mid-rotation reference treatments. Exchangeable content at 15-30cm was significantly greater (p<0.0001) in the upslope position (354 kg/ha) than in the riparian position (177 kg/ha) across all treatments.

Table 14. Effects of watershed treatments and slope position on soil exchangeable magnesium.

0-15cm						
	Mg (mg/kg)			Mg (kg/ha)		
Treatment	Mean	SE	Tukey	Mean	SE	Tukey
Young-pine-with-understory	58	5	C[1]	126	10	C
Thinned - Intercropped	65	12	C	136	30	C
Age-zero - Intercropped	239	25	A	500	48	A
Switchgrass Only	73	6	BC	163	45	BC
Mid-rotation Reference	89	8	B	199	20	B
15-30cm						
Young-pine-with-understory	40	6	C	99	15	D
Thinned - Intercropped	86	17	BC	198	39	CD
Age-zero - Intercropped	243	26	A	551	60	A
Switchgrass Only	77	10	B	188	24	BC
Mid-rotation Reference	116	16	B	291	37	B
0-15cm						
Slope Position	Mean	SE	t-test	Mean	SE	t-test
Upslope	130	16	A[2]	285	32	A
Riparian	79	8	B	165	18	B
15-30cm						
Upslope	148	17	A	354	38	A
Riparian	77	9	B	177	20	B

[1]For each depth, watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]For each depth, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

Among watershed treatments, exchangeable Mn concentration and content at 0-15cm was significantly less (p=0.0011 and p=0.0005, respectively) in the switchgrass-only treatment than in the young-pine-with-understory and mid-rotation reference treatment (Table 15). There was no effect of slope position on exchangeable Mn concentration or content at the 0-15cm depth. There was a significant interaction between watershed treatment and slope position for exchangeable Mn concentration at 15-30cm depth (Table 16). Within each watershed treatment, exchangeable Mn concentration at 15-30cm for each slope position (upslope, riparian) was similar for the thinned-intercropped, age-zero intercropped, and switchgrass only treatments, but differed significantly for the young-pine-with-understory [8 mg/kg (riparian) and 17 mg/kg (upslope); p=0.0099], and the mid-rotation reference [21 mg/kg (riparian) and 10 mg/kg (upslope); p=0.0188] treatments. Exchangeable Mn concentration at 15-30cm in the upslope position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the thinned-intercropped and switchgrass only treatments. Exchangeable Mn concentration at 15-30cm in the riparian position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the young-pine-with-understory treatment.

Within each watershed treatment, exchangeable Mn content at 15-30cm for each slope position (upslope, riparian) was similar for the thinned-intercropped, age-zero intercropped, and switchgrass only treatments, but differed significantly for the young-pine-with-understory [20 kg/ha (riparian) and 42 kg/ha (upslope); p=0.0073], and mid-rotation reference [51 kg/ha (riparian) and 26 kg/ha (upslope); p=0.001] treatments (Table 16). Exchangeable Mn content at 15-30cm in the upslope position was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the thinned-intercropped treatment. Exchangeable Mn content at 15-30cm in the riparian position was significantly greater (p<0.0001) in the mid-rotation reference treatment than in the young-pine-with-understory treatment.

Table 15. Effects of watershed treatments and slope position on soil exchangeable manganese at 0-15cm.

Treatment	**Mn (mg/kg)**			**Mn (kg/ha)**		
	Mean	SE	Tukey	Mean	SE	Tukey
Young-pine-with-understory	25	2	AB[1]	56	5	AB
Thinned - Intercropped	19	4	BC	40	7	BC
Age-zero - Intercropped	20	2	ABC	43	4	ABC
Switchgrass Only	17	2	C	38	4	C
Mid-rotation Reference	28	3	A	63	6	A
Slope Position	Mean	SE	t-test	Mean	SE	t-test
Upslope	20	1	**NSD**[2]	46	3	**NSD**
Riparian	24	2		50	4	

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

Table 16. Effects of watershed treatments and slope position on soil exchangeable manganese at 15-30cm.[1]

Treatment	Slope Position	Mn (mg/kg)			Watershed Treatment		Mn (kg/ha)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian	Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	17	3	A[2]	ab[3]		42	6	A	ab	
Young-pine-with-understory	Riparian	8	1	B		b	20	3	B		b
Thinned - Intercropped	Upslope	9	2	A	b		24	7	A	b	
Thinned - Intercropped	Riparian	18	5	A		ab	38	10	A		ab
Age-zero - Intercropped	Upslope	19	3	A	a		45	7	A	a	
Age-zero - Intercropped	Riparian	19	3	A		a	43	6	A		ab
Switchgrass-only	Upslope	10	2	A	b		24	5	A	ab	
Switchgrass-only	Riparian	13	2	A		ab	31	6	A		ab
Mid-rotation Reference	Upslope	10	2	B	ab		26	5	B	ab	
Mid-rotation Reference	Riparian	21	4	A		ab	51	9	A		a

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

There was a significant interaction between watershed treatment and slope position for exchangeable Fe concentration at both 0-15cm and 15-30cm depths (Table 17). Within each watershed treatment, exchangeable Fe concentration at 0-15cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the thinned-intercropped [112 mg/kg (riparian) and 16 mg/kg (upslope); p<0.0001] treatment. No significant difference (p=0.1250) was observed in exchangeable Fe concentration at 0-15cm in the upslope position among all watershed treatments. Exchangeable Fe concentration at 0-15cm in the riparian position was significantly greater (p=0.0018) in the thinned-intercropped treatment than in the young-pine-with-understory and age-zero intercropped treatments.

Within each watershed treatment, exchangeable Fe content at 0-15cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the thinned-intercropped [161 mg/kg (riparian) and 40 mg/kg (upslope); p=0.0002] treatment (Table 17). No significant difference (p=0.1774) was observed in exchangeable Fe content at 0-15cm in the upslope position among all watershed treatments. Exchangeable Fe content at 0-15cm in the riparian position was significantly greater (p=0.0264) in the thinned-intercropped treatment than in the age-zero intercropped treatment. Exchangeable Fe concentration and content at 15-30cm for each slope position (upslope, riparian) was similar for all watershed treatments, except for the thinned-intercropped [76 mg/kg and 156 kg/ha (riparian) versus 12 mg/kg and 30 kg/ha (upslope); p<0.0001] treatment. Exchangeable Fe concentration and content at 15-30cm in the upslope position was significantly greater (p=0.0485 and p=0.0497, respectively) in the switchgrass only treatment than in the thinned-intercropped treatment. Exchangeable Fe concentration and content at 15-30cm in the riparian position was significantly greater (p=0.0112 and p=0.0116, respectively) in the thinned-intercropped treatment than in the young-pine-with-understory and age-zero intercropped treatments.

Table 17. Effects of watershed treatments and slope position on soil exchangeable iron.[1]

Treatment	Slope Position	Fe (mg/kg)			Watershed Treatment		Fe (kg/ha)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian	Mean	SE	Slope Position	Upslope	Riparian
0-15cm											
Young-pine-with-understory	Upslope	30	8	A[2]	**NSD[3]**		67	16	A	**NSD**	
Young-pine-with-understory	Riparian	36	11	A		b	72	18	A		ab
Thinned - Intercropped	Upslope	16	3	B			40	7	B		
Thinned - Intercropped	Riparian	112	24	A		a	161	28	A		a
Age-zero - Intercropped	Upslope	21	4	A			46	10	A		
Age-zero - Intercropped	Riparian	23	5	A		b	47	8	A		b
Switchgrass-only	Upslope	30	5	A			71	13	A		
Switchgrass-only	Riparian	65	22	A		ab	133	41	A		ab
Mid-rotation Reference	Upslope	30	8	A			71	21	A		
Mid-rotation Reference	Riparian	54	21	A		ab	114	41	A		ab
15-30cm											
Young-pine-with-understory	Upslope	14	3	A	ab		36	7	A	ab	
Young-pine-with-understory	Riparian	23	5	A		b	52	10	A		b
Thinned - Intercropped	Upslope	12	2	B	b		30	6	B	b	
Thinned - Intercropped	Riparian	76	17	A		a	156	32	A		a
Age-zero - Intercropped	Upslope	17	4	A	ab		40	10	A	ab	
Age-zero - Intercropped	Riparian	22	4	A		b	48	8	A		b
Switchgrass-only	Upslope	27	5	A	a		71	14	A	a	
Switchgrass-only	Riparian	43	11	A		ab	100	22	A		ab
Mid-rotation Reference	Upslope	20	18	A	ab		54	18	A	ab	
Mid-rotation Reference	Riparian	31	25	A		ab	73	19	A		ab

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each depth and watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each depth and slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Cation Exchange Capacity (CEC)

There was a significant interaction between watershed treatment and slope position for CEC at 0-15cm depths (Table 18). Within each watershed treatment, CEC at 0-15cm for each slope position (upslope, riparian) was similar for the young-pine-with-understory, thinned-intercropped, and switchgrass-only treatments, but was significantly different (p=0.0004) for the age-zero intercropped treatment [6.5 meq/100g (riparian) and 11.7 meq/100g (upslope)] and for the mid-rotation reference treatment [4.3 meq/100g (riparian) and 5.5 meq/100g (upslope)]. CEC at 0-15cm in upslope positions was significantly greater (p<0.0001) in the age-zero intercropped treatment than in the other four treatments. CEC at 0-15cm in riparian positions was significantly greater (p=0.0004) in the age-zero intercropped treatment than in the young-pine-with-understory, thinned-intercropped, and switchgrass-only treatments.

Among watershed treatments, CEC at 15-30cm was significantly greater (p<0.0001) in the age-zero intercropped treatment than in all other watershed treatments and CEC was significantly lower in the young-pine-with-understory treatment than the other watershed treatments (Table 19). CEC at 15-30cm was significantly greater (p=0.0259) in the upslope position (5.5 meq/100g) than in the riparian position (3.6 meq/100g) across all treatments.

Table 18. Effects of watershed treatments and slope position on soil cation exchange capacity at 0-15cm.[1]

Treatment	Slope Position	CEC (meq/100g)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	3.9	0.5	A[2]	bc[3]	
Young-pine-with-understory	Riparian	3.5	0.3	A		b
Thinned - Intercropped	Upslope	3.2	0.8	A	c	
Thinned - Intercropped	Riparian	3.8	0.4	A		b
Age-zero - Intercropped	Upslope	11.7	1.0	A	a	
Age-zero - Intercropped	Riparian	6.5	0.7	B		a
Switchgrass-only	Upslope	4.0	0.5	A	bc	
Switchgrass-only	Riparian	3.7	0.3	A		b
Mid-rotation Reference	Upslope	5.5	0.3	A	b	
Mid-rotation Reference	Riparian	4.3	0.3	B		ab

[1]A significant interaction between watershed treatment and slope position is present.
[2]For each watershed treatment, slope positions not followed by the same letter are significantly different (α=0.05), according to t-test.
[3]For each slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Table 19. Effects of watershed treatments and slope position on soil cation exchange capacity 15-30cm.

Treatment	CEC (meq/100g)	SE	Tukey
Young-pine-with-understory	2.1	0.3	C[1]
Thinned - Intercropped	3.7	0.5	B
Age-zero - Intercropped	9.0	0.9	A
Switchgrass-only	3.5	0.3	B
Mid-rotation Reference	4.4	0.5	B
Slope Position	**CEC (meq/100g)**	SE	t-test
Upslope	5.5	0.6	A[2]
Riparian	3.6	0.3	B

[1]Watershed treatment means not followed by the same letter are significantly different, according to Tukey's HSD.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

Forest Floor

Mass

There was a significant interaction between watershed treatment and slope position for forest floor mass (Table 20). Within each watershed treatment, forest floor mass for each slope position (upslope, riparian) was similar for the thinned-intercropped and mid-rotation reference treatments, but was significantly different for the young-pine-with-understory [7,360 kg/ha (riparian) and 5,120 kg/ha (upslope); p=0.0229], age-zero intercropped treatment [9,107 kg/ha (riparian) and 4,607 kg/ha (upslope); p=0.0172], and switchgrass only [6,424 kg/ha (riparian) and 2,407 kg/ha (upslope); p=0.0023] treatments. Forest floor mass in upslope positions was significantly greater (p<0.0001) in the mid-rotation reference treatment than in all other watershed treatments. Forest floor mass in riparian positions was significantly greater (p<0.0001) in the mid-rotation reference treatment than in the thinned-intercropped and switchgrass only treatments.

Table 20. Effects of watershed treatments and slope position on forest floor mass.[1]

Treatment	Slope Position	Mass (kg/ha)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	5120	732	B[2]	b[3]	
Young-pine-with-understory	Riparian	7360	506	A		ab
Thinned – Intercropped	Upslope	2411	357	A	c	
Thinned – Intercropped	Riparian	2804	362	A		c
Age-zero - Intercropped	Upslope	4607	619	B	bc	
Age-zero - Intercropped	Riparian	9107	1576	A		ab
Switchgrass-only	Upslope	2407	520	B	c	
Switchgrass-only	Riparian	6424	982	A		bc
Mid-rotation Reference	Upslope	10562	753	A	a	
Mid-rotation Reference	Riparian	10120	792	A		a

[1]A significant interaction between watershed treatment and slope position is present.
[2]For each watershed treatment, slope positions not followed by the same letter are significantly different (α=0.05), according to t-test.
[3]For each slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Total Carbon

There was a significant interaction between watershed treatment and slope position for forest floor C concentration (Table 21). No significant difference was observed in forest floor total C concentration for each slope position (upslope, riparian) within each watershed treatment. Forest floor total C concentration in the upslope position was significantly greater (p=0.0002) in the young-pine-with-understory[418 g/kg], thinned-intercropped [383 g/kg], and mid-rotation reference [407 g/kg] treatments than in the switchgrass-only treatment [322 g/kg]. Forest floor total C concentration in the riparian position was significantly greater (p=0.0073) in the young-pine-with-understory[436 g/kg], thinned-intercropped [413 g/kg], and age-zero intercropped [416 g/kg] treatments than in the switchgrass-only treatment[333 g/kg].

There was a significant interaction between watershed treatment and slope position for forest floor C content (Table 21). Within each watershed treatment, forest floor total C content for each slope position (upslope, riparian) was similar for the thinned-intercropped and mid-rotation reference treatments, but significantly different in the young-pine-with-understory [3,185 kg/ha (riparian) and 2,049 kg/ha (upslope); p=0.0090], age-zero intercropped [1,544 kg/ha (riparian) and 1,075 kg/ha (upslope); p=0.0004], and switchgrass only [1,740 kg/ha (riparian) and 684 kg/ha (upslope); p=0.0005] treatments. Forest floor total C content in the upslope position was significantly greater (p<0.0001) in the mid-rotation reference treatment than in the other four treatments. Forest floor total C content in the riparian position was significantly greater (p<0.0001) in the young-pine-with-understory, age-zero intercropped, and mid-rotation reference treatments, than in the thinned-intercropped and switchgrass only treatments.

Total Nitrogen

There was a significant interaction between watershed treatment and slope position for forest floor N concentration (Table 22). Within each watershed treatment, forest floor total N concentration for each slope position (upslope, riparian) was similar for the young-pine-with-understory, age-zero intercropped, and switchgrass only treatments, but significantly different in the thinned-intercropped [8,490 mg/kg (riparian) and 6,272 mg/kg (upslope); p=0.0284], and mid-rotation reference [8,649 mg/kg (riparian) and 6,682 mg/kg (upslope); p=0.0093] treatments. Forest floor total N concentration in the upslope position was significantly greater (p=0.0051) in the young-pine-with-understory treatment than in the thinned-intercropped and switchgrass only treatments. Forest floor total N concentration in the riparian position was significantly greater (p<0.0001) in the thinned-intercropped and mid-rotation reference treatments than in the age-zero intercropped treatment.

There was a significant interaction between watershed treatment and slope position for forest floor N content (Table 22). Within each watershed treatment, forest floor total N content for each slope position (upslope, riparian) was significantly different in each watershed. Forest floor total N content in both the upslope and riparian positions was significantly greater (p<0.0001) in the mid-rotation reference treatment than in the other four treatments.

Table 21. Effects of watershed treatments and slope position on forest floor total carbon.[1]

Treatment	Slope Position	C (g/kg)			Watershed Treatment		C (kg/ha)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian	Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	417	18.9	A[2]	a[3]		2049	310	B	b	
Young-pine-with-understory	Riparian	435	11.7	A		a	3185	224	A		a
Thinned - Intercropped	Upslope	383	10.9	A	a		946	151	A	c	
Thinned - Intercropped	Riparian	412	19.2	A		a	1075	126	A		b
Age-zero - Intercropped	Upslope	375	10.2	A	ab		1544	234	B	bc	
Age-zero - Intercropped	Riparian	415	16.9	A		a	3347	330	A		a
Switchgrass-only	Upslope	322	15.5	A	b		684	124	B	c	
Switchgrass-only	Riparian	333	30.4	A		b	1740	211	A		b
Mid-rotation Reference	Upslope	407	10.6	A	a		3972	217	A	a	
Mid-rotation Reference	Riparian	395	13.5	A		ab	4107	378	A		a

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each slope position, treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Table 22. Effects of watershed treatments and slope position on forest floor total nitrogen.[1]

Treatment	Slope Position	N (mg/kg)			Watershed Treatment		N (kg/ha)			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian	Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	8799	729	A[2]	a[3]		41	6	B	b	
Young-pine-with-understory	Riparian	8252	328	A		ab	59	3	A		b
Thinned - Intercropped	Upslope	6272	565	B	b		15	2	B	cd	
Thinned - Intercropped	Riparian	8490	727	A		a	22	2	A		c
Age-zero - Intercropped	Upslope	7143	473	A	ab		30	4	B	bc	
Age-zero - Intercropped	Riparian	6315	359	A		b	54	8	A		b
Switchgrass-only	Upslope	5821	498	A	b		12	2	B	d	
Switchgrass-only	Riparian	7030	477	A		ab	38	6	A		bc
Mid-rotation Reference	Upslope	6682	435	B	ab		67	6	B	a	
Mid-rotation Reference	Riparian	8649	504	A		a	89	6	A		a

[1]A significant interaction between watershed treatment and slope position is present.

