# Landscape Design Field Tour
# March 4th, 2014
# New Bern, NC


**Weyerhaeuser Company**

**Timberlands Technology Sustainability Research**

Jami Nettles, Ph.D.

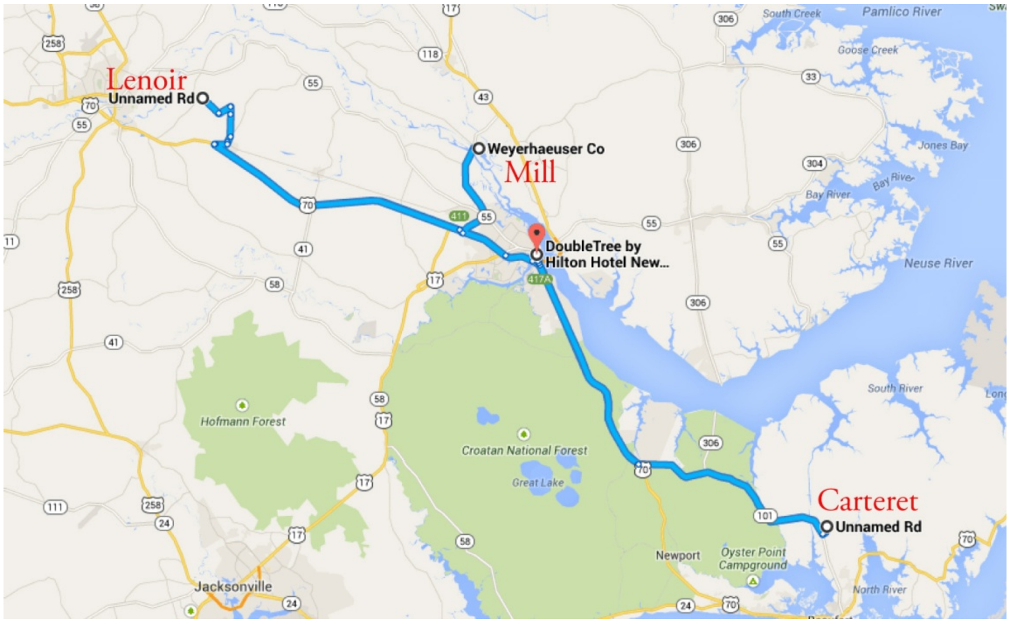
Zakiya Leggett, Ph.D.

Jessica Homyack, Ph.D., CWB®

## Agenda

| | | | |
|---|---|---|---|
| 8:00 – 8:15 | Doubletree, New Bern | Welcome, safety overview | Andres Villegas, Catchlight Energy, LLC<br>Aaron Welch, Weyerhaeuser Co. |
| 8:15 – 9:00 | Travel to Lenoir Research Site | | |
| 9:00 – 10:20 | Lenoir Research Site | Overview of environmental and bioenergy research (5) | Jami Nettles, Weyerhaeuser Co. |
| | | Lenoir site, soil, and carbon research (10) | Zakiya Leggett, Weyerhaeuser Co. |
| | | Biodiversity and biomass harvesting guidelines research (25) | Jessica Homyack, Weyerhaeuser Co. |
| | | Soil moisture, water and groundwater results (10) | Julian Cacho, NC State University |
| | | Productivity and water use (10) | John King, NC State University |
| 10:20 – 11:20 | Travel to Weyerhaeuser mill | | |
| 11:20 – 1:40 | Weyerhaeuser mill and lunch | Tour of sawmill | Jason Watters, Weyerhaeuser Co. |
| | | Planning and logistics | Billy Tucker, Weyerhaeuser Co. |
| | | Wood products | Gail Johnson, Weyerhaeuser Co. |
| 1:40 – 2:40 | Travel to Carteret Research Site | | |
| 2:40 – 4:00 | Carteret Research Site | History of research at Carteret (5) | Chip Chescheir, NC State University |
| | | Carteret site and instrumentation (10) | Cliff Tyson, Weyerhaeuser Co. |
| | | Results from silviculture and bioenergy research (10) | Devendra Amatya, US Forest Service |
| | | Nutrient results (10) | Francois Birgand, NC State University |
| | | Modeling (10) | Shiying Tian, NC State University |
| | | Harvest site (10) | Eric Sucre, Weyerhaeuser Co. |
| 4:00 – 5:00 | Return to Doubletree | | |

# Table of Contents




## Introduction:

While site costs and characteristics dominate land use decisions, the physiography of eastern North Carolina lends itself to productive agriculture and forestry, with sites easily transitioning from one to the other and sometimes back again. This makes the region a prime place to look for flexible biomass solutions with few constraints from topography and topology. This tour will focus on forestry, but within the context of a landscape composed of not just forestry, but also agriculture and growing coastal communities.

The goal of the tour is to examine the life cycle of sustainable forest products, including understanding sustainability through collaborative research, operational implementation, and production of certified wood products. We will visit several sites and hear multiple speakers discuss our sustainability research and cover the supply chain – from growth to final product.

## Themes:

- Landscape design – optimizing land acquisition, planning, management, and use for productivity and sustainability;
- Research - understanding and communicating the ecological effects of our current and potential practices;
- Sustainability indicators – participating in public discussions on sustainability by using our research to inform potential standard metrics;
- Certification – assuring accountability by certifying our products to the Sustainable Forestry Initiative™.

## Landscape design:

Plantation forestry in the southeastern U.S. is a study in landscape design. Optimizing productivity, intensity, location, and site layout has led to a system that now produces over 4 times more volume per acre at harvest than in 1940 (Fig. 1), while maintaining much of the ecological value present in unmanaged forests.

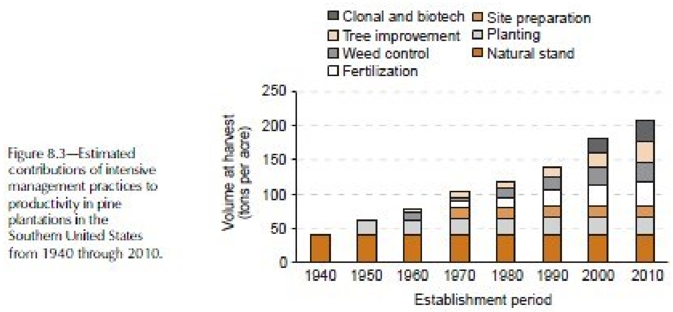



**Figure 1. Fox et al., 2004**

The increasing intensity of operations and return in productivity shown in Fig. 1 means much less land is required to produce a given harvest volume, both at a landscape level and within operational tracts. Our environmental management approach identifies and focuses conservation measures on those portions of the landscape with highest ecological value and sensitivity to management. At a regional scale, our management produces a distribution of habitat types across the landscape.

Several options are available for sensitive areas or locations of special concern. In the southeast, Weyerhaeuser manages these tracts with two internal programs:

- Special Places –sites with threatened or endangered plants or animals or other ecologically important features, unusual or unique geological formations, or features of cultural or historical significance to the surrounding community or population at large.
- Forests of Exceptional Conservation Value –plant or animal communities that are deemed G1 (global) or S1 (state) critically imperiled or G2/S2 imperiled, which occur in known and viable populations meriting protection. These sites are identified through the Natural Heritage organizations in the respective state in which they occur.

The process used for protection can include internal and external experts, and outcomes include a wide range of alternatives including special management plans, conservation easements, and joint management with ENGOs.