[2]For each watershed treatment, slope position means not followed by the same letter are significantly different (α=0.05), according to t-test.

[3]For each slope position, treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Carbon:Nitrogen (C:N)

There was a significant interaction between watershed treatment and slope position for forest floor C:N (Table 23). Within each watershed treatment, forest floor C:N for each slope position (upslope, riparian) was similar for the young-pine-with-understory and switchgrass-only treatments, but differed significantly for the thinned-intercropped [51 (riparian) and 73 (upslope); p=0.0450], age-zero intercropped [67 (riparian) and 54 (upslope); p=0.0146] and mid-rotation reference [47 (riparian) and 63 (upslope); p=0.0031] treatments. No significant difference (p=0.0812) was observed in forest floor C:N in upslope positions among watershed treatments. Forest floor C:N in riparian positions was significantly greater (p=0.0112) in the age-zero intercropped treatment than in the switchgrass-only and mid-rotation reference treatments.

Table 23. Effects of watershed treatments and slope position on forest floor C:N.[1]

Treatment	Slope Position	C:N			Watershed Treatment	
		Mean	SE	Slope Position	Upslope	Riparian
Young-pine-with-understory	Upslope	52	6	A[1]	**NSD[2]**	
Young-pine-with-understory	Riparian	54	2	A		ab
Thinned - Intercropped	Upslope	73	9	A		
Thinned - Intercropped	Riparian	51	4	B		ab
Age-zero - Intercropped	Upslope	54	3	B		
Age-zero - Intercropped	Riparian	67	3	A		a
Switchgrass-only	Upslope	58	5	A		
Switchgrass-only	Riparian	49	6	A		b
Mid-rotation Reference	Upslope	63	4	A		
Mid-rotation Reference	Riparian	47	3	B		b

[1]A significant interaction between watershed treatment and slope position is present.
[2]For each watershed treatment, slope positions not followed by the same letter are significantly different (α=0.05), according to t-test.
[3]For each slope position, watershed treatments not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Loblolly Pine Needle Litter Decomposition

Decomposition Rate (k)

No significant differences (p=0.2198) were observed in decomposition rates of loblolly pine needle litter among watershed treatments nor were significant difference (p=0.2123) observed in loblolly pine needle litter decomposition rates between the two slope positions across all five watershed treatments (Table 24).

Table 24. Effects of watershed treatments and slope position on decomposition rate (k) of loblolly pine needles.

Treatment	k (yr^{-1}) Mean	SE	Tukey
Young-pine-with-understory	0.80	0.05	**NSD**[1]
Thinned – Intercropped	0.83	0.08	
Age-zero - Intercropped	0.67	0.06	
Switchgrass-only	0.85	0.08	
Mid-rotation Reference	0.83	0.04	
Slope Position	Mean	SE	t-test
Upslope	0.81	0.05	**NSD**[2]
Riparian	0.79	0.03	

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to t- test.

Total Carbon of Loblolly Pine Needle Litter

At the start of the litter decomposition study in January 2013, a composite of fifteen litter bags containing loblolly pine needles had a total C concentration of 506 g/kg. In March 2013, after two months, seasonal litter bag total C was significantly greater (p=0.0286) in the thinned-intercropped treatment (506 g/kg) than in the switchgrass-only treatment (496 g/kg), among watershed treatments (Figure 3). At this point in the decomposition study, mean seasonal net litter bag total C was significantly greater (p=0.0269) in the riparian position (504 g/kg) than in the upslope position (500 g/kg) across all treatments (Figure 4). In June 2013, after five months, no significant difference (p=0.5924) was observed in seasonal litter bag total C concentration among watershed treatments and no significant difference (p=0.4198) was observed in seasonal litter bag total C concentration between slope positions across all treatments. In August 2013, after seven months, no significant difference (p=0.2429) was observed in seasonal litter bag total C concentration among watershed treatments and no significant difference (p=0.3334) was observed in seasonal litter bag total C concentration between slope positions across all treatments. In September 2013, after eight months, seasonal litter bag total C concentration was significantly greater (p=0.0096) in the young-pine-with-understory (494 g/kg) than in the age-zero intercropped (450 g/kg), and the switchgrass-only (448 g/kg) treatments. Seasonal net litter bag total C concentration was significantly greater (p=0.0163) in the riparian position (484 g/kg) than in the upslope position (460 g/kg) across all treatments. In November 2013, after ten months, seasonal litter bag total C concentration was significantly greater (p=0.0190) in the mid-rotation reference (486 g/kg) than in the young-pine-with-understory (426 g/kg), and the age-zero intercropped (442 g/kg) treatments. No significant difference (p=0.7602) was observed in seasonal litter bag total C concentration between slope positions across all treatments. At the conclusion of the litter decomposition study in January 2014 after 12 months, seasonal litter bag total C concentration was significantly greater (p=0.0165) in the mid-rotation reference (490 g/kg) than in the age-zero intercropped (448 g/kg), and in the switchgrass-only (449 g/kg) treatments. No significant difference (p=0.1239) was observed in seasonal litter bag total C between slope positions across all treatments after 12 months

Figure 3. Effect of watershed treatments on mean total C concentration of loblolly pine needle litter. Month "0" = January 2013. Error bars are one standard error of the mean.

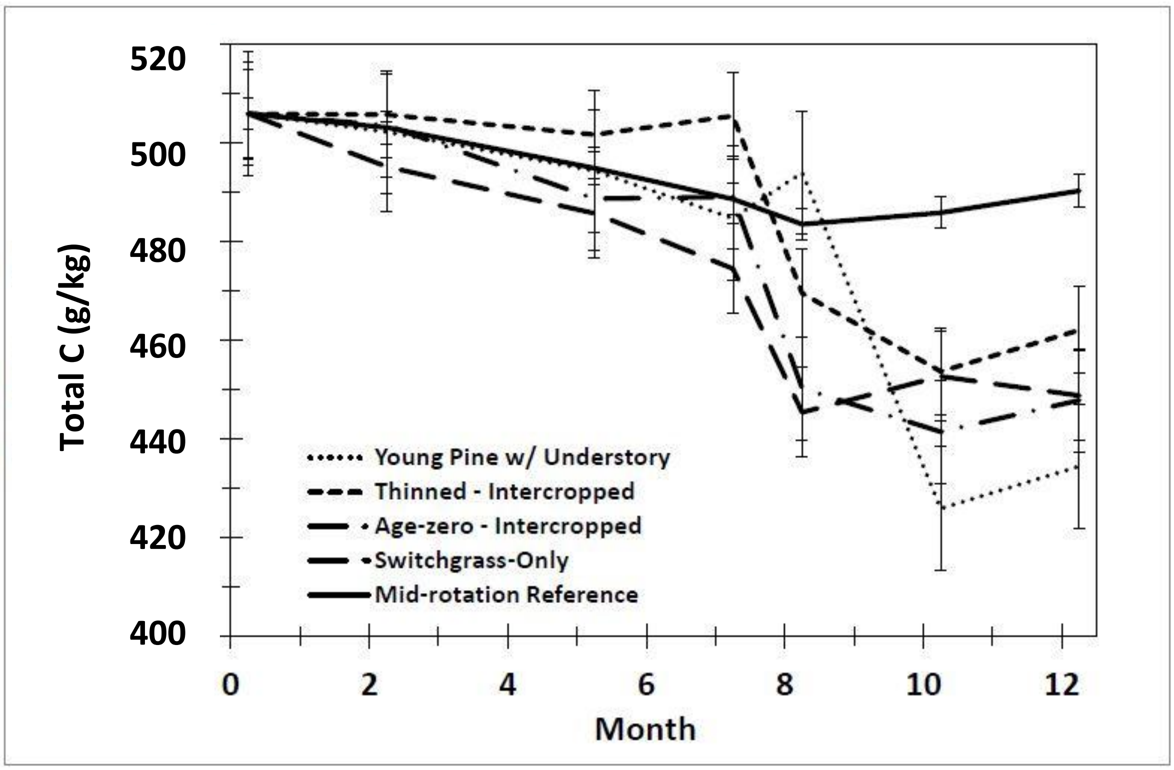
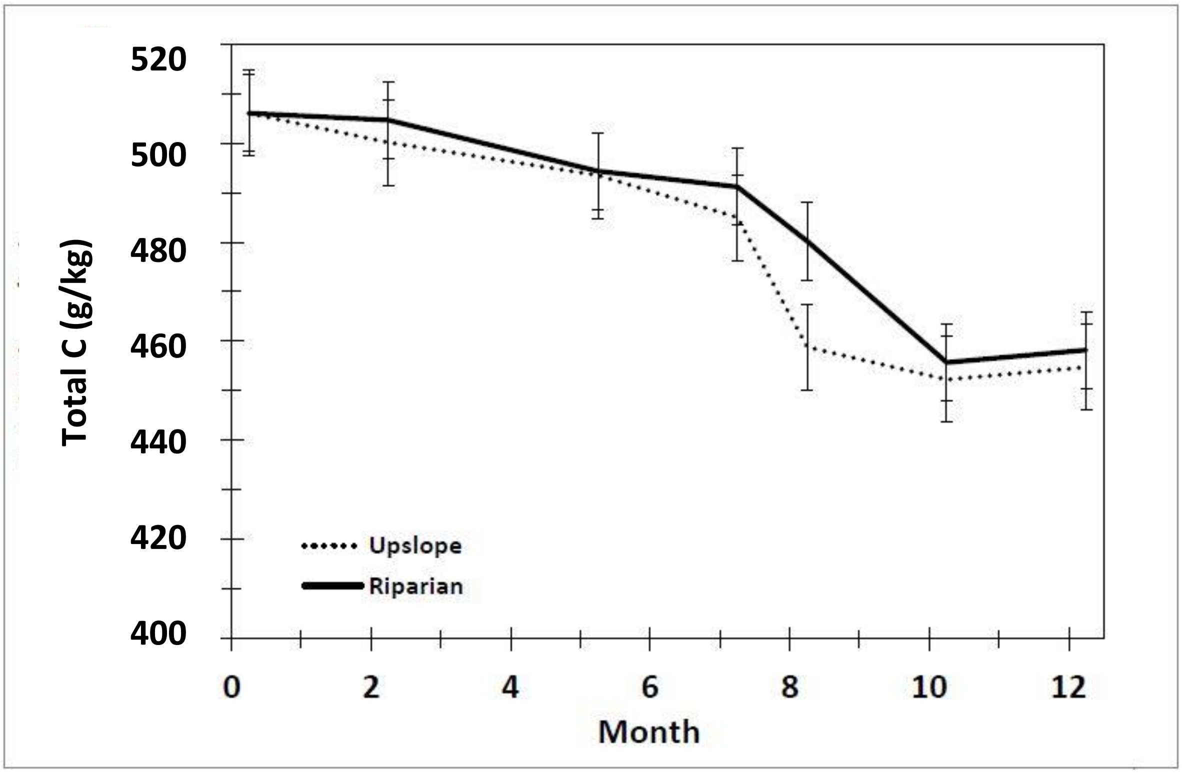


Figure 4. Effect of slope position on mean total C concentration of loblolly pine needle litter. Month "0" = January 2013. Error bars are one standard error of the mean.



Total Nitrogen of Loblolly Pine Needle Litter

At the start of the litter decomposition study in January 2013, a composite of fifteen loblolly pine needle litter bag samples had a total N concentration of 12,100 mg/kg. In March 2013, after two months, seasonal litter bag total N concentration was not significantly different (p=0.9649 and p=0.9704) among watershed treatments or between slope positions across all treatments, respectively (Figure 5). In June 2013, after five months, seasonal litter bag total N concentration was significantly greater (p=0.0008) in the mid-rotation reference (13,753 mg/kg) than in all the other watershed treatments. No significant difference (p=0.8931) was observed in seasonal litter bag total N concentration between the riparian position and the upslope position across all treatments (Figure 6). In August 2013, after seven months, seasonal litter bag total N concentration was significantly greater (p=0.0452) in the mid-rotation reference (16,013 mg/kg) than in the young-pine-with-understory (14,244 mg/kg) treatment. No significant difference (p=0.3231) was observed in seasonal litter bag total N concentration between slope positions across all treatments. In September 2013, after eight months, seasonal litter bag total N concentration was significantly greater (p=0.0336) in the mid-rotation reference (15,695 mg/kg) than in the thinned-intercropped (14,476 mg/kg) treatment. No significant difference (p=0.1040) was observed in seasonal litter bag total N concentration between slope positions across all treatments. In November 2013, after ten months, seasonal litter bag total N concentration was significantly greater (p=0.0004) in the mid-rotation reference (16,920 mg/kg) than in the young-pine-with-understory (14,039 mg/kg), the thinned-intercropped (14,324 mg/kg), and the age-zero intercropped (14,247 mg/kg) treatments. No significant difference (p=0.4959) was observed in seasonal litter bag total N concentration between slope positions across all treatments. At the conclusion of the litter decomposition study in January 2014 after 12 months, seasonal litter bag total N concentration was significantly greater (p=0.0001) in the mid-rotation reference (16,851 mg/kg) than in all the other watershed treatments. No significant difference (p=0.5520) was observed in seasonal litter bag total N concentration between slope positions across all treatments after 12 months.

Figure 5. Effect of watershed treatments on mean total N concentration of loblolly pine needle litter. Month "0" = January 2013. Error bars are one standard error of the mean.

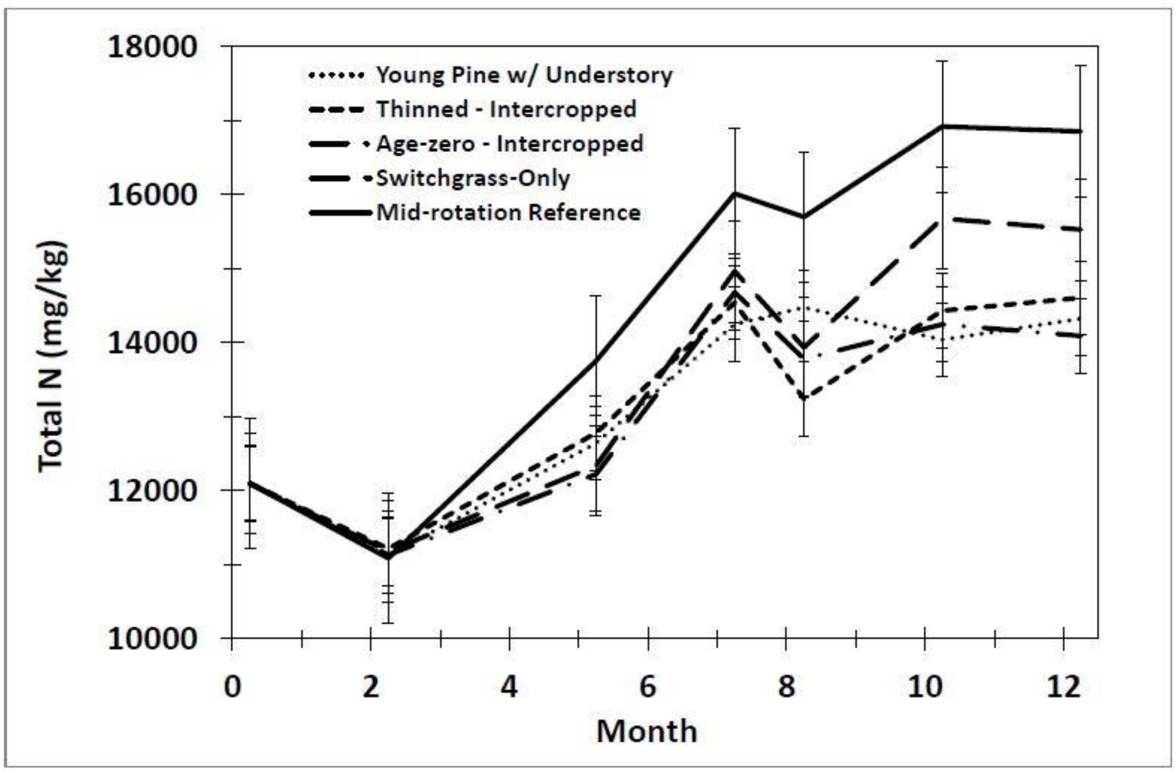
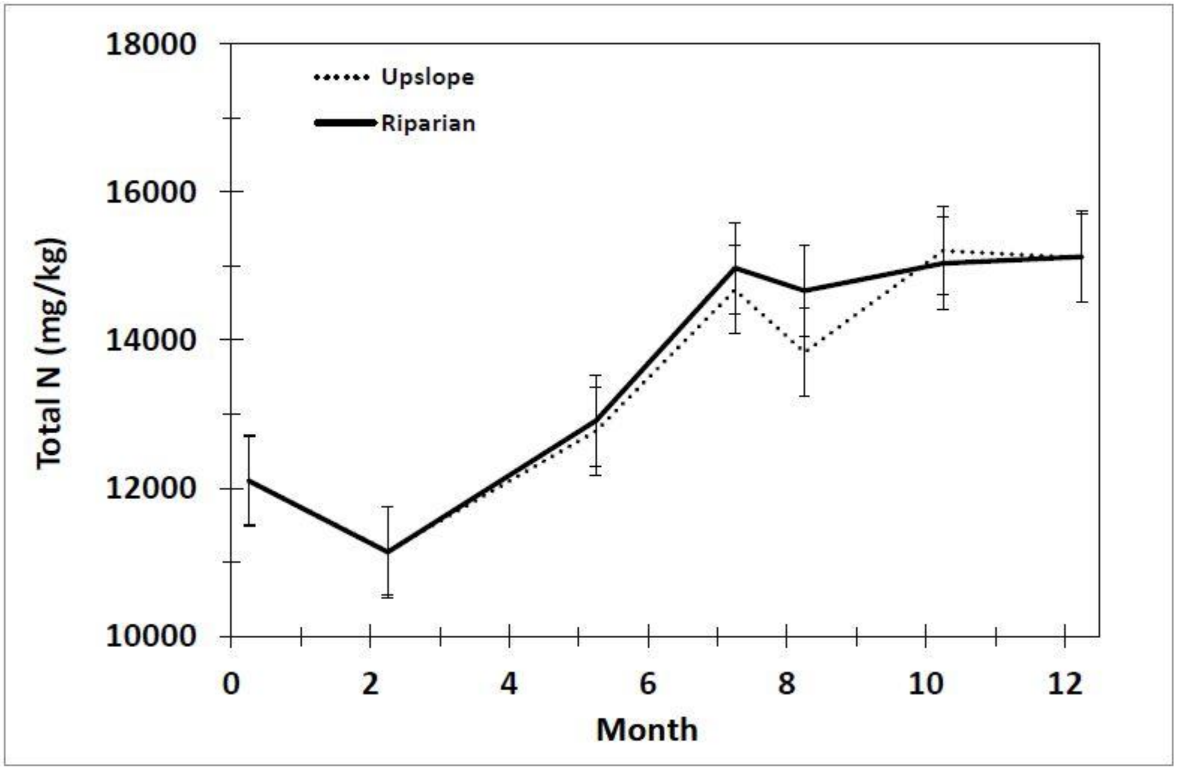


Figure 6. Effect of slope position on mean total N concentration of loblolly pine needle litter. Month "0" = January 2013. Error bars are one standard error of the mean.



Carbon:Nitrogen of Loblolly Pine Needle Litter

At the start of the litter decomposition study in January 2013, a composite of fifteen bags containing loblolly pine needle litter had a mean C:N of 42. In March 2013, after two months, mean seasonal loblolly pine needle litter bag C:N ranged from 44 to 46 and was not significantly different (p=0.8181 and p=0.4492) among watershed treatments or between slope positions across all treatments, respectively (Figure 7, 8). In June 2013, after five months, mean seasonal loblolly pine needle litter bag C:N was significantly greater (p=0.0018) in the young-pine-with-understory (39), the thinned-intercropped (39), and the age-zero intercropped (41) treatments than in the mid-rotation reference (36) treatment. No significant difference (p=0.5176) was observed in mean seasonal pine needle litter bag C:N between slope positions across all treatments (Figure 8). In August 2013, after seven months, mean seasonal pine needle litter bag C:N was significantly greater (p=0.0104) in the young-pine-with-understory (34) and the thinned-intercropped (35) treatments than in the mid-rotation reference (31) treatment, whereas no significant difference (p=0.8906) was observed in seasonal pine needle litter bag C:N between slope positions across all treatments. In September 2013, after eight months of decomposition, mean seasonal pine needle litter bag C:N was significantly greater (p=0.0140) in the thinned-intercropped (36) treatment than in the mid-rotation reference (31) treatment. No significant difference (p=0.6990) was observed in mean seasonal pine needle litter bag C:N between slope positions across all treatments. In November 2013, after ten months, mean seasonal pine needle litter bag C:N was significantly greater (p=0.0015) in the thinned-intercropped (32) than in the switchgrass-only (29) and in the mid-rotation reference (29) treatments. No significant difference (p=0.1090) was observed in mean seasonal pine needle litter bag C:N between slope positions across all treatments. At the conclusion of the pine needle litter decomposition study in January 2014 after 12 months, mean seasonal litter bag C:N was significantly greater (p<0.0001) in the thinned-intercropped (32) and the age-zero intercropped (32) treatments than in the switchgrass-only (29) and in the mid-rotation reference (29) treatments. No significant difference (p=0.3907) was observed in seasonal litter bag C:N between slope positions across all treatments after 12 months of decomposition.

Figure 7. Effect of watershed treatments on mean loblolly pine needle litter C:N. Month "0" = January 2013. Error bars represent one standard error of the mean.

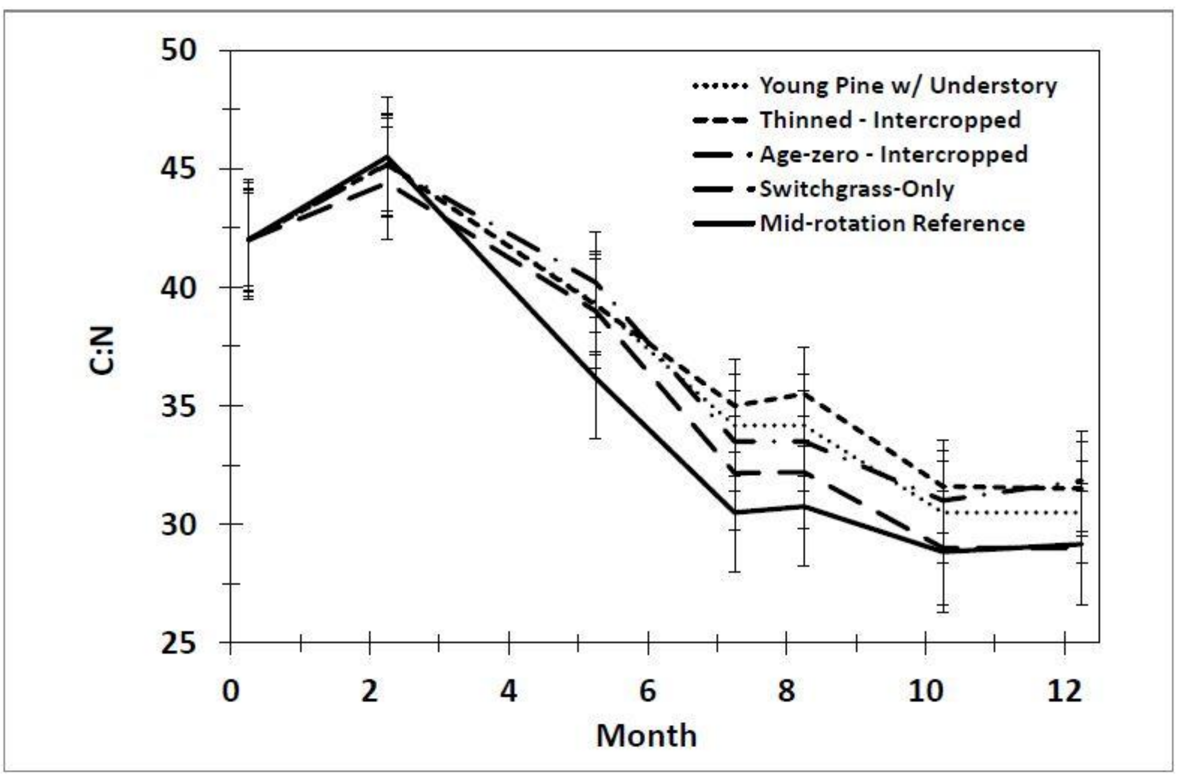
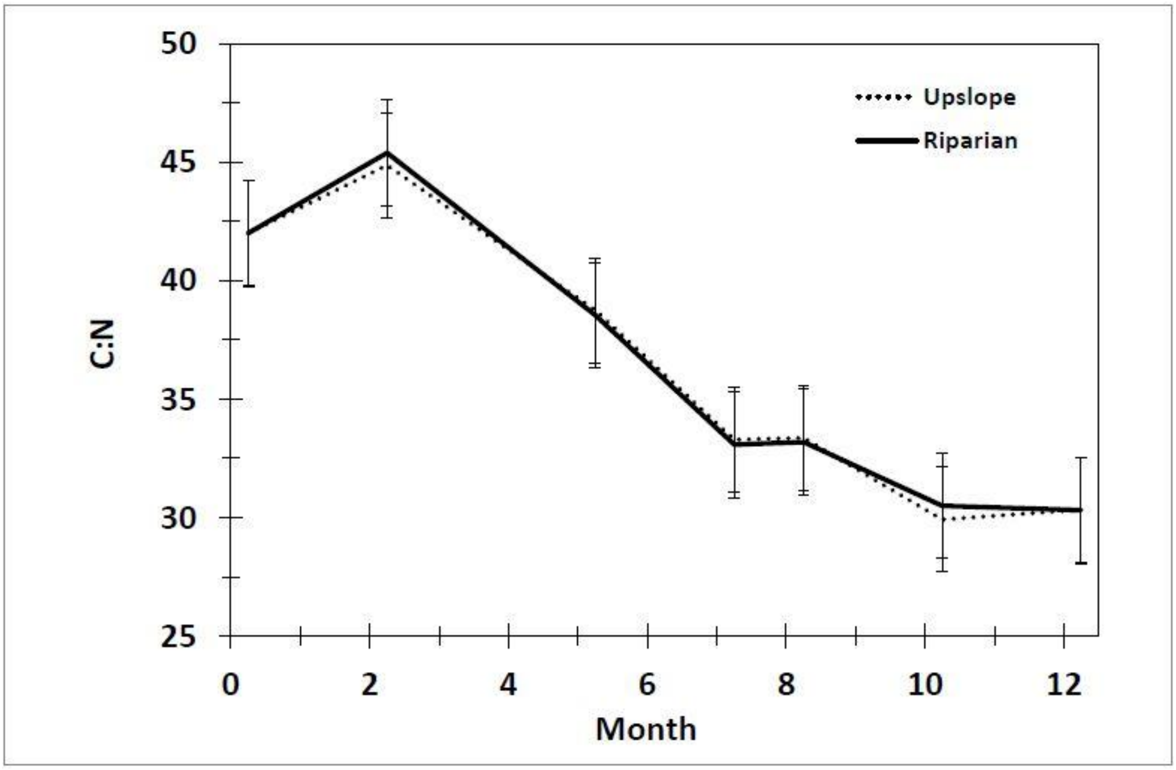


Figure 8. Effect of slope position on mean loblolly pine needle litter C:N. Month "0" = January 2013. Error bars represent one standard error of the mean.



Net Nitrogen Mineralization

Net Ammonification

During the August 2012-January 2013 incubation, no significant differences were observed in mean *in situ* net ammonification (mg NH_4-N/kg/28d) among watershed treatments or between riparian and upslope positions across all treatments (p=0.6664 and p=0.4350, respectively) [Figure 9]. During the January-March 2013 incubation, mean net ammonification was significantly greater (p=0.0419) in the switchgrass-only treatment (6.5 mg NH_4-N/kg/28d) than in the age-zero intercropped treatment (-3.3 mg NH_4-N/kg/28d) and mean seasonal net ammonification was significantly greater (p=0.0015) in the riparian position (6.8 mg NH_4-N/kg/28d) than in the upslope position (-0.5 mg NH_4-N/kg/28d) across all treatments (Figure 10). During the March-June 2013 incubation, mean seasonal net ammonification was significantly less (p=0.0001) in the age-zero intercropped treatment (-4.9 mg NH_4-N/kg/28d) than in the young-pine with understory (-0.5 mg NH_4-N/kg/28d), the thinned-intercropped (-0.6

mg NH_4-N/kg/28d), and the switchgrass-only (-1.1 mg NH_4-N/kg/28d) treatments and no significant difference (p=0.6131) were observed in mean seasonal *in situ* net N ammonification between riparian and upslope positions across all treatments. During the June-September 2013 incubation, mean seasonal net ammonification was significantly greater ($p<0.0001$) in the mid-rotation reference treatment than in all other watershed treatments and no significant difference (p=0.0513) were observed in mean seasonal *in situ* net N ammonification between riparian and upslope positions across all treatments. During the September 2013-January 2014 interval, mean seasonal net ammonification was significantly greater ($p<0.0001$) in the age-zero intercropped treatment (-1.8 mg NH_4-N/kg/28d) than in the young-pine-with-understory (-5.6 mg NH_4-N/kg/28d) and the mid-rotation reference (-9.5 mg NH_4-N/kg/28d) treatments. No significant difference (p=0.8016) was observed in mean seasonal *in situ* net N ammonification between riparian and upslope positions across all treatments during this final interval.

Figure 9. Effects of watershed treatments on seasonal net ammonification between August 2012 and January 2014. Error bars represent one standard error of the mean.

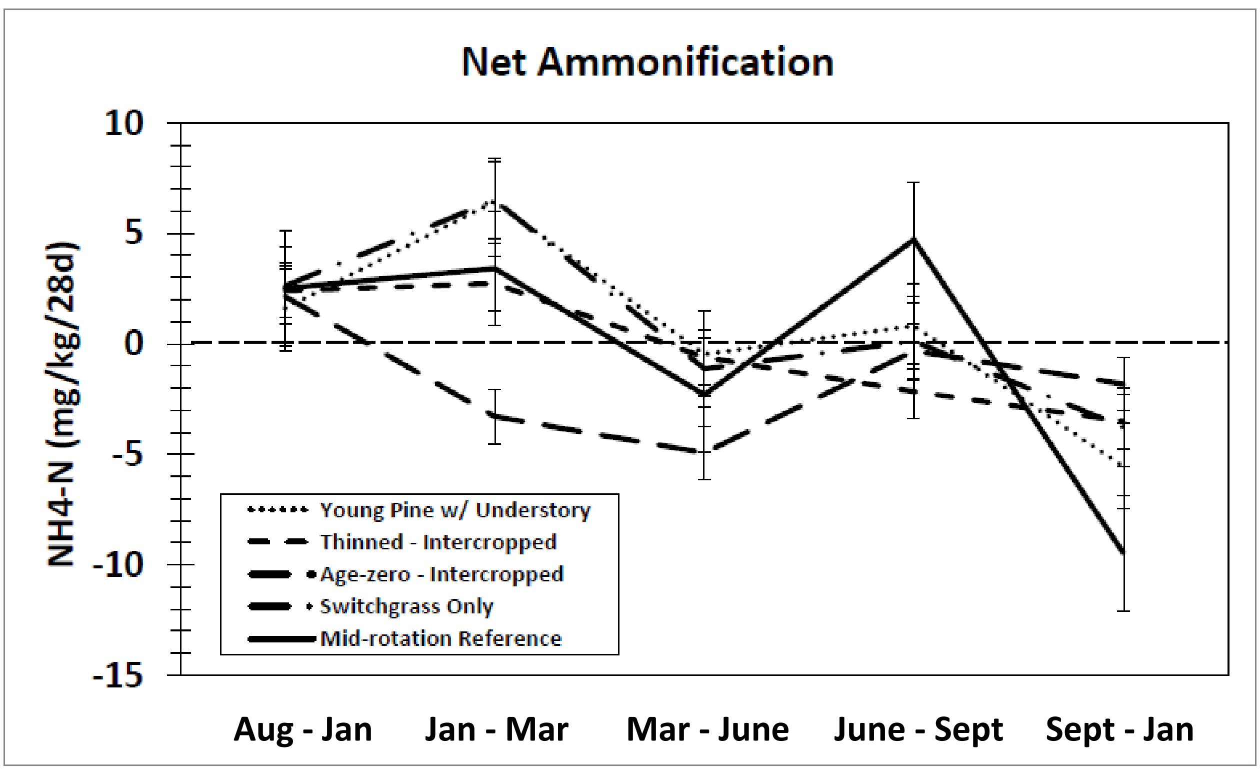
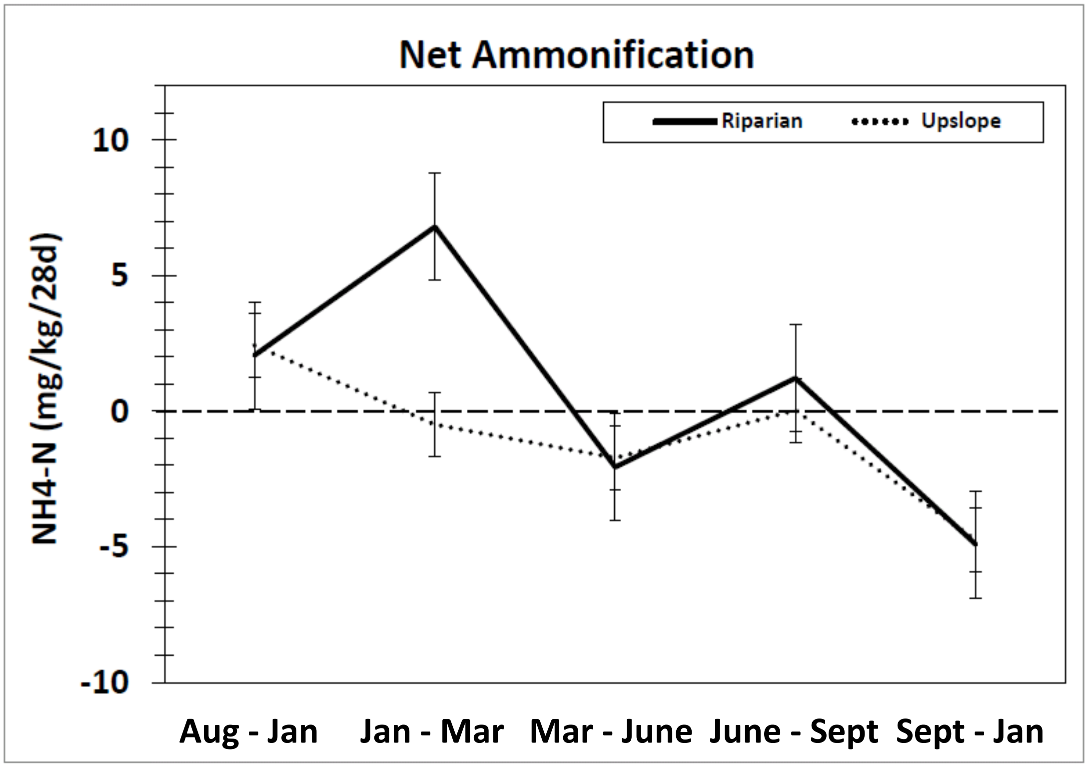


Figure 10. Effects of slope position on seasonal net ammonification between August 2012 and January 2014. Error bars represent one standard error of the mean.