At the stand scale, we protect riparian systems and take measures to conserve and, in some cases, enhance wildlife habitat. In the southeastern U.S., site layouts are managed by compliance with Best Management Practices (BMPs). Areas are set aside for riparian buffers, channel migration zones, and unstable slopes. Fig. 2, a pine and switchgrass intercropped site in Alabama, shows the complexity of site layouts. Silvicultural riparian buffers are visible along streams, and the yellow lines delineate the operational areas for biomass planting. These additional boundaries were determined by operators during site preparation for the next rotation, which in this case included a biomass crop, to minimize erosion.

**Figure 2**

However, efficiency is now critical for the carbon life cycle sustainability of biomass feedstock. Extremely wide or sinuous ecological buffers could increase fuel usage to a negative carbon balance, more intense practices could decrease usage but reduce biodiversity. Understanding the trade-offs requires knowledge of productivity, ecology, operations, and economics beyond what has been required for traditional silviculture, with new research into each area.

## Research:

Weyerhaeuser has a long history of silviculture-related environmental, tree improvement, and forest productivity research. The environmental research is open, non-proprietary, and collaborative. Our field research includes plant to watershed scale research, with modeling used to extrapolate to even larger scales.

The sustainable biomass platform is built on and extends the silvicultural research. Initiated by Catchlight Energy, LLC, a Chevron|Weyerhaeuser joint venture, the research has expanded to include many cooperators and multiple funding sources. The study consists of sustainability, life-cycle analysis, soil productivity, biodiversity, and water resource components. The biomass studies were initiated in 2009, based on production methods that are still subject to technical, economic, and regulatory uncertainties, so were selected to not only represent the best available knowledge, but also span a range of sites, slopes, and management intensities.

### Lenoir:

These are 0.8 ha field plots used to quantify efffects of intercropping stands on hydrology and water quality, soil nitrogen dynamics, soil physical and hydraulic properties, carbon dynamics, and response of wildlife communities (reptiles, amphibians, and small mammals) (Fig.4). The site has deep, poorly drained, moderately permeable soils and is artificially drained with ditches approximately every 100m. The study is a complete randomized block design with 4 replicates of the following treatments:

- Pine silviculture, high value timber regime, with residuals left on site
- Pine silviculture, high value timber regime, with residuals removed
- Pine-switchgrass intercropped with residuals left on site
- Pine-switchgrass intercropped with residuals removed
- Pine intercropped with flat-planted pine with residuals left on site
- Pine intercropped with flat-planted pine with residuals removed
- Switchgrass only

Switchgrass was mowed after the first growing season and has been mowed and baled in every following year. Further site information can be found in Leggett and Sucre, 2012.

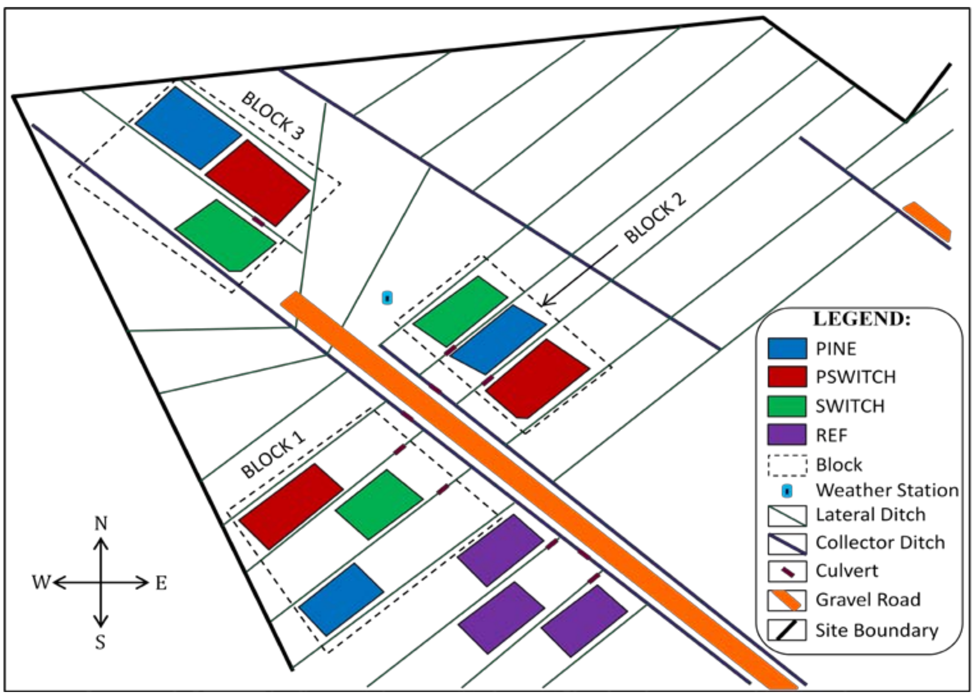



**Figure 3. Lenoir site layout**

### Carteret:

Carteret is part of a larger watershed study across the southeastern US (Fig. 4). Each study site includes at least four small, operational-scale sub-watersheds that are instrumented to provide data on precipitation stream discharge, weather, groundwater table and water quality. The Carteret sites are flat and have a shallow water table. Each is around 25 ha and is artificially drained, with ditches approximately 100m apart. (Fig. 5) Further site information can be found in Amatya et al., 1996.

The treatments are:

- Mid-rotation pine plantation
- Pine silviculture, high value timber regime
- Pine silviculture, high value timber regime, interplanted with switchgrass
- Pine and switchgrass interplanted at the same time (Age Zero)
- Switchgrass

Carteret does not have the Age Zero treatment.

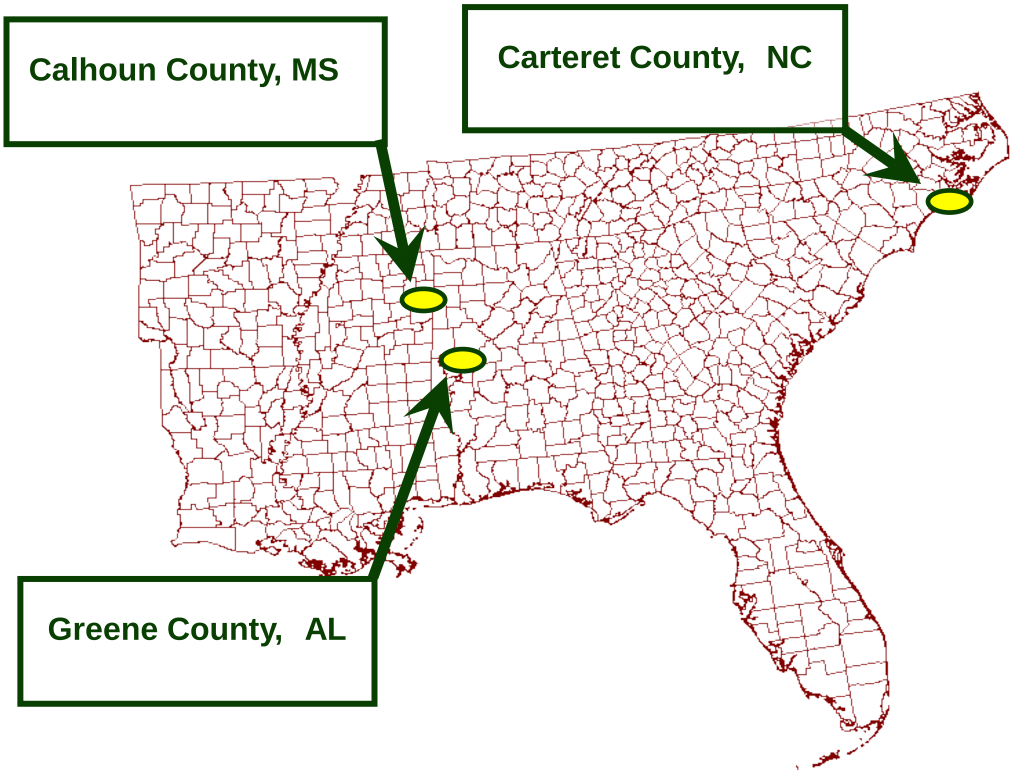



**Figure 4. Watershed studies**

Carteret is unique because of its history as a research watershed. With over 20 years of cooperative research and 160+ publications, models and data from Carteret studies provide insight into the interactions between trees, water volume, and water quality in poorly drained forests. As a silvicultural cycle ended, the biomass treatments were installed. This continuity give a rich data set for both silviculture and biomass research.