Among watershed treatments, no significant difference in mean monthly net ammonification was observed among watershed treatments (p=0.0974) [Table 25]. Mean monthly net ammonification was significantly greater (p=0.0150) in the riparian position (0.6 mg NH_4-N/kg/28d) than in the upslope position (-0.9 mg NH_4-N/kg/28d) across all treatments.

Net Nitrification

During the August 2012-January 2013 incubation, no significant differences were observed in mean *in situ* net nitrification (mg NO_3-N/kg/28d) among watershed treatments or between riparian and upslope positions across all treatments (p=0.2717 and p=0.6263, respectively) (Figure 11, 12). During the January-March 2013 incubation, mean net nitrification was significantly greater (p=0.0006) in the young-pine-with-understory treatment (8.5 mg NO_3-N/kg/28d) than in the thinned intercropped (-2.1 mg NO_3-N/kg/28d), and the age-zero intercropped treatment (-3.6 mg NO_3-N/kg/28d) treatments.

Table 25. Effects of watershed treatments and slope position on mean monthly net ammonification.

Net Ammonification (NH_4-N mg/kg/28d)			
Treatment	Mean	SE	Tukey
Young-pine-with-understory	0.6	9.5	**NSD**[1]
Thinned - Intercropped	-0.3	4.2	
Age-zero - Intercropped	-1.6	4.1	
Switchgrass-Only	0.9	7.2	
Mid-rotation Reference	-0.2	6.7	
Slope Position	Mean	SE	t-test
Upslope	-0.9	4.4	B[2]
Riparian	0.6	8.3	A

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to t-test.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

No significant difference (p=0.8220) was observed in seasonal *in situ* net nitrification between riparian and upslope positions across all treatments during the January-March 2013 incubation (Figure 12). During the March-June 2013 incubation, mean seasonal net nitrification was significantly greater (p=0.0023) in the young-pine-with-understory (2.3 mg NO_3-N/kg/28d) and thinned-intercropped (1.1 mg NO_3-N/kg/28d) treatments than in the mid-rotation reference (-4.1 mg NO_3-N/kg/28d) treatment and no significant difference (p=0.7532) was observed in mean seasonal *in situ* net nitrification between riparian and upslope positions across all treatments. During the June-September 2013 incubation, mean seasonal net nitrification was significantly greater (p=0.0014) in the switchgrass-only (2.3 mg NO_3-N/kg/28d) and mid-rotation reference (2.6 mg NH_4-N/kg/28d) treatments than in the thinned-intercropped (-0.4 mg NO_3-N/kg/28d) treatment. Mean seasonal net nitrification was significantly greater (p=0.0070) in the riparian position (1.9 mg NH_4-N/kg/28d) than in the upslope position (0.5 mg NO_3-N/kg/28d) across all treatments between June and September 2013. During the September 2013-January 2014 interval, no significant difference was observed in mean seasonal *in situ* net nitrification among watershed treatments or between riparian and upslope positions across all treatments (p=0.0772 and p=0.1693, respectively).

Figure 11. Effects of watershed treatments on mean seasonal net nitrification between August 2012 and January 2014. Error bars represent one standard error of the mean.

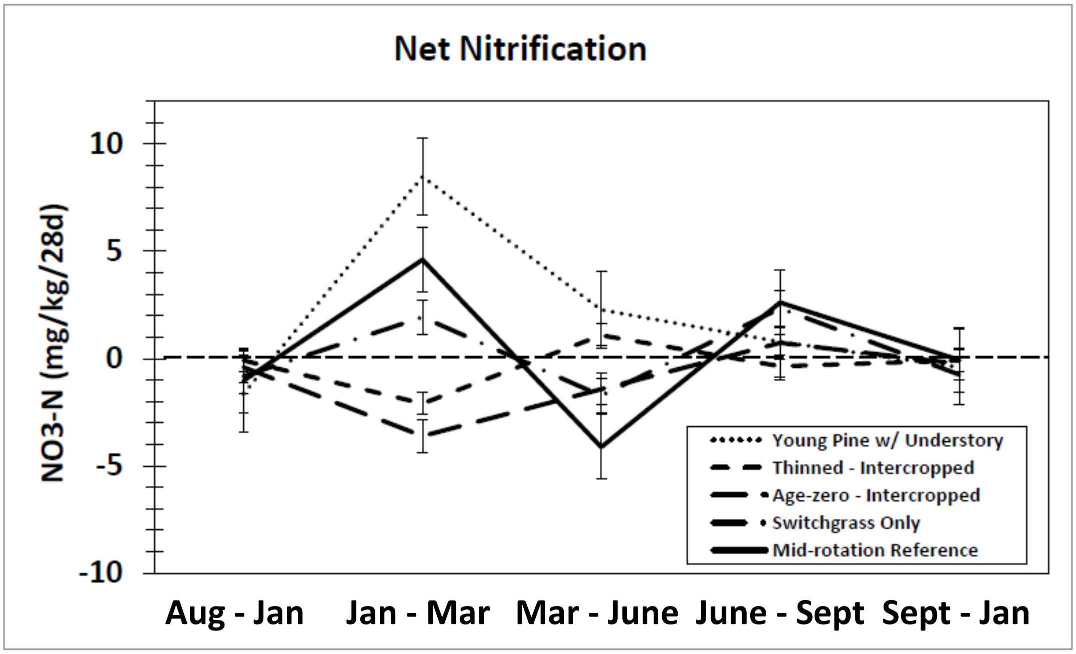
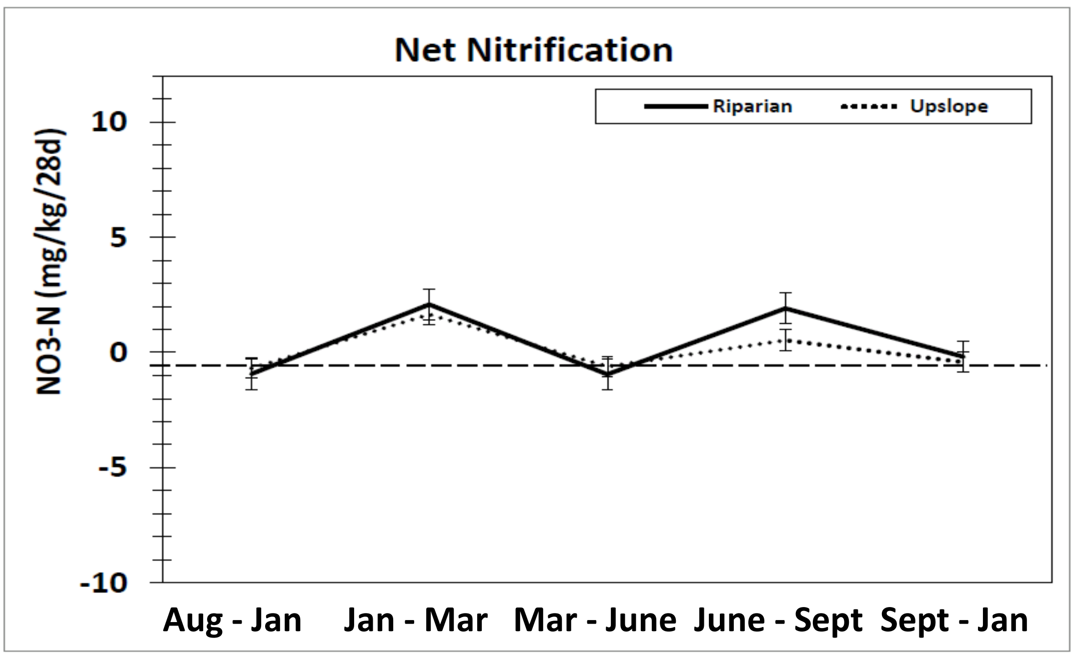


Figure 12. Effects of slope position on seasonal net nitrification between August 2012 and January 2014. Error bars represent one standard error of the mean.



Among watershed treatments, mean monthly net nitrification was significantly greater (p=0.0057) in the young-pine-with-understory treatment (1.9 mg NO_3-N/kg/28d) than in the thinned- intercropped treatment (-0.3 mg NO_3-N/kg/28d) and the age-zero intercropped treatment (-1.0 mg NO_3-N/kg/28d) [Table 26]. No significant difference (p= 0.5629) was observed in mean annual net nitrification between the riparian position and the upslope position across all treatments.

Table 26. Effects of watershed treatments and slope position on mean monthly net nitrification.

Net Nitrification (NO_3-N mg/kg/28d)			
Treatment	Mean	SE	Tukey
Young-pine-with-understory	1.9	6.9	A[1]
Thinned - Intercropped	-0.3	3.7	B
Age-zero - Intercropped	-1.0	2.9	B
Switchgrass-Only	0.2	7.3	AB
Mid-rotation Reference	0.4	4.4	AB
Slope Position	Mean	SE	t-test
Upslope	-0.9	4.0	**NSD[2]**
Riparian	0.6	6.6	

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to t-test.
[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Net N Mineralization

During the August 2012-January 2013 incubation, no significant differences were observed in mean *in situ* net N mineralization (mg NH_4-N+NO_3-N/kg/28d) among watershed treatments or between riparian and upslope positions across all treatments (p=0.1471 and p=0.3243, respectively) [Figure 13]. During the January-March 2013 incubation, mean net N mineralization was significantly greater (p<0.0001) in the young-pine-with-understory treatment (14.9 mg NH_4-N+NO_3-N/kg/28d) than in the thinned intercropped (0.6 mg NH_4-N+NO_3-N/kg/28d), and the age-zero intercropped (-6.91 mg NH_4-N+NO_3-N/kg/28d) treatments. Mean seasonal net N mineralization was significantly greater (p=0.0046) in the riparian position (8.9 mg NH_4-N+NO_3-N/kg/28d) than in the upslope position (1.2 mg NH_4-N+NO_3-N/kg/28d) across all treatments (Figure 14). During the March-June 2013 incubation, mean seasonal net N mineralization was significantly greater (p=0.0002) in the young-pine-with-understory (1.8 mg

NH_4-N+NO_3-N/kg/28d) and thinned intercropped (0.5 mg NH_4-N+NO_3-N/kg/28d) treatments than in the age-zero intercropped (-6.4 mg NH_4-N+NO_3-N/kg/28d) and mid-rotation reference (-6.4 mg NH_4-N+NO_3-N /kg/28d) treatments. No significant difference was observed in mean seasonal *in situ* net N mineralization between riparian and upslope positions across all treatments (p=0.6309). During the June-September 2013 incubation, mean seasonal net N mineralization was significantly greater (p<0.0001) in the mid-rotation reference treatment (7.3 mg NH_4-N+NO_3-N/kg/28d) than in all other watershed treatments and seasonal net mineralization was significantly greater (p=0.0047) in the riparian position (3.1 mg NH_4-N+NO_3-N/kg/28d) than in the upslope position (0.6 mg NH_4-N+NO_3-N/kg/28d) across all treatments. During the September 2013-January 2014 interval, mean seasonal net N mineralization was significantly greater (p<0.0001) in the age-zero intercropped treatment (-2.1 mg NH_4-N+NO_3-N/kg/28d) than in the young-pine-with-understory (-6.0 mg NH_4-N+NO_3-N/kg/28d), and the mid-rotation reference (-9.5 mg NH_4-N+NO_3-N/kg/28d) treatments. No significant difference (p=0.9065) was observed in mean seasonal *in situ* net N mineralization between riparian and upslope positions across all treatments (p=0.9065).

Figure 13. Effects of watershed treatments on seasonal net N mineralization between August 2012 and January 2014. Error bars represent one standard error of the mean.

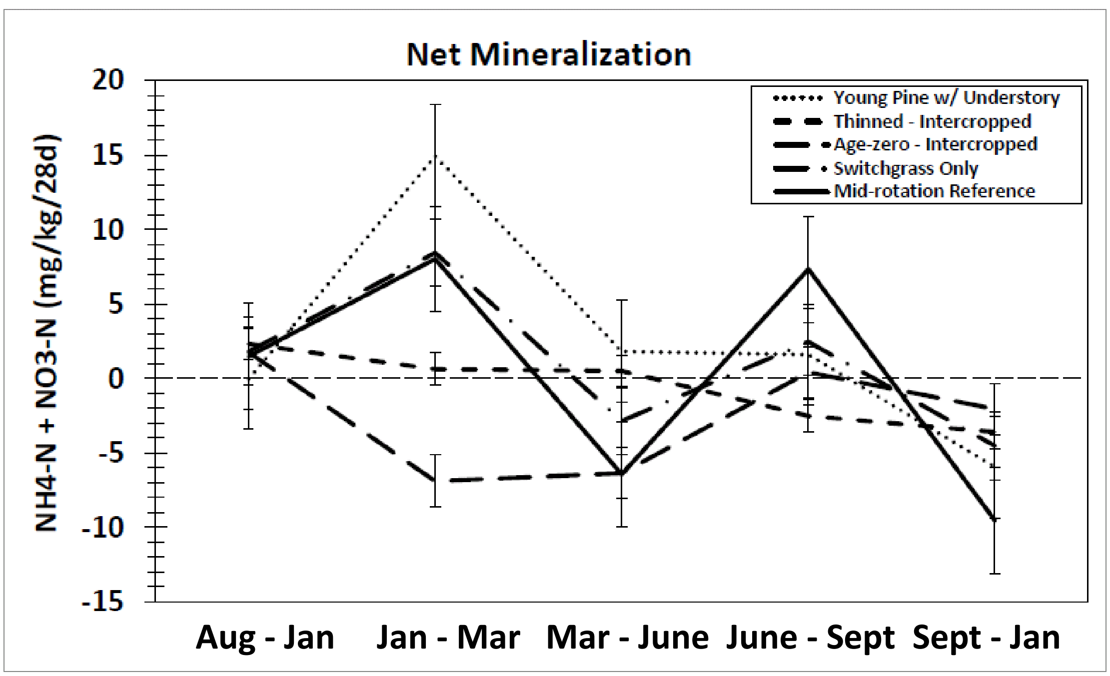
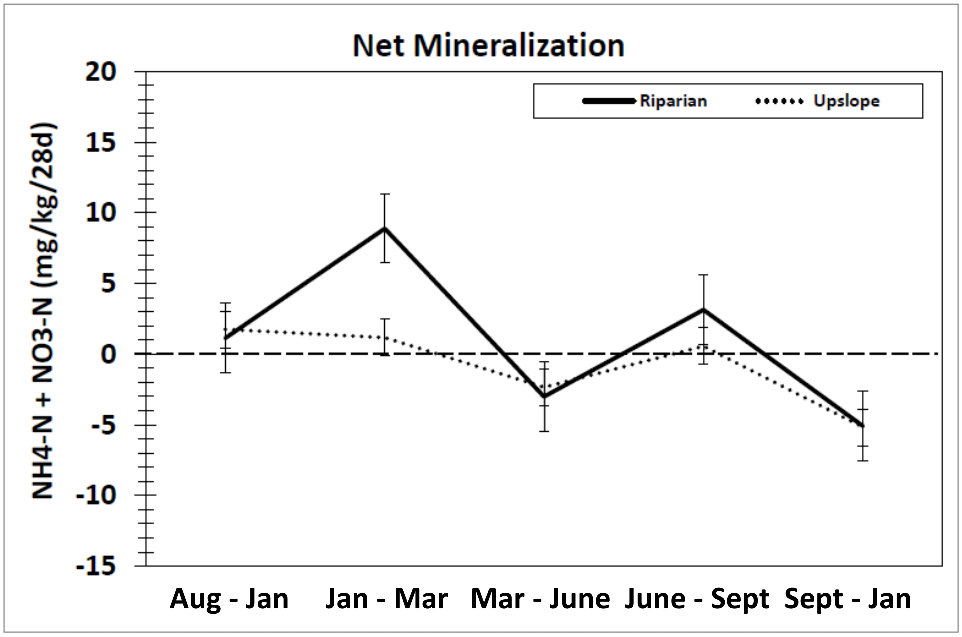


Figure 14. Effects of slope position on seasonal net N mineralization between August 2012 and January 2014. Error bars represent one standard error of the mean.



Among watershed treatments, mean monthly net N mineralization was significantly greater (p=0.0019) in the young-pine-with-understory treatment (2.5 mg NH_4-N+NO_3-N/kg/28d) and in the switchgrass-only treatment (1.1 mg NH_4-N+NO_3-N/kg/28d) than in age-zero intercropped treatment (-2.6 mg NH_4-N+NO_3-N/kg/28d) [Table 27]. Mean annual net N mineralization was significantly greater (p=0.0282) in the riparian position (1.0 mg NH_4-N+NO_3-N/kg/28d) than in the upslope position (-0.8 mg NH_4-N+NO_3-N/kg/28d) across all treatments.

Table 27. Effects of watershed treatments and slope position on mean monthly net N mineralization.

Net N Mineralization (NH_4-N+NO_3-N mg/kg/28d)			
Treatment	Mean	SE	Tukey
Young-pine-with-understory	2.5	11.2	A[1]
Thinned - Intercropped	-0.6	5.4	AB
Age-zero - Intercropped	-2.6	5.7	B
Switchgrass-Only	1.1	10.7	A
Mid-rotation Reference	0.2	9.1	AB
Slope Position	Mean	SE	t-test
Upslope	-0.8	6.0	B[2]
Riparian	1.0	11.0	A

[1]Watershed treatment means not followed by the same letter are significantly different (α=0.05), according to t-test.

[2]Slope position means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Anaerobic Nitrogen Mineralization Potential

Among watershed treatments, anaerobic N mineralization potential at 0-15cm was significantly greater ($p<0.0001$) in the thinned-intercropped treatment (62 mg NH_4-N/kg/7d) than in all other watershed treatments (range: 11-33 mg NH_4-N/kg/7d) [Table 28]. Among watershed treatments, anaerobic N mineralization potential at 15-30cm was also significantly greater ($p=0.0045$) in the thinned-intercropped treatment (54 mg NH_4-N/kg/7d) than in all other watershed treatments (range: 12-25 mg NH_4-N/kg/7d). No significant differences were observed between slope positions at either depth.

Table 28. Effects of watershed treatments and slope position on anaerobic nitrogen mineralization potential.

	0-15cm		
Treatment	**(NH_4-N mg/kg/7d)**	SE	Tukey
Young-pine-with-understory	33.2	5.3	B[1]
Thinned - Intercropped	61.6	11.3	A
Age-zero - Intercropped	20.2	4.7	B
Switchgrass-only	11.0	1.4	B
Mid-rotation Reference	15.8	3.3	B
	15-30cm		
Young-pine-with-understory	24.7	3.9	B
Thinned - Intercropped	53.9	9.9	A
Age-zero - Intercropped	22.5	5.3	B
Switchgrass-only	12.2	1.7	B
Mid-rotation Reference	20.4	4.7	B
	0-15cm		
Slope Position	**(NH_4-N mg/kg/7d)**	SE	t-test
Upslope	28.7	4.9	NSD[2]
Riparian	28.1	4.5	
	15-30cm		
Upslope	26.4	4.2	NSD
Riparian	27.1	4.2	

[1]For each depth, watershed treatment means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.
[2]For each depth, slope position means not followed by the same letter are significantly different (α=0.05), according to Tukey's HSD.

Associations between Soil Properties and Measured Carbon and Nitrogen Dynamics

Correlations between each of the measured soil chemical and physical properties at 0-15 cm (a total of 30 variables) and soil C and N dynamics (*in situ* litter decomposition, *in situ* net N mineralization, and anaerobic N mineralization potential) were examined by slope position (upland, riparian) across all watershed treatments. Based on p-values of these results and Spearman's correlation ρ, variables with significant associations with measured soil C and N dynamics were selected for further evaluation using linear regression models in an effort to examine associations between the most influential soil chemical and physical properties and the selected soil C and N dynamics. Only significant ($p<0.05$) correlations among explanatory variables (soil total N, soil total C, soil C:N, soil extractable P, forest floor (FF) mass, FF total C, and FF total N) are reported here. A table of all correlation coefficients is in Appendix A.

Although soil total N and soil total C at 0-15 cm and FF mass and FF total N had a statistically significant ($p=0.005$, $p=0.005$, $p=0.005$, $p=0.008$, respectively) influence on the variation in annual net ammonification, they only explain 18%, 13%, 1% and 9% of the variation in annual net ammonification in the upslope position across all five watershed treatments, respectively (Figures 15, 16, 17, and 18) and are negatively correlated with net ammonification. In the upslope position across all watersheds, the most significant ($p=0.026$) soil property associated with annual net nitrification, which was soil C:N, only accounted for 7% of the variation in annual net nitrification (Figure 19) and was positively correlated with annual net nitrification. Soil total N, C:N and total C were significant ($p=0.009$, 0.011, and 0.014, respectively) in explaining variation in annual net N mineralization in the upslope position across all watersheds, accounting for 12%, 13%, and 8% of the variation in annual net N mineralization, respectively (Figures 20, 21 and 22). Soil total N and total C were negatively correlated, while soil C:N was positively correlated, with annual net N mineralization.

In contrast to soil total N, total C, and C:N being most significant in the upslope position, soil extractable P and FF total N were most significant ($p=0.027$ and $p=0.036$, respectively) in the riparian area, explaining 13% and 4% of the variation in annual net N mineralization in this slope position (Figures 23 and 24), and were positively correlated with annual net N mineralization.

Forest Floor total N also had a significant (p=0.019) positive correlation with annual net nitrification in the riparian position across all watersheds, but the association accounted for only 10% of the variation in annual net nitrification (Figure 25).

Soil total N and total C were positively correlated with anaerobic N mineralization potential in the riparian position across all watersheds and accounted for 10% and 7% of the variation of anaerobic N mineralization potential, respectively (Figures 26 and 27). Forest floor mass, FF total C, and FF total N also were significantly correlated with anaerobic N mineralization potential in riparian zones across all watersheds, but to a lesser extent than soil total N and C described above. (Figures 28, 29, and 30). Forest floor total C and FF total N were positively correlated with anaerobic N mineralization potential, but FF mass was negatively correlated with anaerobic N mineralization potential.

Figure 15. Association between soil total N at 0-15 cm and monthly net ammonification in upslope positions.

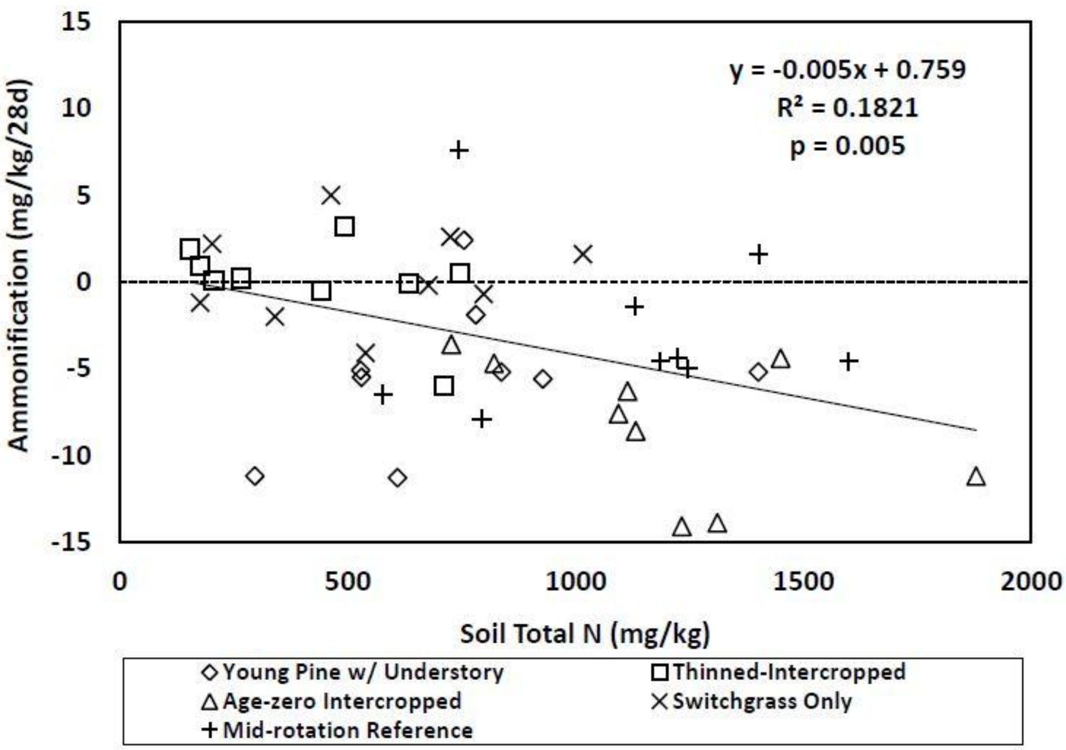


Figure 16. Association between soil total C at 0-15 cm and monthly net ammonification in upslope positions.

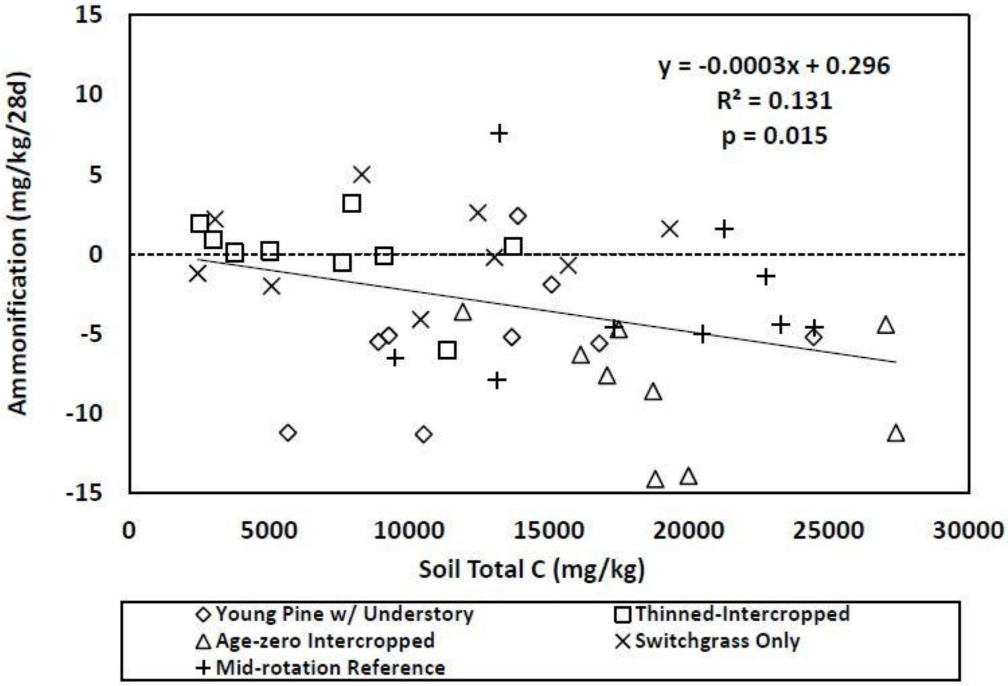


Figure 17. Association between forest floor mass and monthly net ammonification in upslope positions.

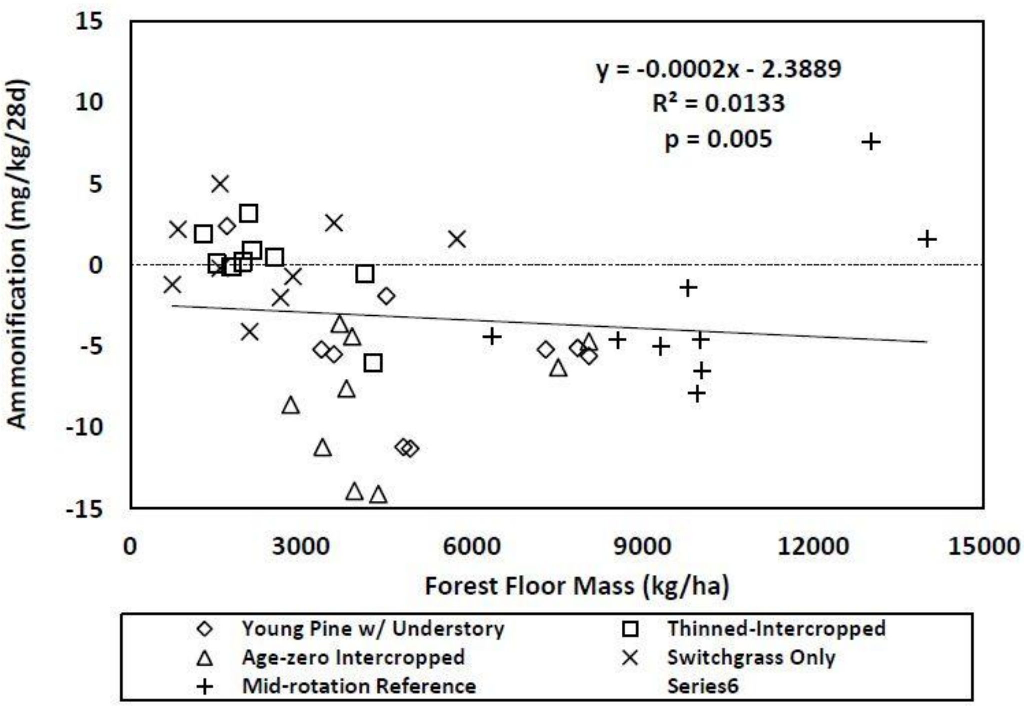


Figure 18. Association between forest floor total N and monthly net ammonification in upslope positions.

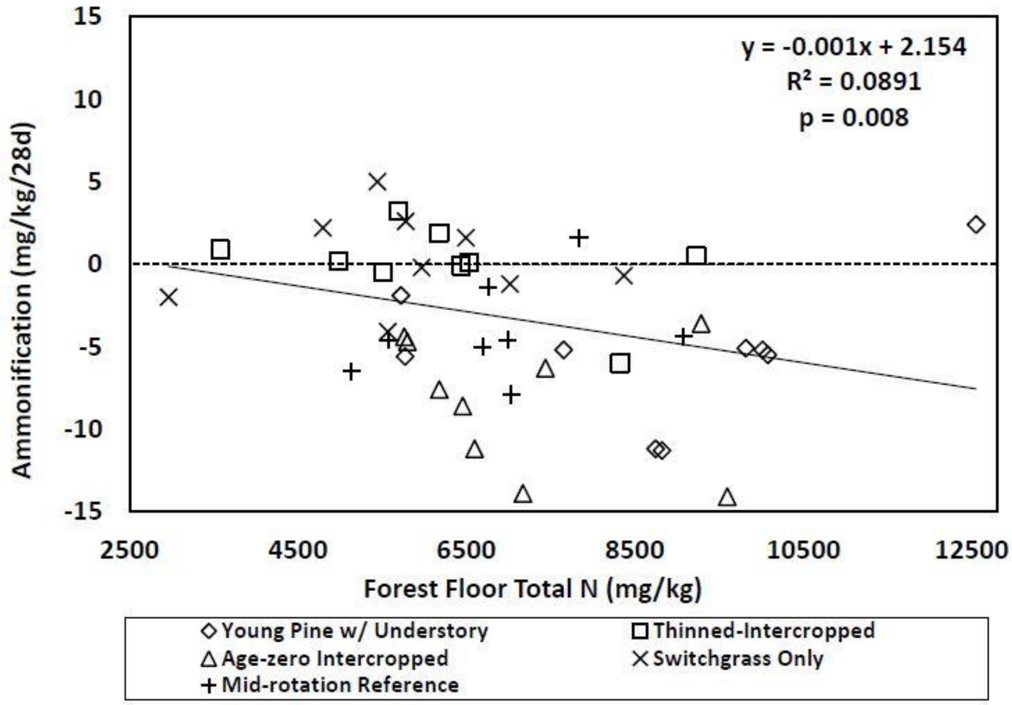


Figure 19. Association between soil C:N at 0-15 cm and monthly net nitrification in upslope positions.