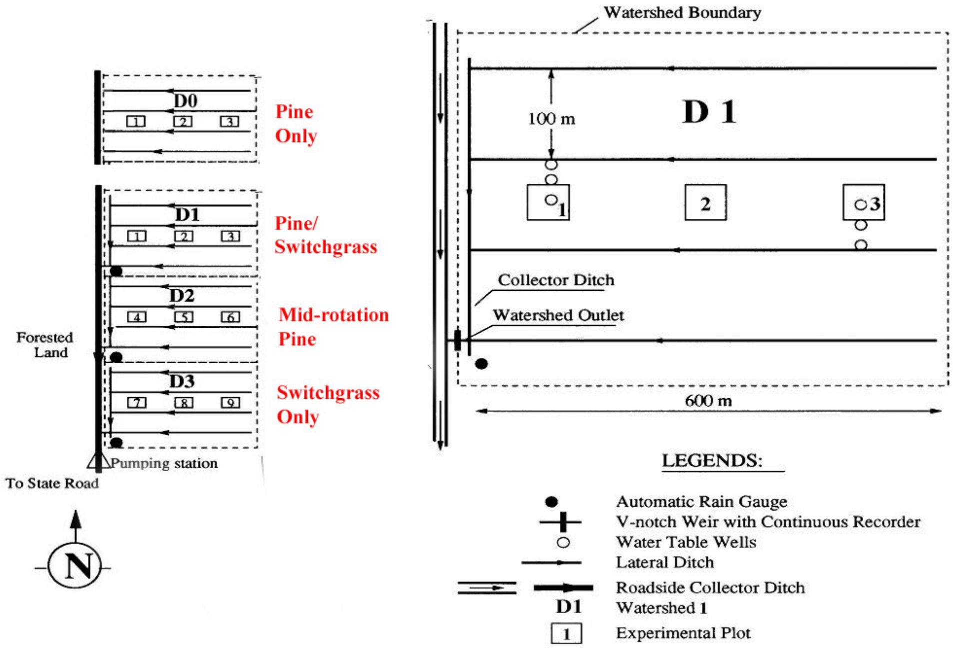



**Figure 5. Carteret site layout**

## Sustainability indicators:

Our research addresses a wide range of environmental and productivity topics, targeted by site and practice. The following are environmental (Table 1) and social sustainability (Table 2) indicators proposed for bioenergy.

| Category | Indicator | Units |
|---|---|---|
| Soil quality | 1. Total organic carbon | Mg/ha |
| | 2. Total nitrogen (N) | Mg/ha |
| | 3. Extractable phosphorus (P) | Mg/ha |
| | 4. Bulk density | g/cm3 |
| Water quality and quantity | 5. Nitrate concentration | mg/L |
| | Nitrate export | kg/ha/year |
| | 6. Total phosphorus (P) concentration | mg/L |
| | Total phosphorus (P) export | kg/ha/year |
| | 7. Suspended sediment concentration | mg/L |
| | Suspended sediment export | kg/ha/year |
| | 8. Herbicide concentration | mg/L |
| | Herbicide export | kg/ha/year |
| | 9. Peak storm flow | L/s |
| | 10. Minimum base flow | L/s |
| | 11. Consumptive water use - field | m3 /ha/day; |
| | Consumptive water use - biorefinery | m3 /day |

| | | |
|---|---|---|
| Greenhouse gases | 12. CO2 equivalent emissions (CO2 and N2 O) | kg Ceq /GJ |
| Biodiversity | 13. Presence of taxa of special concern | Presence |
| | 14. Habitat area of taxa of special concern | ha |
| Air quality | 15. Tropospheric ozone | ppb |
| | 16. Carbon monoxide | ppm |
| | 17. Total particulate matter less than 2.5 µm dia | µg/m3 |
| | 18. Total particulate matter less than 10 µm dia | µg/m3 |
| Productivity | 19. Aboveground net primary productivity (ANPP)/yield | g C/m2 /year |

**Table 1. Environmental Sustainability Indicators, McBride et al., 2011**

| Category | Indicator | Units |
|---|---|---|
| Social well- being | Employment | Number of full time equivalent (FTE) jobsa |
| | Household income | Dollars per day |
| | Work days lost due to injury | Average number of work days lost |
| | Food security | Percent change in food price volatilityb |
| Energy security | Energy security premium | Dollars per gallon of biofuel |
| | Fuel price volatility | Standard deviation of monthly percent price changes over one year |
| External trade | Terms of trade | Ratio (price of exports/price of imports) |
| | Trade volume | Dollars (net exports or balance of payments) |
| Profitability | Return on investment(ROI) | Percent (net investment/initial investment) |
| | Net present value (NPV)c,d | Dollars (present value of benefits minus present value of costs) |
| Resource conservation | Depletion of non-renewable energy resources | Amount of petroleum extracted per year (MT) |
| | Fossil Energy Return on Investment (fossil EROI) | Ratio of amount of fossil energy inputs to amount of useful energy output (MJ) (adjusted for energy quality) |
| Social acceptability | Public opinion | Percent favorable opinion |

| | | |
|---|---|---|
| | Transparency | Percent of indicators for which timely and relevant performance data are reported |
| | Effective stakeholder participation | Percent of documented responses addressing stakeholder concerns and suggestions, reported on an annual basis |
| | Risk of catastrophe | Annual probability of catastrophic event |

**Table 2. Social Sustainability Indicators, Dale et al., 2013**

The water quality and quantity indicators are parameters that we address. However, understanding each indicator requires a lengthy and expensive research-level investigation and modeling effort. Calculating effect of biofuel practices across different settings at this level of detail will require sophisticated models and good vegetation, soils, and weather data.

Each speaker on the tour will address one key aspect of this process.

### Certification:

Weyerhaeuser has had an environmental policy for over 40 years. Our environmental performance is critical to:

- Meeting regulatory and certification obligations
- Retaining customers
- Maintaining our "public license to operate"

Our environmental management system is third-party certified

- Sustainable Forestry Initiative (SFI) in the U.S. and Canada
- Forest Stewardship Council (FSC) in Uruguay

## Summary:

Bioenergy solutions are likely to come from diverse sources . Weyerhaeuser and Catchlight Energy, working with collaborators included on the tour and others cited in the bibliography, are pleased to show you the research that will help guide us and others to sustainable solutions. In addition, the overview of the product supply chain from planning through final product should give an insight into the system used to optimize forest products.

Amatya, D.M., Skaggs, R., Gregory, J., 1996. Effects of controlled drainage on the hydrology of drained pine plantations in the North Carolina coastal plain. J. Hydrol. 181, 211–232.

Dale, V.H., Efroymson, R.A., Kline, K.L., Langholtz, M.H., Leiby, P.N., Oladosu, G.A., Davis, M.R., Downing, M.E., Hilliard, M.R., 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures. Ecol. Indic. 26, 87–102.