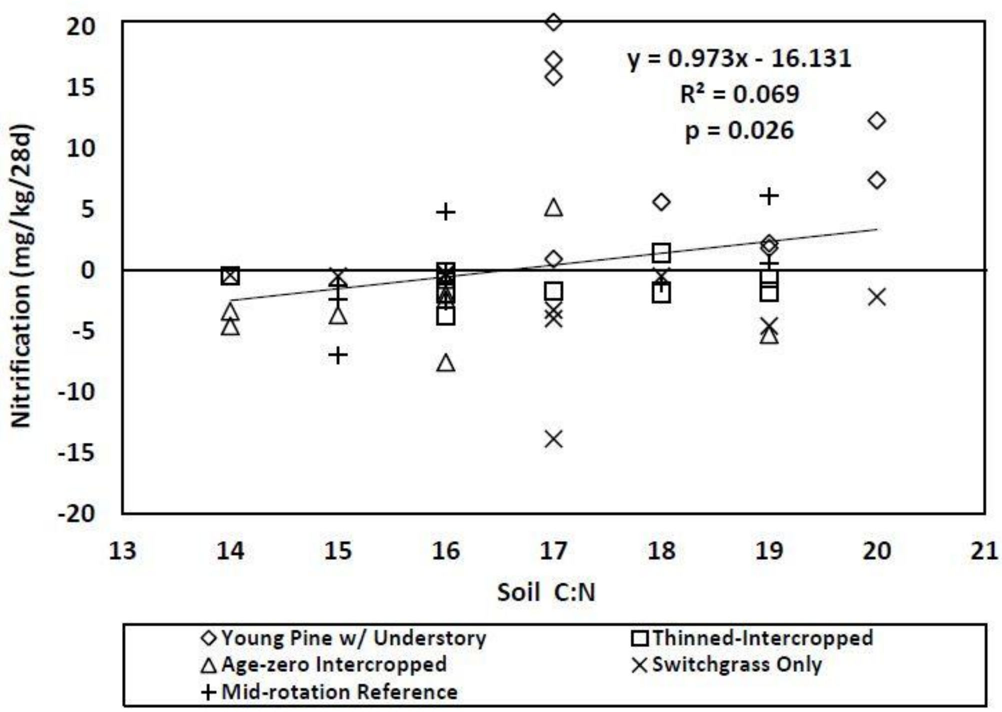


Figure 20. Association between soil total N at 0-15 cm and monthly net mineralization in upslope positions.

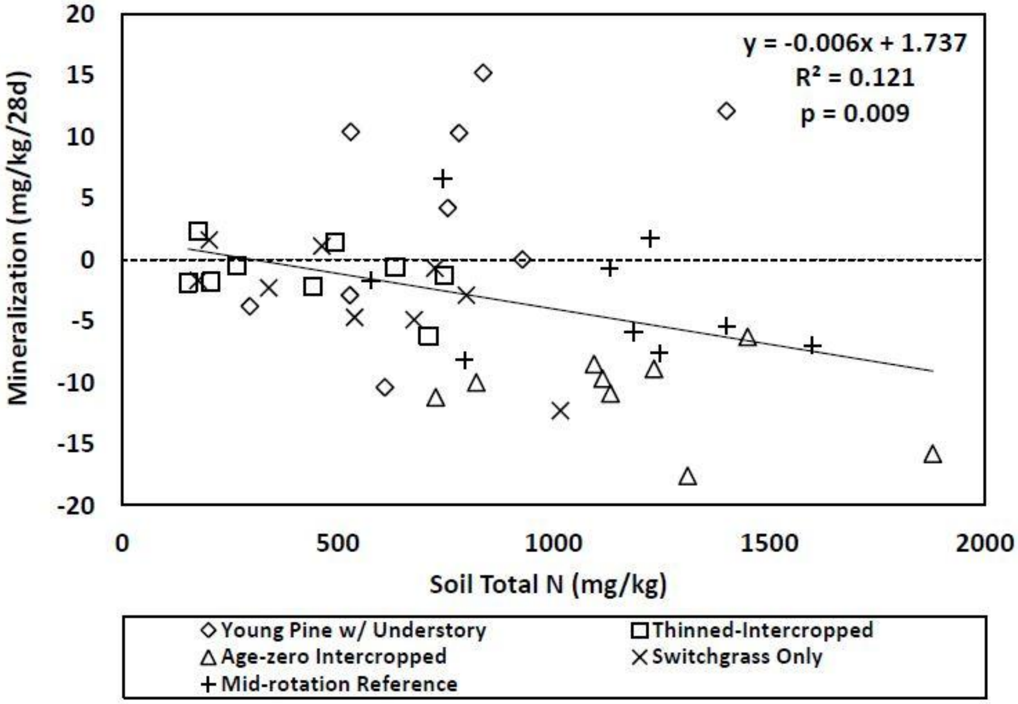


Figure 21. Association between soil C:N at 0-15 cm and monthly net mineralization in upslope positions.

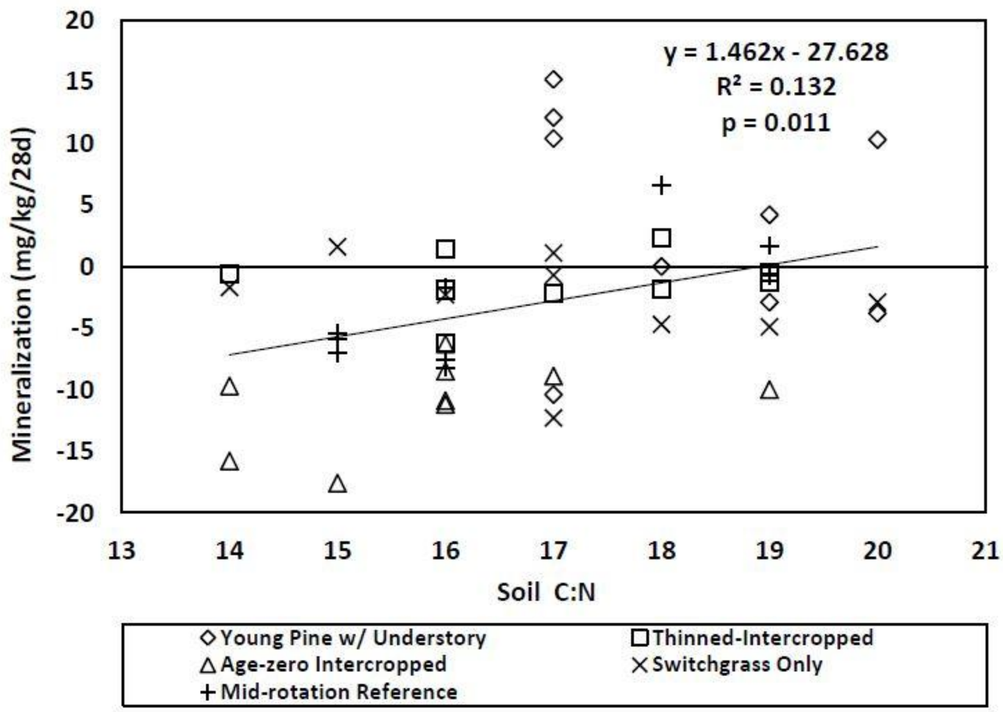


Figure 22. Association between soil total C at 0-15 cm and monthly net mineralization in upslope positions.

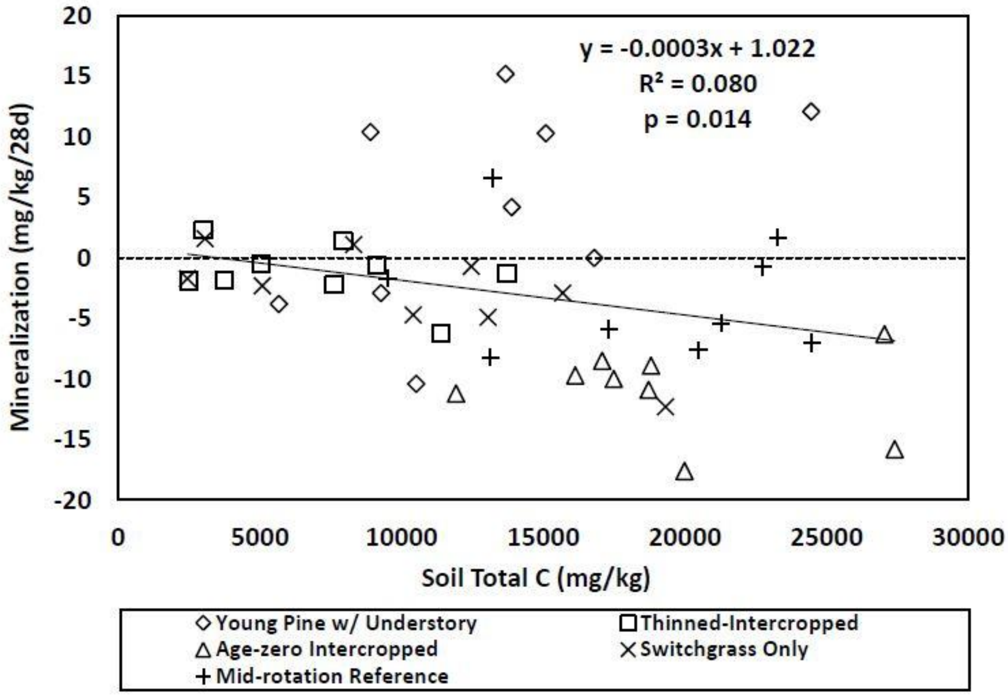


Figure 23. Association between soil P at 0-15 cm and monthly net mineralization in riparian positions.

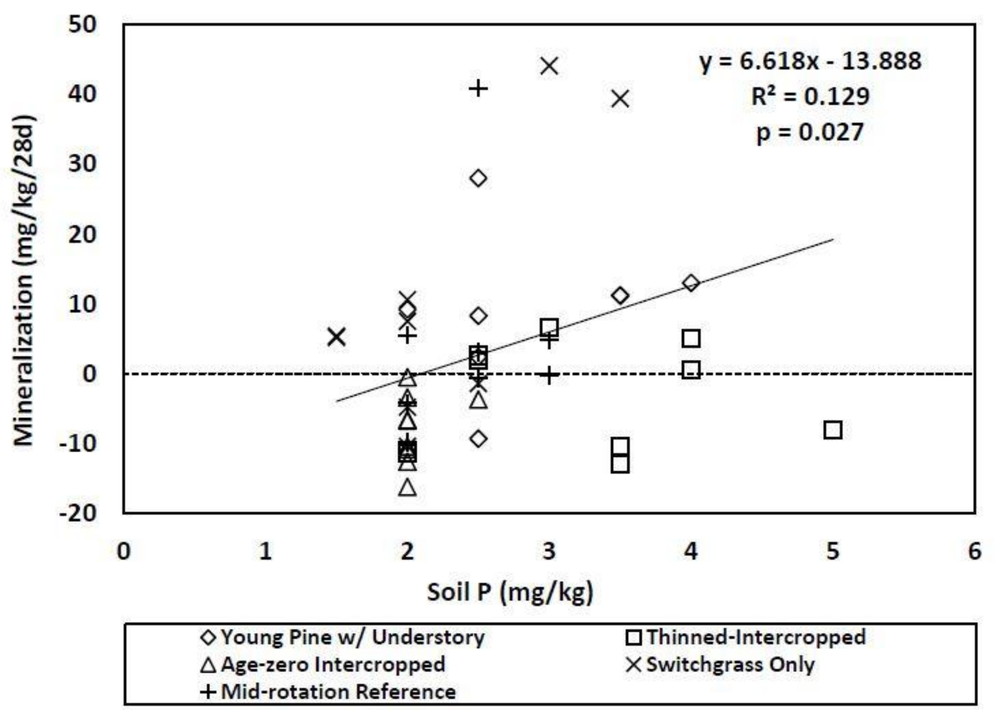


Figure 24. Association between forest floor total N and monthly net mineralization in riparian positions.

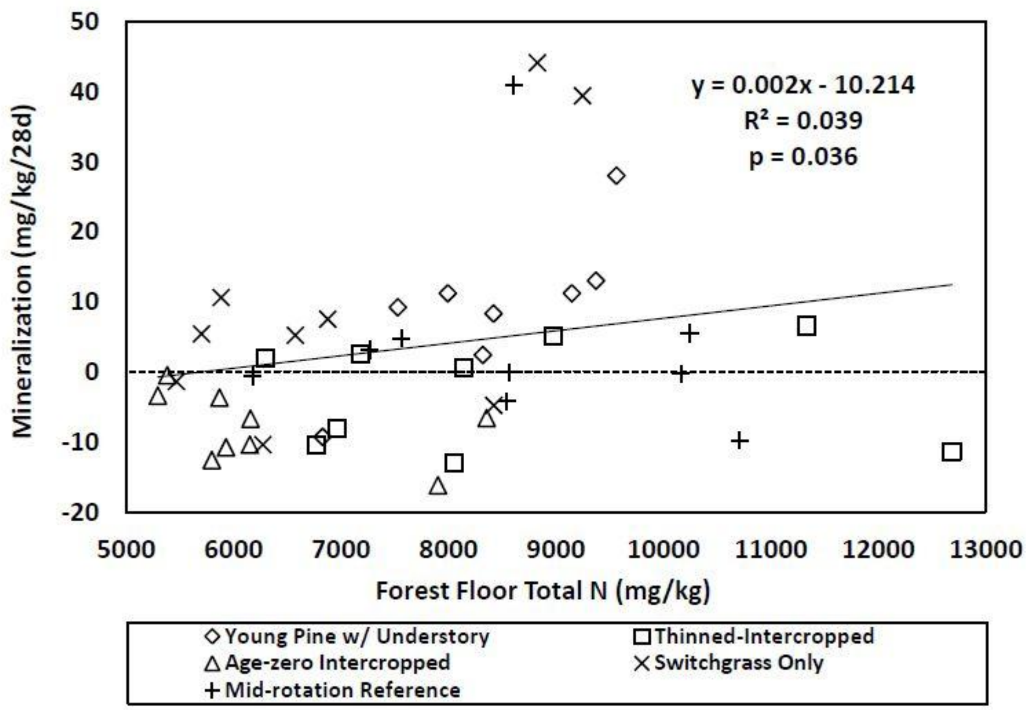


Figure 25. Association between forest floor total N and monthly net nitrification in riparian positions.

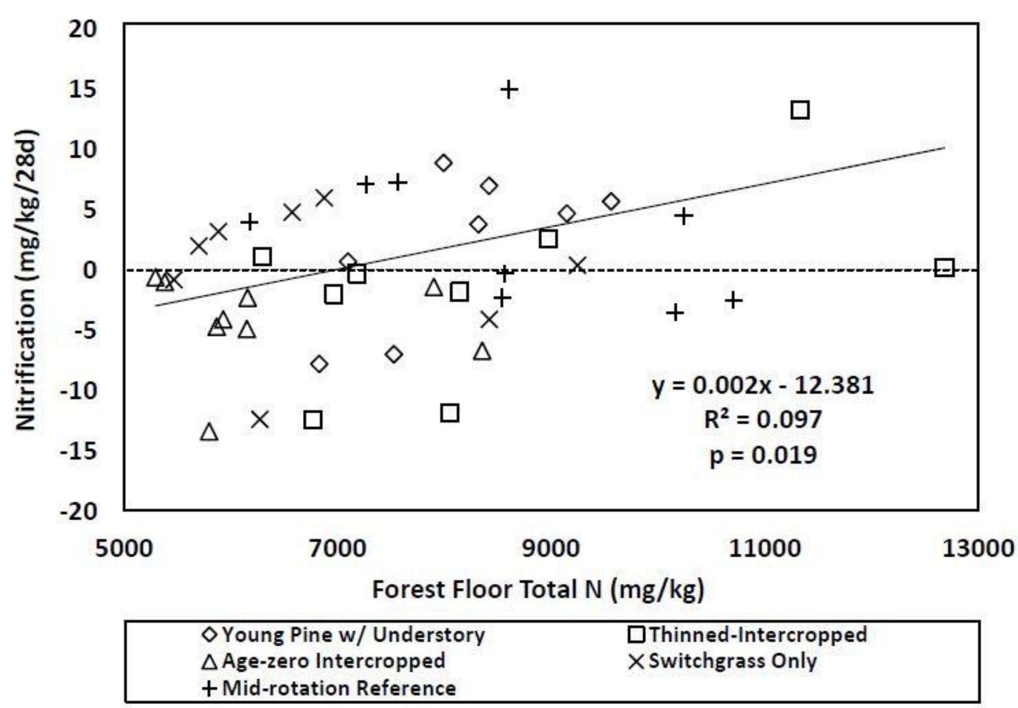


Figure 26. Association between soil total N at 0-15 cm and anaerobic nitrogen mineralization potential in riparian positions.

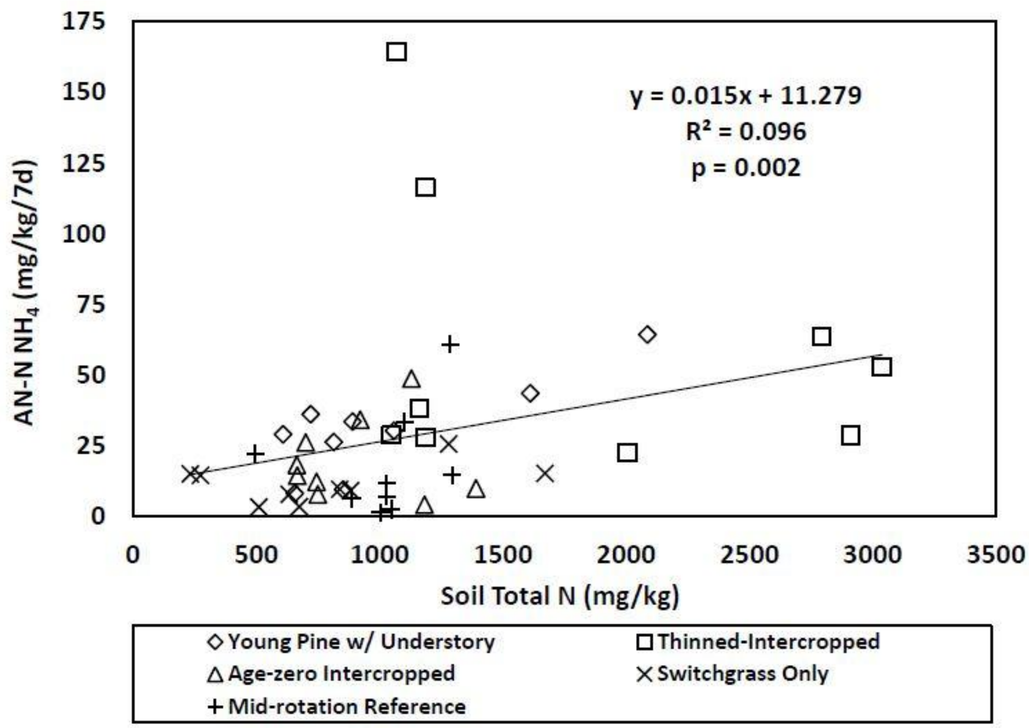


Figure 27. Association between soil total C at 0-15 cm and anaerobic nitrogen mineralization potential in riparian positions.

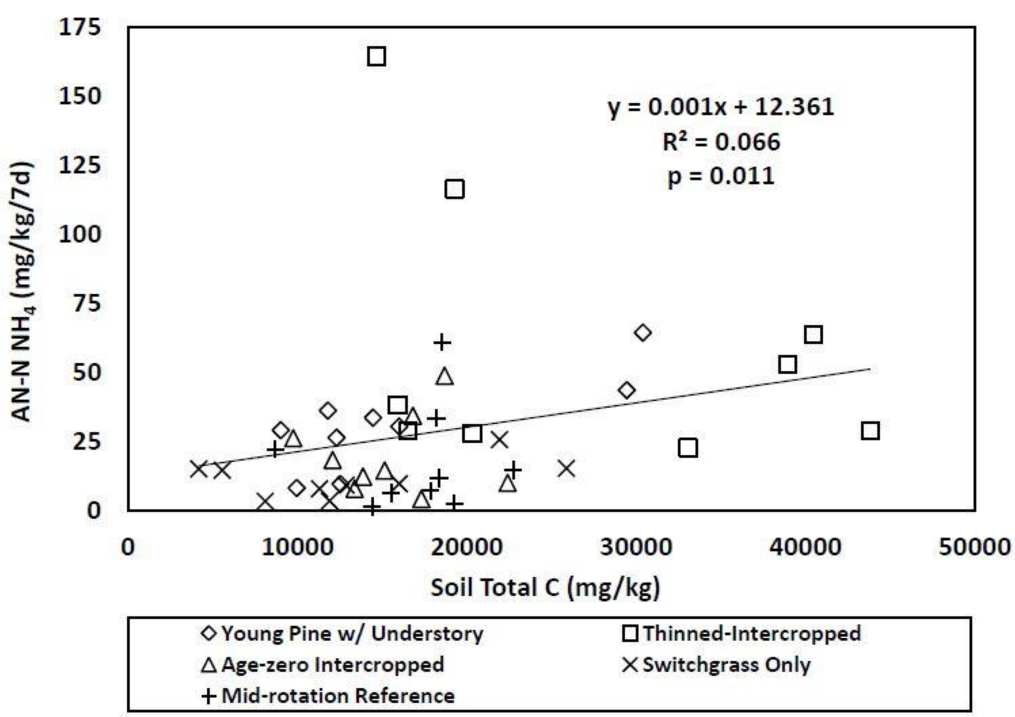


Figure 28. Association between forest floor mass and anaerobic nitrogen mineralization potential in riparian positions.

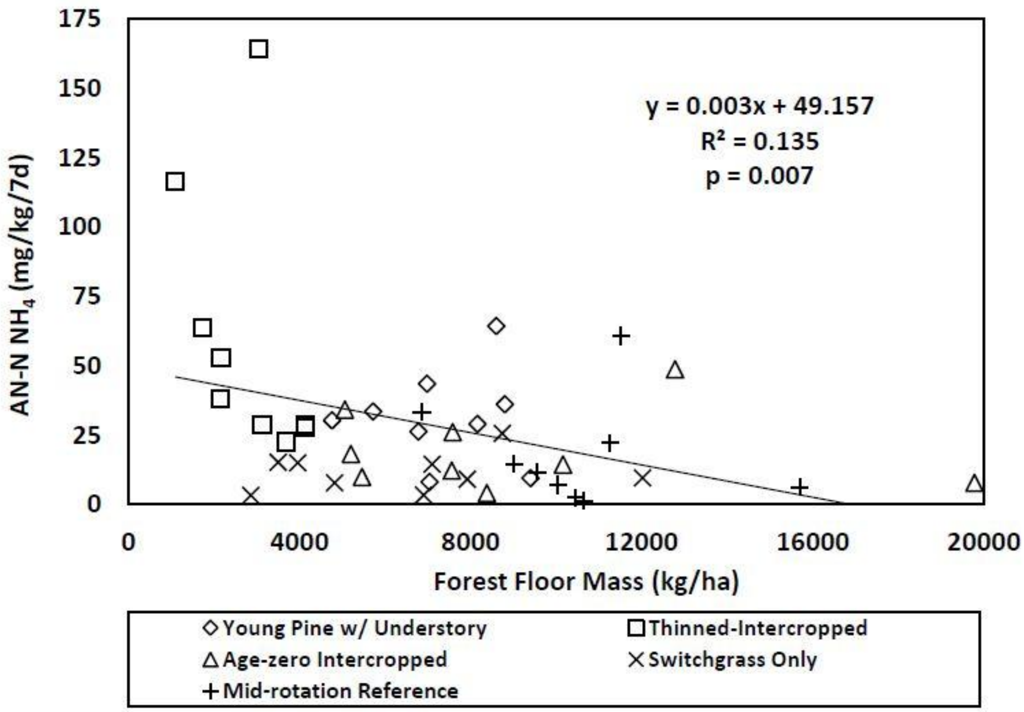


Figure 29. Association between forest floor total C and anaerobic nitrogen mineralization potential in riparian positions.

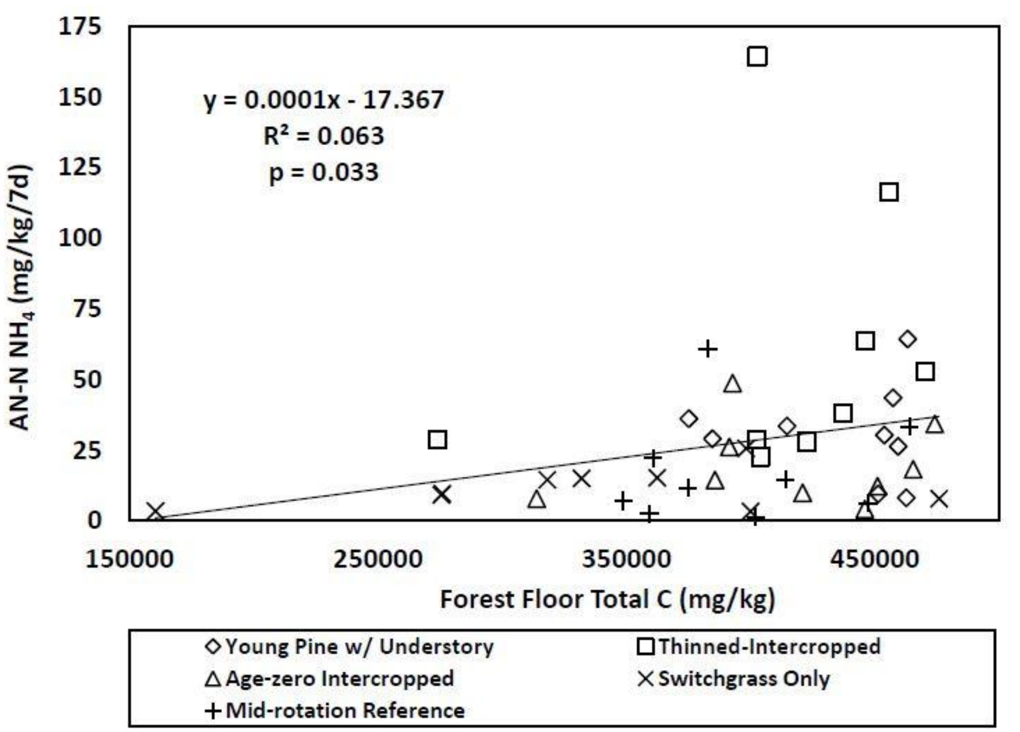
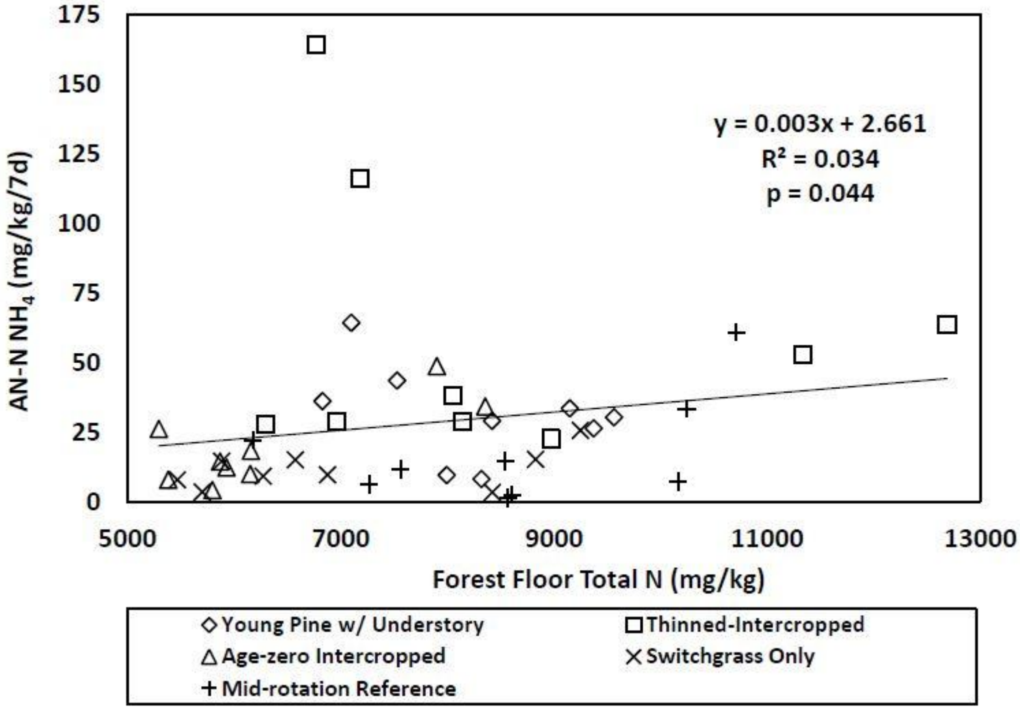


Figure 30. Association between forest floor total N and anaerobic nitrogen mineralization potential in riparian positions.



Chapter 4 - Discussion

Soil Physical Properties

Bulk density at 0-15cm depth in the upslope position was similar across all watershed treatments, and only the thinned-intercropped treatment bulk density differed among watershed treatments in the riparian position. Generally, bulk density at 0-15cm depth between the upslope and riparian positions within each watershed treatment was similar, with the exception of the thinned-intercropped and mid-rotation reference treatments where bulk density was higher in the upslope position. Bulk density at 15-30cm depth was greatest in the switchgrass-only and mid-rotation reference treatments, and greater in the upslope position than in the riparian position.

All watershed treatments contained 53-77% sand at 0-15cm depth and 46-82% at 15-30cm depth. Both riparian and upslope positions had similar particle-size distribution across all watershed treatments, except for the age-zero intercropped, which had more silt and less sand in the upslope area than the other treatments.

Mean bulk density was not significantly different among the watershed treatments at 0-15cm depth, and only differed between slope positions within the thinned-intercropped treatment likely due to management practices in the upslope position where bulk density was greater, and possibly due to presence of large macro-pores observed in the riparian position, which would lower bulk density. Studies have shown management practices similar to those used in this study to cause inconsistent changes in soil bulk density. Schmer *et al*. (2011) found after five years following switchgrass establishment, bulk density in the upper few centimeters of soil increased by an average of 0.16 Mg/m^3 in fields in Nebraska but also observed a decrease in bulk density in fields in South and North Dakota by an average of 0.18 and 0.42 Mg/m^3, respectively. A decrease in bulk density, along with increased infiltration rates, at 0-10cm depth seven years after switchgrass establishment was observed in Ohio (Bonin *et al*., 2012).

Timber harvesting also has the capacity to affect soil bulk density. In a Eucalyptus stand in Australia, Whitford and Mellican (2011) found that timber harvesting increased bulk density at 0-10cm depth by 20% compared to non-harvested sites. A review of studies on a multitude of harvesting practices in the Atlantic Coastal Plain found that level of disturbance and associated resistance and resilience of sites caused by harvesting practices varies widely among soil type (especially texture) and soil moisture conditions (Miwa *et al*., 2004).

Particle-size distribution was generally similar among watersheds likely because of their proximity to each other, similar positions in the landscape, and similar soils. Variability in particle-size distribution from one watershed to another may be an artifact of previous land management (e.g. disking, tilling, etc), which could have mixed soils from different depths. Land-use and vegetation types can significantly influence particle-size distribution in surface soils by either promoting or preventing soil erosion (Erskine *et al*., 2002; Basic *et al*., 2004). Rab (1996) found that soil disturbance caused by logging practices significantly altered particle-size distribution in the Victorian Central Highlands in Australia. Removal of vegetation coupled with erosion can result in changes in soil particle-size distribution (Liu *et al*., 2009). A study in a northern Wisconsin forest showed that particle-size distribution beneath and around tree-throws was significantly altered at both 0-30cm and 30-90cm depths, but not at depths >90cm (Meyers and McSweeney, 1995). In my study, all watershed treatments contained between 53 and 77% sand. Both riparian and upslope positions were similar across all watershed treatments, except for the age-zero intercropped, which had more silt and less sand in the upslope area than the other treatments. My results suggest that the cellulosic biofuel treatments used within the conditions of this study did not create sufficient surface soil disturbance to alter particle-size distribution or significantly affect bulk density.

Soil Chemical Properties

Soil total C and N concentrations at 0-15cm depth in upslope positions were highest in the age-zero intercropped and mid-rotation reference treatments and lowest in the thinned-intercropped and switchgrass-only treatments. In contrast, soil total C and N at 0-15cm depth in riparian positions were highest in the thinned-intercropped treatment and lowest in the switchgrass-only treatment. Soil total C and N concentrations at 15-30cm depth were highest in the age-zero intercropped treatment, similarly lower in the switchgrass-only and the mid-rotation reference treatments, and lowest in the young-pine-with-understory and thinned-intercropped treatments. Soil C:N ratios were similar in riparian positions among all watershed treatments, and similar in the upslope position among all treatments, with the exception of the age-zero intercropped treatment, which had a lower C:N ratio. The young–pine-with-understory treatment had a significantly lower pH than all the other watershed treatments. The young-pine-with-understory and the thinned-intercropped treatments had the highest concentrations of extractable P, followed by the mid-rotation reference, then by the age-zero intercropped and switchgrass-only treatments. Overall, the age-zero intercropped watershed treatment had significantly higher concentrations of soil exchangeable K, Ca, Mg, Mn, and CEC than the other treatments.

Soil total C and N concentrations varied between slope positions within watershed treatments and among treatments within slope positions in this study. One possible explanation is that the watersheds have inherently different soil properties, but that is likely not the case given they are all mapped as similar, closely-related soil series (Falaya, Faceville, Ochlockonee, Smithdale) and have similar historic land uses. However, a study by Usher (1970) found that after taking sixteen $4cm^2$ x 3cm soil cores in a Scots pine forest and separating them at 1cm depth intervals, soil total N was found to be randomly distributed horizontally and vertically. For any given block of sixteen $4cm^2$ x 3cm soil cores, coefficients of variation ranged from 8-36%, and total N concentration often varied by as much as four times over a 4cm horizontal distance (Usher 1970). Another possible explanation is that evidence of soil total C and N responses to management activities can be quite variable over time and is not always apparent (Johnson and Curtis, 2001). The type and intensity of management activities (e.g. harvesting, site preparation, etc) will influence the degree to which effects of management are manifested in soil chemical properties (Knoepp and Swank, 1997). An increase in soil total C and N can result from biomass being incorporated into the soil following harvesting where residues are left on site (Black and Harden, 1995). In southeastern Australia, increased N mineralization rates were observed within 2-3 months upon clear-felling *Pinus radiata*, and coupled with no uptake by trees, led to an increase in concentration of mineral N in both litter and soil for at least three years (Smethurst and Nambiar, 1990). In a southern Appalachian forest, soils on a south-facing slope (similar to this study) showed a considerable interannual difference in N concentrations, but were overall generally stable (Knoepp and Swank, 1997). Soil C:N ratios can act as a signature for influence of harvest residuals. For example, soil C:N ratios can be higher initially due to incorporation of woody residues with high C:N ratios, and eventually decrease over time to approach equilibrium (Black and Harden, 1995).