Fox, T.R., Jokela, E.J., Allen, H.L., 2004. The evolution of pine plantation silviculture in the southern United States. South. For. Sci. Past Present Future Gen Tech Rept SRS-75 Asheville NC USDA For. Serv. South. Res. Stn.

Leggett, Z.H., Sucre, E.B., 2012. Evaluating the impact of switchgrass intercropping in loblolly pine plantations on long-term soil productivity. Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA. Paper 4.9., in: Proceedings from Sun Grant National Conference. Presented at the : Science for Biomass Feedstock Production and Utilization, New Orleans, LA.

McBride, A.C., Dale, V.H., Baskaran, L.M., Downing, M.E., Eaton, L.M., Efroymson, R.A., Garten Jr, C.T., Kline, K.L., Jager, H.I., Mulholland, P.J., 2011. Indicators to support environmental sustainability of bioenergy systems. Ecol. Indic. 11, 1277–1289.

## Field tour

**Overview of research platform – silviculture and bioenergy**, **Jami Nettles, Weyerhaeuser Co.**


# OUR FORESTS PROVIDE MORE THAN TIMBER

**19,543**
Bee box leases provided from our timberlands in Uruguay and the western U.S.

Annually, we measure and report on **18 ecosystem services** provided by our timberlands.

**3.5**
Million acres of timberland included in formal habitat management agreements



## KEY TIMBERLAND STATISTICS

| | |
|---|---|
| Area owned or managed | 20.8 million acres |
| Seedlings planted in 2012 | 63 million |
| Percentage of land harvested in 2012 | |
| Canada | 0.1% |
| United States – West | 1.7% |
| United States – South | 3.3% |
| Uruguay | 5.8% |
| Area harvested in 2012 | 205,112 acres |
| Replanted within two years (US and Canada) | 99% |
| Harvested land replanted or naturally regenerated | 100% |

## Environmental Research Strategy

- **Conducted with a wide range of collaborators**
- **Open and non-proprietary**
- **Peer reviewed**
- **External advisors**
- **Multiple funding sources**
- **Integrates with public and proprietary research, such as growth and yield models**
- **Results are used to continuously improve practices**

## Sustainability Research – Biomass

**Designed to understand options compatible with a high value timber regime**

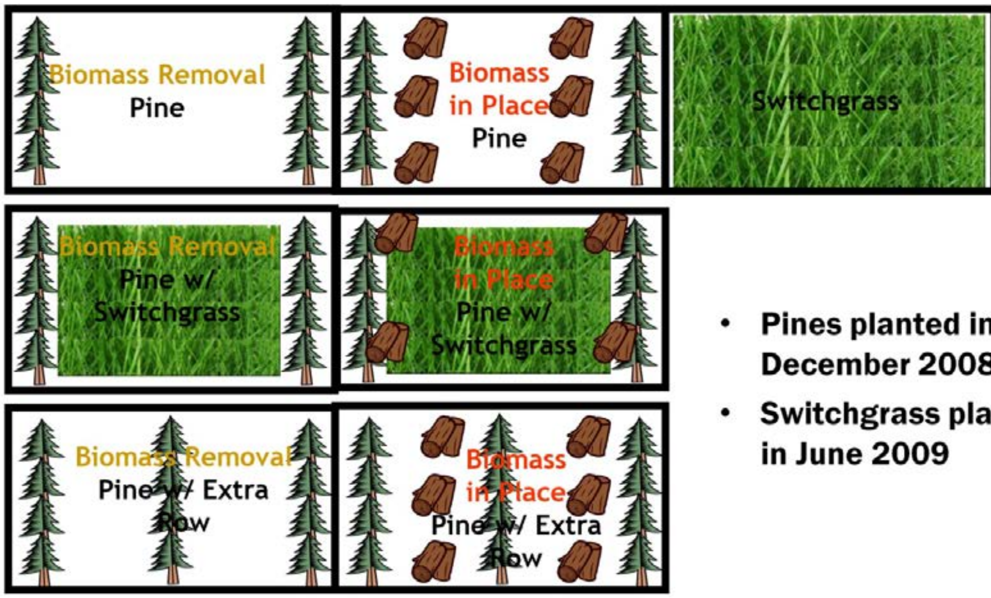
- **Harvest residual removal**
- **Natural understory harvest**
- **Planted understory harvest – non-crop trees**
- **Interplanted dedicated energy crop**

**Consists of**

- **Biodiversity**
- **Carbon Life Cycle Analysis**
- **Hydrology**
- **Soil Productivity/Sustainability**

**Lenoir site characteristics and history, soil and carbon research, Zakiya Leggett, Weyerhaeuser Co.**

# LENOIR 1 TREATMENTS




- **Pines planted in December 2008**
- **Switchgrass planted in June 2009**

3

3

# JUSTIFICATION/QUESTIONS

- **Is it feasible to establish and maintain a dedicated crop in pine plantations?**
- **What happens with multiple entries of harvesting equipment for the dedicated crop?**
- **How much soil nitrogen, phosphorus, calcium, etc. are required to maintain both species?**
- **Are we having an effect on soil carbon sequestration and storage?**
- **Are there negative effects on pine tree productivity with the introduction of another species being purposely grown in the interbed region?**

4

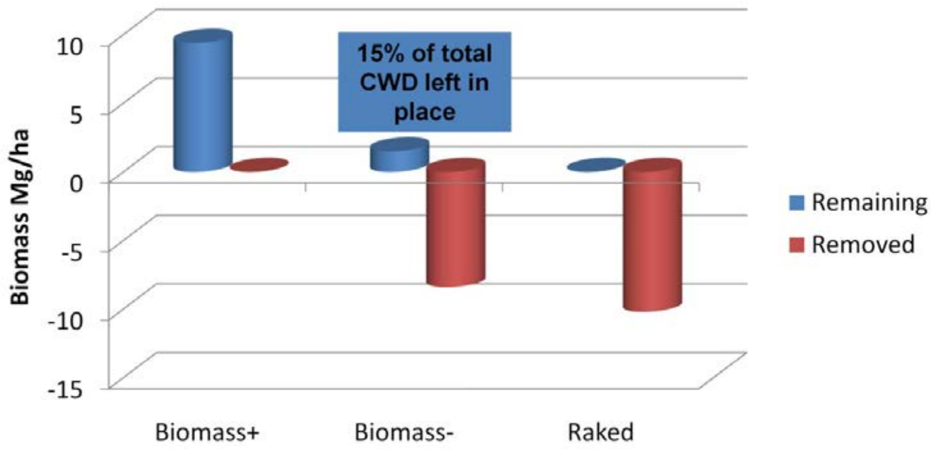
# RESEARCH PROJECTS

| Project | Cooperator | Status |
|---|---|---|
| Baseline soil assessment for Lenoir 1 | Virginia Tech. Univ. | Completed |
| Coarse woody debris assessment for Lenoir 1 | Duke Univ. | Study completed; manuscript in preparation |
| Evaluate impact of multiple entries associated with heavy vehicle traffic required to harvest and maintain an annual biomass crop | Internal | Data collection each year |
| Aboveground productivity assessment for Lenoir 1 | Internal | Data collection each year |
| Soil carbon and nutrient cycling assessment for Lenoir 1 | Virginia Tech. Univ. | Study completed; manuscript submitted |
| Microbial community structure and function for Lenoir 1 (3 projects) | Yale, Roanoke, Virginia Tech. Univ. | Study completed; thesis published and manuscript submitted |
| Estimation of biomass and net primary productivity at Lenoir 1 | USFS | Data collection each year |