Soil total C and N concentrations at 0-15cm in upslope positions were lowest in the thinned-intercropped and switchgrass-only treatments, suggesting that establishment of switchgrass may initially lower soil C and N concentrations. This is contradicted by the notion that perennial grass biofuel crops (i.e. switchgrass) have been observed to add C and N to surface soils due to their enhanced belowground organic-matter inputs (Davis *et al*., 2010). However, if forest clearing is involved in land-use conversion to switchgrass, then decreases in soil C may result from the disturbance and changes in micro-climate (Chen *et al*., 2000). Lower soil total C and N concentrations in the age-zero intercropped treatment were not observed, likely due to the fact that when the trees planted in 2006 were removed in October 2012, operators left a small buffer (~5m) on either side of all three sampling transects established for this study.

Slope position has been shown to influence soil edaphic and microclimate conditions (Lavelle *et al*., 1993). Riparian soils, compared to upslope soils, are often saturated with water and occasionally flooded (Ruan *et al*., 2005). Soil chemical differences between riparian and upslope soils may be caused by variability in soil activity resulting from these water-content differences (Willig *et al*., 1996). For instance, soil microbial C and respiration in riparian areas have been shown to be significantly higher than in upslope areas (Ettema *et al*., 1999). Upslope soils are often relatively low in N content compared to riparian soils (Scatena and Lugo, 1995), which is similar to what I observed in this study, except for the age-zero intercropped treatment. A study by McDowell *et al*. (1992) showed that in two tropical watersheds with different soils and geomorphology N loss was greater in riparian areas than in upslope areas. This may result from increased plant uptake or soil microbial activity, or a combination of the two (Ruan *et al*., 2005).

In general, differences in soil C may point toward disturbances and changes in the quantity and structure of plant material returning to the soil through litter and rooting (Lugo & Brown, 1993), though in a review of forest harvesting effects, most studies showed no significant change (±10%) in soil C (Johnson, 1992). This may help explain the similarity of mean soil C:N that was observed among watershed treatments in this study.

In this study, exchangeable cation (K^{+}, Ca^{+2}, Mg^{+2}, Mn^{+2}) concentrations were higher, on average, in the age-zero intercropped soil, but varied between slope positions and among watershed treatments. These variations may result from treatment effects or from slight variations in mineralogy, particle-size distribution, hydrology, and plant species composition and their nutrient uptake efficiency along varying landscape positions (Brady and Weil, 2008).

Forest Floor

Forest floor mass was highest in the mid-rotation reference treatment, followed by the young-pine-with-understory and the age-zero intercropped treatments. The switchgrass-only and thinned-intercropped treatments had the lowest forest floor mass and the lowest forest floor C (switchgrass-only) and N in the upslope position. Forest floor C and N concentration was similar between the upslope and riparian position in each of the watershed treatments, with the exception of the thinned-intercropped and mid-rotation reference treatments, which had less N in the upslope position, but forest floor C and N content varied depending on forest floor mass. Forest floor C:N ratios in the upslope position were similar among all watershed treatments, and in the riparian position were lowest in the switchgrass-only and mid-rotation reference treatments.

Forest floor mass generally met expectations of watershed treatment effects in this study. Forest floor mass in the mid-rotation reference treatment (10,562 kg/ha) is in agreement with findings in the southeastern U.S. For example, forest floor mass ranged from 10,100 kg/ha to 16,600 kg/ha in a 10-year-old loblolly stand in Georgia and was 25,300 kg/ha in a 23-year-old loblolly stand in North Carolina (Kiser and Fox, 2012). The intercropped treatments had less forest floor mass than the mid-rotation reference and young-pine-with-understory treatments and greater mass than the switchgrass-only treatment because competing pines likely produce more litter than switchgrass. The switchgrass-only treatment had the lowest forest floor mass because of the relative sparseness of vegetation in the recently established switchgrass treatment in the upslope position. Differences in forest floor mass between the upslope position and the riparian position across all watershed treatments can be attributed to exposure to biofuel treatment, vegetation type, increased litter production with age, and slower decomposition rates in the riparian zones (Lawrence and Foster, 2002).

Forest floor N content was significantly greater in the riparian position than in the upslope position for all watershed treatments, and forest floor C content showed a similar pattern except for in the mid-rotation reference and thinned-intercropped treatments. This can probably be explained by increased productivity of the larger trees, and thus more litter, in riparian positions than in upslope, aside from the mid-rotation reference where trees in the upslope position are large enough to produce a sufficient quantity of litter to supply the forest floor with a C content similar to the riparian position (Binkley, 2002). For this reason, along with likely increased temperature (Bengtsson *et al*., 2003) from greater sun exposure leading to photodegradation (Austin and Vivanco, 2006; Brandt *et al*., 2010), less forest floor C and N were observed in the three treatments with switchgrass. One may expect the forest floor C:N to be higher in the treatments with a switchgrass component (C:N ~100 range) than in treatments without switchgrass (e.g. *Pinus taeda* where C:N ~40 range). Typically, higher forest floor C:N equates to increased forest floor mass and a decrease in C quality (Kelly *et al*., 2011). However, no significant differences in forest floor C:N ratios in the upslope position were observed in this study.

Litter Decomposition

Neither watershed treatment nor slope position had a significant effect on loblolly pine needle litter decomposition rate in this study. Total C concentration of pine needles in litter bags decreased over time in all watershed treatments, with the least loss of total C occurring in the mid-rotation reference treatment, and the greatest loss occurring in the young-pine-with-understory treatment. Total C decreases in pine needles were similar in riparian and upslope positions across all watershed treatments. Total N concentration of pine needles in litter bags increased over time in all watershed treatments, with the greatest increase of total N occurring in the mid-rotation reference treatment, followed by the switchgrass-only treatment. Total N increases were similar in riparian and upslope positions across all watershed treatments. C:N ratios of pine needles decreased over time in all watershed treatments, where the mid-rotation reference treatment decreased more than the other treatments throughout most of the study, followed by the switchgrass-only treatment. The two intercropped treatments had slightly higher C:N ratios than the other watershed treatments at the end of the study. Total C:N changes were similar in riparian and upslope positions across all watershed treatments.

Neither watershed treatment nor slope position had a significant effect on decomposition rate of loblolly pine needles in this study. This suggests a lack of treatment effects and slope-position effects on abiotic factors that often control litter decomposition. Abiotic factors known to affect litter decomposition rate are temperature and moisture (Gurlevik *et al*., 2004), photodegradation (Austin and Vivanco, 2006; Brandt *et al*., 2010), and photochemical mineralization (Brandt *et al*., 2009). I hypothesized that litterbags placed in switchgrass, whether in the switchgrass-only or in between tree rows in the intercropped treatments, to have higher decomposition rates resulting from increased temperature (Gurlevik *et al*., 2003), photodegradation (Austin and Vivanco, 2006; Brandt *et al*., 2010), and/or photochemical mineralization (Brandt *et al*., 2009); however, increased decomposition rates of pine needle litter were not observed in my study.

Decrease in concentration of total C and increase in concentration of total N over time was observed to be greatest in the mid-rotation reference treatment. Piatek and Allen (2001) also observed similar results in a mid-rotation loblolly stand in North Carolina, where N concentration in pine needles and a mix of pine needle to hardwood litter (1:5) decreased slightly in the first few months, then increased throughout the rest of the year. Total nitrogen (N) concentration of pine needles in litter bags increased over time in all watershed treatments, indicating that loblolly pine litter loses N more slowly than other components of the litter, resulting in a relative increase in N concentration. Similar observations in a loblolly stand in North Carolina support this finding (Sanchez, 2001). An initial increase in C:N was caused by an initial decrease in litter N. As time progressed, more labile C fractions (e.g. cellulose, hemicellulose, carbohydrates) were released from the litter more rapidly than N was decomposed. A similar process of differential decomposition of C versus N likely caused a decrease in C:N over time in all watershed treatments in my study. No significant difference ($p=0.3907$) was observed in changes in total C:N between riparian and upslope positions across all watershed treatments or among all watersheds for each slope position, suggesting that abiotic controlling factors mentioned previously (e.g. temperature, moisture, photodegradation) that can affect decomposition rates of C and N were similar across watershed treatments and between slope positions.

Net Nitrogen Mineralization

Net ammonification occurred during winter for all watershed treatments except for the age-zero intercropped treatment, and was followed by immobilization within all watershed treatments during spring. Net ammonification occurred again during summer for the mid-rotation reference and young-pine-with-understory treatments, whereas the other three watershed treatments were at near zero ammonification or slightly immobilizing ammonium. During fall of 2013, net immobilization occurred for all watershed treatments. During winter, net ammonification in the riparian position was much higher than the upslope, which was near zero.

Net nitrification occurred during winter for the young-pine-with-understory, mid-rotation reference, and switchgrass-only treatments, and net immobilization occurred in the two intercropped sites. The mid-rotation reference and switchgrass-only treatments immobilized N during spring. Then net nitrification occurred for all watershed treatments during the summer, and decreased to nearly zero in fall of 2013. Net nitrification patterns for riparian and upslope positions across all watersheds followed a similar pattern and differed only in summer, where the riparian position had higher net nitrification.

When net ammonification and net nitrification were combined, total net N mineralization showed similar patterns for the young-pine-with-understory, the switchgrass-only, and the mid-rotation reference treatments—increased mineralization in winter, immobilization in spring (except for the young-pine-with-understory), increased mineralization in summer and immobilization in fall of 2013. The thinned-intercropped treatment changed from slightly mineralizing in the fall of 2012 along a slow and nearly steady decrease throughout the year to slightly immobilizing in the fall of 2013. The age-zero intercropped treatment immobilized throughout winter and spring, then increased to near zero net immobilization in summer, and back to immobilization in the fall of 2013. Net N mineralization was much higher in the riparian position than in the upslope position during winter and slightly higher in the fall.

Net ammonification, nitrification, and N mineralization values were quite variable both seasonally and when seasons were combined for an annual monthly mean among the five watershed treatments in this study, as well as within slope positions within a given watershed treatment. Such variability has been observed in previous studies (e.g. Peterjohn 1999; Gilliam *et al*., 2005) and may be attributed to heterogeneity in substrate qualities (Burger and Pritchett, 1984; Gilliam *et al*., 2005) soil moisture (Gonclaves and Carlyle, 1994; Groffman *et al*., 1996) soil temperature (Gonclaves and Carlyle, 1994; Evans *et al*., 2011) and other micro-climatic fluctuations (Burger and Pritchett, 1984; Khanna, 1994). Another explanation for this variability may be the amount and type of vegetative cover, including tree size. This has been shown to account for more than 40% of variation in soil solution NO_3-N (Kohlpaintner *et al*., 2009), which is strongly related to soil inorganic N. Increased net nitrification can result from soil disturbance, increasing soil moisture with minimal plant uptake, along with increasing temperatures with added exposure to sunlight (Ritter and Versterdal, 2006). For this study, in areas of recent (<1 year) soil disturbance, I generally did not make this observation. Rather I observed higher annual net nitrification rates in the two treatments with the least recent disturbance (young-pine-with-understory and mid-rotation reference treatments).

Positive correlation has been shown to exist between total soil C or N content and N mineralization rate (Connell *et al*., 1995), but change in total C or N content is likely to be a much less sensitive indicator of change than change in N mineralization rates (Raison and Rab, 2001). Connell *et al*. (1995) found total P, along with C:N ratios and percentage of sand, silt, and clay, to be poorly correlated with N mineralization both spatially and temporally in Australian forest soils. C:N ratios have to be below 20 to 25 to obtain appreciable N mineralization (Harmsen and Kolenbrander, 1965), but one drawback of this idea is that certain organic fractions are relatively recalcitrant, thus explaining observed poor correlations between C:N ratios and net mineralization (Lamb, 1975). One consistent pattern observed in the *in situ* sequential core net N mineralization portion of this study was that on average, riparian positions had higher net ammonification, nitrification, and total N mineralization than in upslope positions, across all watershed treatments. Gilliam *et al*. (2005) also observed a similar pattern in a study conducted in the Fernow Experimental Forest in West Virginia. However, we observed a high degree of variability in correlations between these variables in this study. Our correlations between each of these major variables (soil total C, soil total N, soil C:N, soil P) and annual net ammonification, nitrification, and N mineralization were relatively weak with high variability, which is in agreement with a study by Burger and Pritchett (1984) where C:N ratios do not suggest a difference in N availability in clear-cut and site-prepared areas. Variation in the range of soil C:N values was small in my study, which likely resulted in poor model strength and insignificant R^2 values when evaluating association between C:N and net N ammonification, nitrification, and mineralization.

Anaerobic Nitrogen Mineralization Potential

Anaerobic N mineralization potential values did not significantly correlate ($p=0.65$) with *in situ* annual net N mineralization values in my study. Scott *et al*. (2005) also found similar results, where anaerobic incubation was not useful for estimating mineralizable N in either agricultural field soils or cutover pine soils, which is comparable to watershed treatments in this study. Rather, that study found that a 3-day incubation of rewetted soils was highly correlated to mineralizable N ($p<0.0001$, $r^2=0.88$). Furthermore, data from my study show no significant differences in anaerobic N mineralization potential among treatments with the exception of the thinned-intercropped treatment, which had higher anaerobic N mineralization potential. Arrobas *et al*. (2012) showed that soil inorganic N (as an index) can have high variability over time. The anaerobic N mineralization data measured in my study reflect a point-in-time sampling event (September 2013) and may not be fully representative of effects of these watershed treatments on a per annual basis.

Chapter 5 - Conclusions

The overall outcome of this study is that treatment and slope position effects were less evident than expected and no consistent treatment or slope position effects on measured soil properties and processes were observed. Consequently, based on these results, there is no consistent evidence of treatment effects or slope position effects on soil properties and processes that I assessed. A lack of consistent treatment effects in upslope positions also precluded evaluation of the role of riparian buffers to mediate treatment effects on soil properties and processes. Whether observed differences in soil properties, forest floor characteristics, or C and N dynamics are a result of the experimental treatments or simply an intrinsic difference is inconclusive. This may be due to the early nature of the study in that consistent treatment effects that support my hypotheses have yet to be incorporated into soil properties to a degree that my sampling scheme can detect them. Additionally, my sampling intensity may have been insufficient to detect consistent treatments effects if they exist. More intensive temporal and spatial sampling may be necessary to detect consistent responses of soil properties and processes along the hillslope-riparian continuum as affected by cellulosic biofuel treatments. Nonetheless, this study began at the onset of establishment of these experimental watershed treatments and provides a baseline of data for treatment assessment in the future.

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Appendix A - Correlations of Soil Properties and C and N Dynamics

Table 29. Correlation coeffecients for soil properties at 0-15cm and forest floor properties with soil C and N dynamics in the upslope position.

Upslope	Variable	***k***	**N mineralization**	**AN-N**
Soil 0-15cm	Bulk Density	-0.09	-0.14	0.09
	% Sand	-0.31	0.51	0.31
	% Silt	0.49	-0.53	-0.09
	% Clay	-0.07	0.14	-0.37
	Total C	0.10	-0.28	-0.38
	Total N	0.12	-0.35	-0.35
	C:N	-0.21	0.36	0.02
	pH	0.06	-0.28	-0.02
	bpH	-0.41	0.44	0.13
	P	-0.19	0.20	0.12
	K	0.57	-0.50	-0.27
	Ca	0.38	-0.56	-0.40
	Mg	0.51	-0.59	-0.21
	Mn	-0.05	0.15	-0.08
	Fe	-0.18	0.13	-0.23
	CEC	0.44	-0.55	-0.23
	AN-N	-0.07	0.06	1.00
Forest Floor	Mass	-0.29	-0.07	-0.26
	Total C	-0.14	0.06	0.08
	Total N	-0.04	0.06	0.17
	C:N	-0.19	0.10	0.25

Table 30. Correlation coeffecients for soil properties at 0-15cm and forest floor properties with soil C and N dynamics in the riparian position.

Riparian	Variable	*k*	N mineralization	AN-N
Soil 0-15cm	Bulk Density	-0.10	0.05	-0.24
	% Sand	0.10	-0.15	-0.06
	% Silt	-0.20	-0.08	0.02
	% Clay	-0.05	0.20	0.08
	Total C	-0.08	0.17	0.26
	Total N	-0.05	0.15	0.31
	C:N	-0.02	0.14	-0.29
	pH	0.19	-0.07	-0.16
	bpH	0.26	0.07	-0.07
	P	-0.25	0.36	0.23
	K	-0.04	0.16	-0.12
	Ca	0.06	-0.17	-0.13
	Mg	-0.02	-0.26	-0.08
	Mn	-0.65	0.05	0.02
	Fe	0.08	0.33	0.11
	CEC	-0.17	-0.18	-0.05
	AN-N	0.04	-0.08	1.00
Forest Floor	Mass	-0.37	0.03	-0.37
	Total C	-0.44	0.02	0.25
	Total N	-0.19	0.20	0.19
	C:N	-0.11	-0.18	0.02