# PROJECT STATUS

| Project | Cooperator | Status |
|---|---|---|
| Water cycling and plant ecophysiology study | North Carolina State Univ. | Study completed; manuscript in preparation |
| Greenhouse gas fluxes for Lenoir 1 | Virginia Tech. Univ. | Study completed; thesis published |
| Impacts of managing loblolly pine plantations with miscanthus intercropping for biofuel production on site productivity and sustainability | North Carolina State Univ. | Data collection each year; thesis published and manuscript in preparation |
| Shading effects on productivity of miscanthus and switchgrass | North Carolina State Univ. | Thesis published and manuscript submitted |
| Pine-switchgrass productivity and characteristics across sites and silvicultural treatments | NCASI, Louisiana State Univ., Mississippi State Univ. | Project completed; manuscript submitted |

# COARSE WOODY DEBRIS




8

# NUTRIENT CYCLING

**Justification:**

- **It is unknown how the intercropping of switchgrass will affect soil nutrient cycling and/or storage.**

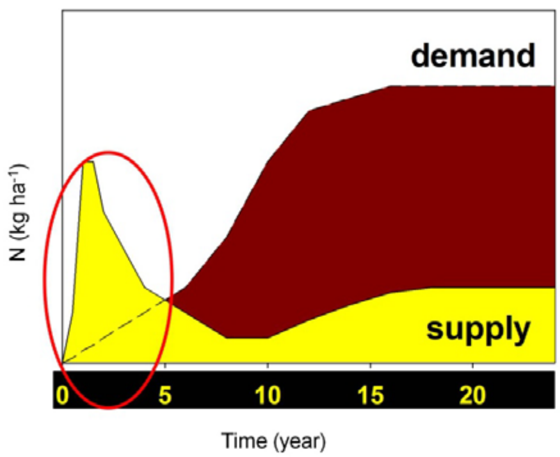
**Status/Key Results:**

- **Two manuscripts are planned for submission this year.**
- **Intercropped treatments had lowest soil nitrogen and the greatest microbial biomass.**

9

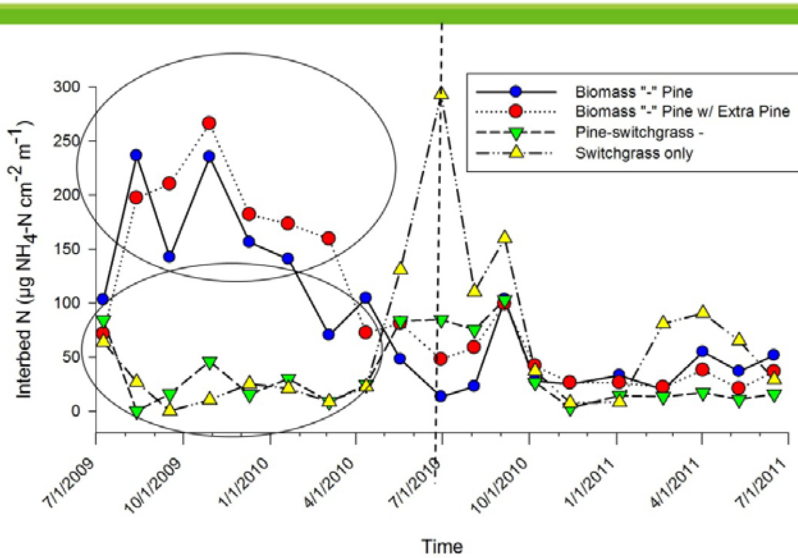
# POST-HARVEST N-DYNAMICS: ASSART EFFECT

TRADITIONAL PATTERN




10

# SWITCHGRASS UTILIZING SOIL N




- Clear assart period for non-switchgrass treatments
- Switchgrass reduced soil $NH_4^+$ and $NO_3^-$ in 2009
- Switchgrass fertilization increased available $NH_4^+$

11

# CARBON CYCLING AND STORAGE

**Justification:**

- **It is possible that switchgrass could increase soil carbon storage and create another "ecosystem service" in addition to being a feedstock for bioenergy.**

**Status/Key Results:**

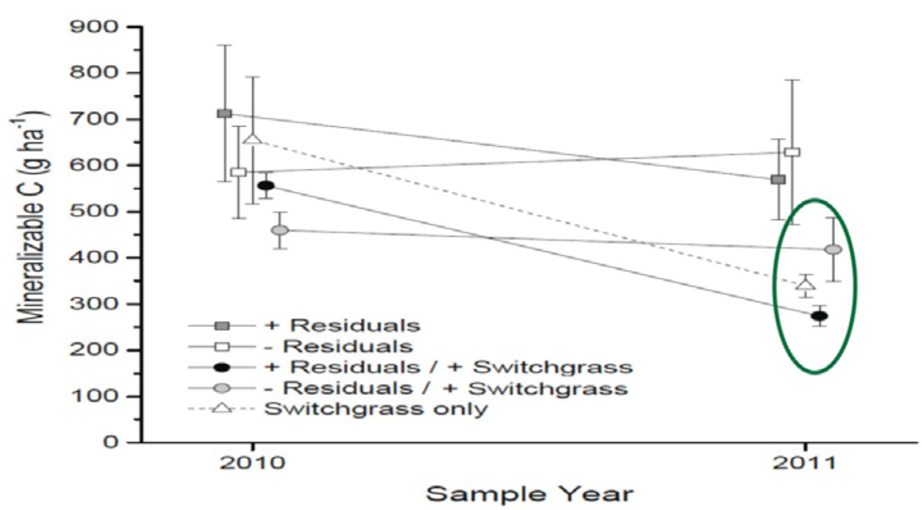
- **A manuscript was recently submitted for publication.**
- **Early in the rotation switchgrass "primed" the soil microbes and lead to lower soil carbon for those treatments.**

VirginiaTech

Yale UNIVERSITY

12

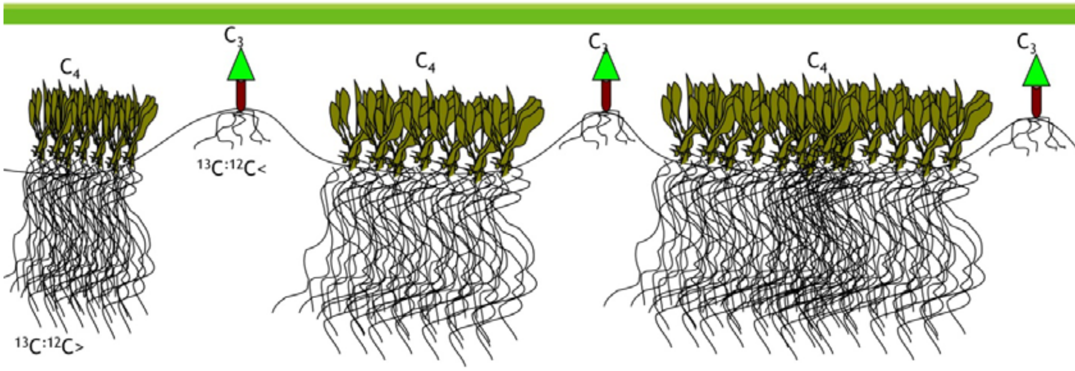
# LOWER SOIL CARBON IN SWITCHGRASS TREATMENTS




**Higher respiration rates *(data not shown)* lead to lower soil carbon.**

13

# $^{13}C$ SOIL SAMPLING PROJECT




- Initial soil samples collected (2009) to have baseline information. In 2012, more soil samples were collected and will be analyzed to partition the total C pool into switchgrass- or pine-derived organic matter.
- This study will assist in determining the contribution of switchgrass to carbon storage on the site.

14

# ROOT DYNAMICS

**Justification:**

•It is not clear how the pine and switchgrass roots interact as far as productivity and carbon dynamics.

•This will help us answer questions raised by other projects.

**Status:**

- A collaborative study is proposed by several cooperators to investigate root dynamics.

15

# SOIL COMPACTION STUDY




16

# SOIL COMPACTION STUDY

**Objective :**

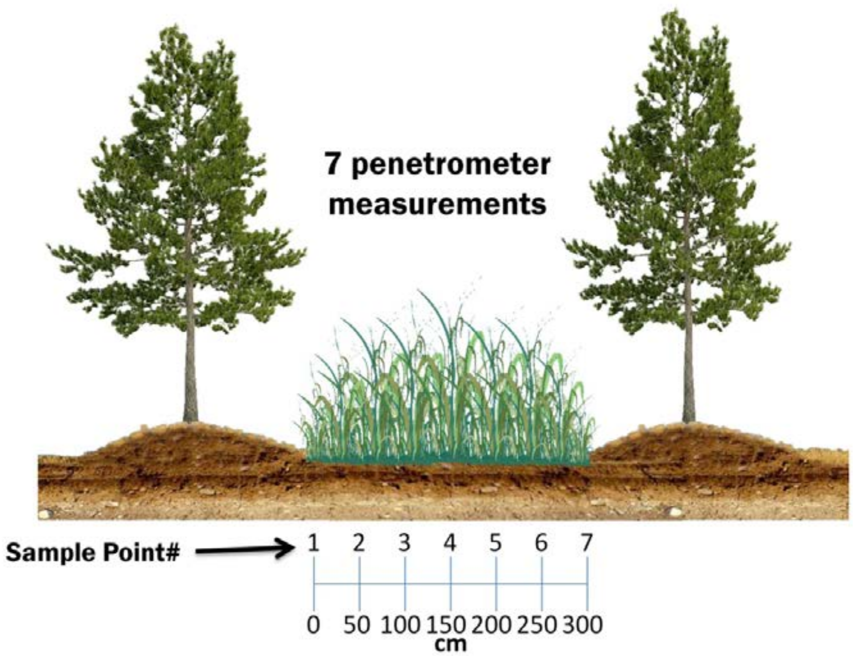
- **Evaluate potential impacts of multiple entries associated with annual harvests of switchgrass.**

**Status/Key Results:**

- **A manuscript is planned for submission this year.**
- **Slight increase in compaction in surface 15cm after 2nd year of harvest.**
- **Study design revised for 3rd year sampling.**

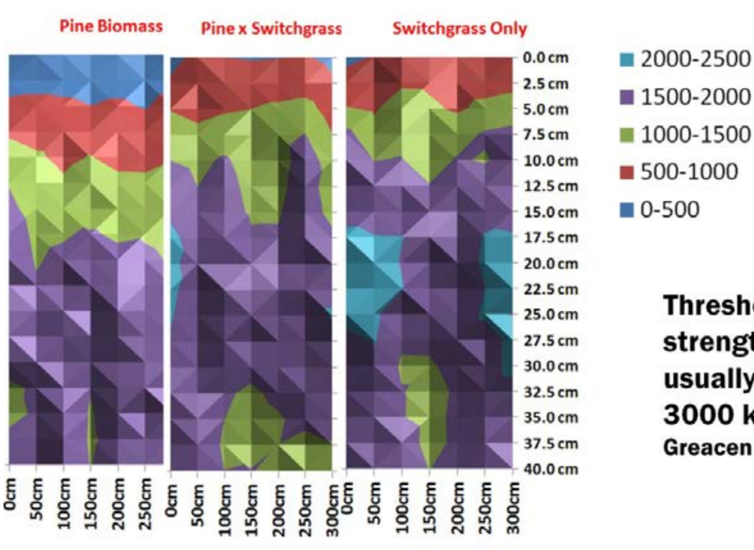
17

# SOIL COMPACTION STUDY




18

# SOIL COMPACTION STUDY – AFTER 3RD YR




**Threshold level at which soil strength hinders plant growth usually ranges from 2000-3000 kPa (Taylor and Brar 1991, Greacen and Sands 1980).**

19

# MISCANTHUS INTERCROPPING

**Objective :**

- **Evaluate potential impacts of intercropping with miscanthus on soil nutrient and carbon cycling and storage.**

**Status:**

- **Planning for new graduate student for August 2014.**

Biofuels Center of North Carolina



# FINANCIAL SUPPORTERS

- **Catchlight Energy, LLC**
- **Biofuels Center of North Carolina**
- **NCASI (National Council for Air and Stream Improvement)**
- **University Partners (9)**
- **US Department of Agriculture – National Institute of Food and Agriculture (AFRI-Sustainable Bioenergy)**
- **US Department of Energy**

## KEY TAKE HOME MESSAGES

- **No red flags**
  - Some research topics need further investigation (i.e. understanding root dynamics)
- **Work is proceeding as planned**
- **Monitoring of soil compaction and soil carbon needs to continue**
- **Switchgrass and pine beginning to interact – we are at the exciting point in time!**

22

## WHAT DO WE NEED TO KNOW

- **What are the interactions between the pine and switchgrass roots?**
- **Will the "priming" effect of the switchgrass continue in the next few years?**
  - How does this affect overall carbon sequestration and storage?
- **How long will the switchgrass persist before being shaded out by the pine trees?**

23

**Biodiversity Responses to Biofuel Feedstock Production, Jessica Homyack, Weyerhaeuser Co**

# BIODIVERSITY RESPONSES TO BIOFUEL FEEDSTOCK PRODUCTION

Jessica A. Homyack
Southern Wildlife Program Leader
Weyerhaeuser Company

2/24/2014

## STRUCTURE

1. Background and justification
2. Study metrics
3. Lenoir 1 biodiversity research
4. Kemper County biodiversity research
5. Weyerhaeuser biomass research
6. Conclusions

2 | 2/24/2014

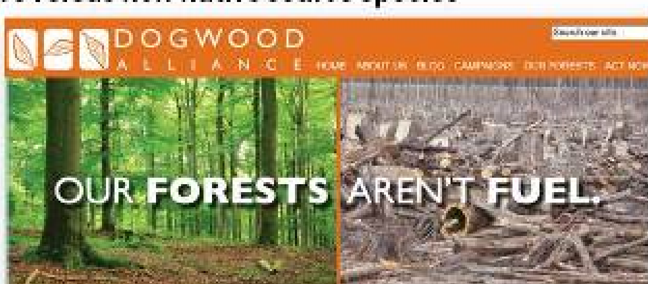
## THE RESEARCH NEED

- **Policies without Scientific Support**
  - **State Biomass Harvesting Guidelines**
  - **Concerns from Environmental NGOs**
  - **Participate in the Science that Shapes Policy**
- **Public License to Operate**
- **Mega-petitions for Endangered Species**
- **Knowledge Gap**



## KEY CONCERNS

- **Intensification of intensive pine management**
- **Simplification of forest structure**
  - Understory vegetation with intercropping
  - Removal of downed woody debris
- **Intercropped feedstocks**
  - Timing of harvesting and nesting habitat
  - Barrier to movements for dispersing animals
  - Native versus non-native source species



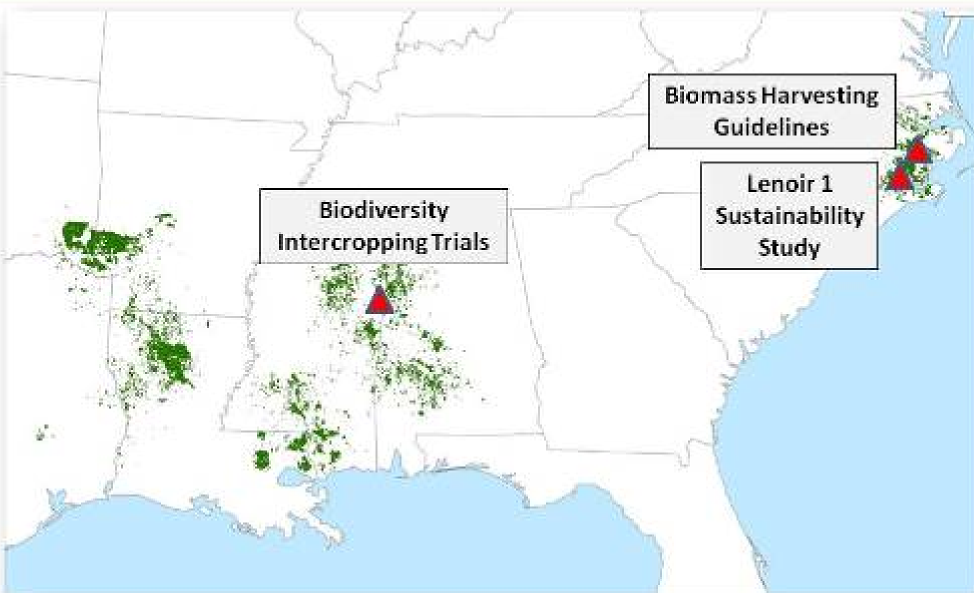
# OUR PARTNERS ARE KEY

- Financial Leveraging
- Credibility of Research
- Policy Influence
- Communication of Message

UNCG
Catchlight Energy
ncasi
MISSISSIPPI STATE UNIVERSITY
NC STATE UNIVERSITY
Biofuels Center of North Carolina
www.biofuelscenter.org

5 | 2/24/2014

# A PLATFORM THAT SPANS THE SOUTH




6 | 2/24/2014

# STUDY METRICS

- **Taxa**
  - Small mammals
  - Herpetofauna
  - Birds
  - Vegetation structure
- **Richness and diversity**
- **Population performance**
  - Survival
  - Home range size
  - Reproduction



# BIOFUELS RESEARCH SITES

# LENOIR 1 BIODIVERSITY RESEARCH

What are the effects of intercropping switchgrass and biomass harvesting on:

1. Rodent abundance, diversity, performance
2. Relationship between native and non-native mice
3. Ecological roles of rodents
4. Amphibian & reptile abundance and diversity

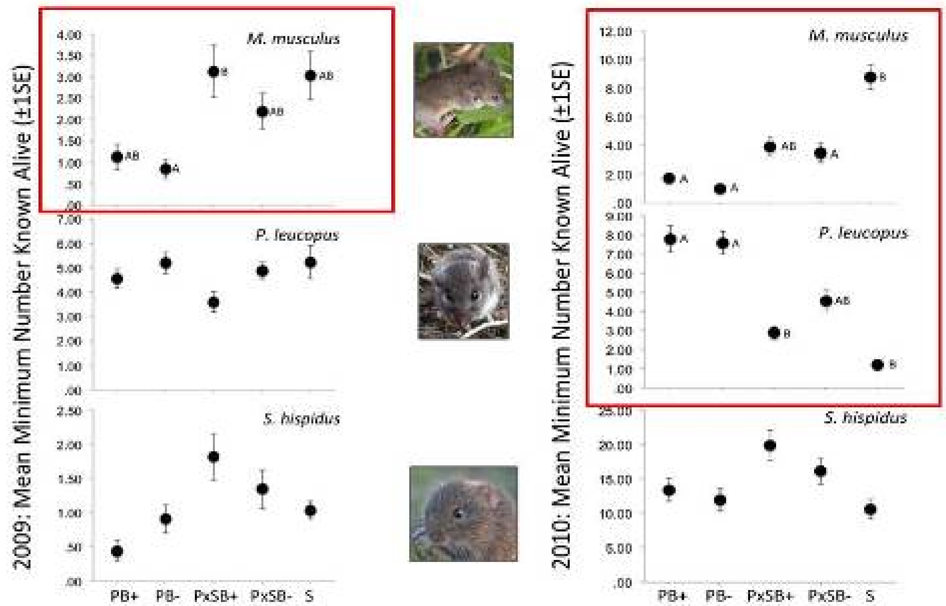
9 | 2/24/2014

# MARK-RECAPTURE OF RODENTS

All photos by K. King

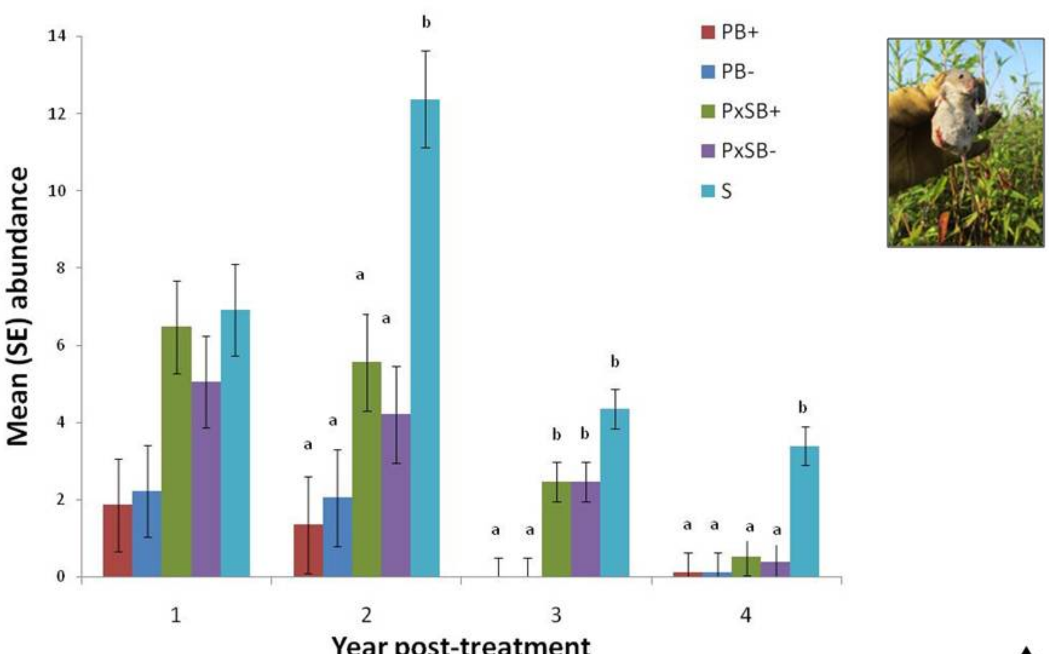
10 | 2/24/2014

## *MUS* ASSOCIATES WITH SWITCHGRASS TREATMENTS



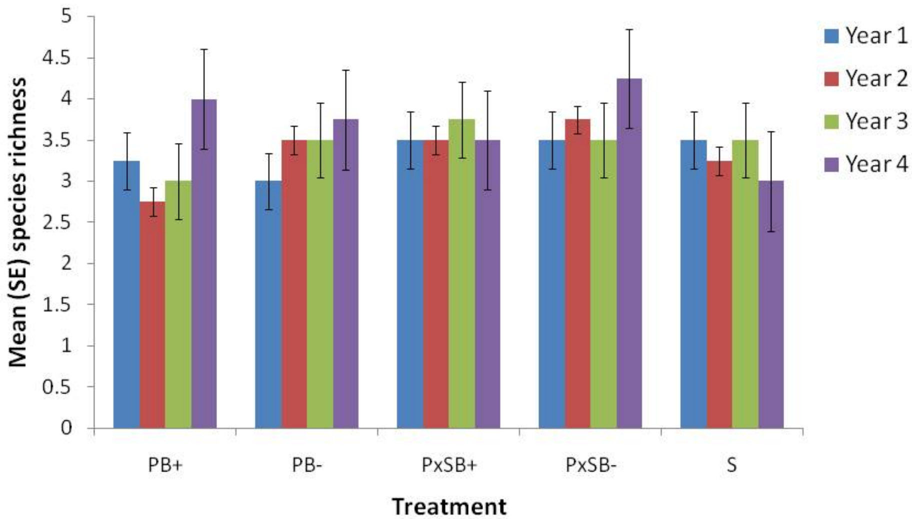

Marshall et al 2012

## DOES *MUS* STILL ASSOCIATE WITH SWITCHGRASS?




Homyack et al. In review

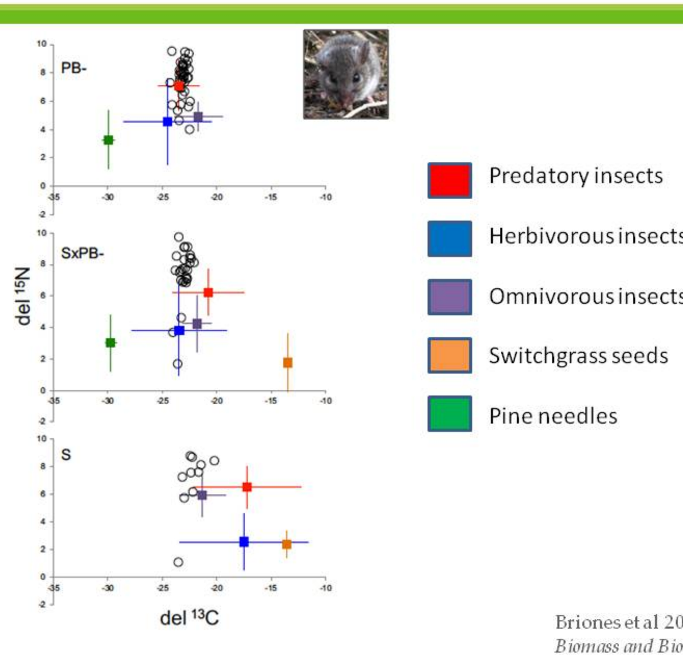
## 4-YEAR RODENT DIVERSITY TRENDS




Homyack et al. In review



## INTERCROPPING DOES NOT CHANGE THE FUNCTIONAL ROLES OF NATIVE RODENTS




Briones et al 2013, *Biomass and Bioenergy*

# DISCUSSION: LENOIR 1 RODENTS

- **<u>Harvesting woody biomass</u> – had little to no detectable effects on rodents at multiple spatial scales**
- **<u>Intercropping switchgrass</u> – species-specific responses to switchgrass**
- **<u>Rodent community</u> – changes through time with succession**
- **<u>Functional role</u> – trophic position and carbon source of native rodent unchanged with intercropping**

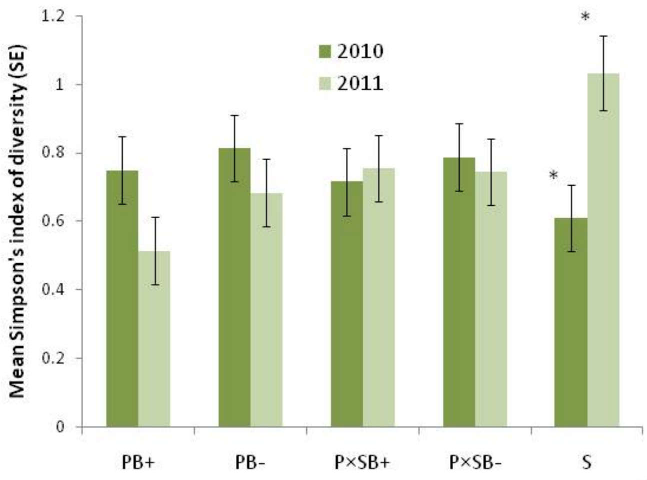


# HERPETOFAUNAL RESPONSES


- Calculated estimates of:
  - Richness
  - Diversity Indices
  - Relative Abundance of Common Species
  - Detection
  - 2010 and 2011

# ANOVA & PLANNED CONTRASTS

- **Very Few Treatment Effects**
  - **Southern Toads in intercropped > switchgrass only**
  - **Simpson's index, Treatment x Time, P = 0.008**




*Homyack et al.* 2013,
Wildlife Society Bulletin



# DISCUSSION: LENOIR 1 HERPETOFAUNA

- No response to removal of 85% of woody debris to 2.5 years post-treatment
- No effects from switchgrass intercropping
- Some effects of switchgrass monoculture
- No "red flags" for short-term effects of biofuels production from intensive forestry

*Weaker relationship between herpetofauna and woody debris in coastal plain?*

*Homyack et al.* 2013,
Wildlife Society Bulletin

# KEMPER COUNTY BIODIVERSITY

- **Broad-scale study with 2 components**
  1. Comparison of established intercropped stands with established pine stands
  2. Biodiversity study plots established 2012
     - 5 Replicates with 3 current treatments (control, intercropped, switchgrass)
     - 25 acre plot sizes, forested matrix
- **Biodiversity Metrics**
  1. Vegetation structure and biomass
  2. Avian diversity and reproduction
  3. Rodent abundance, diversity, behavior

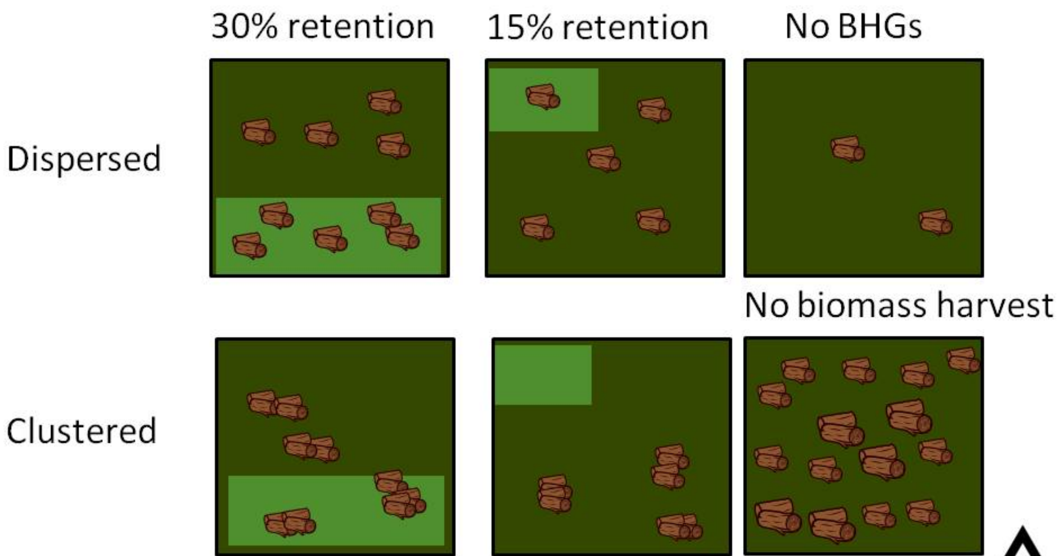


# VEGETATION STRUCTURE & DIVERSITY

- **Stand structure characterized**
  – Green trees and snags reduced with intercropping
  – DWD similar in intercropped & non-intercropped stands
  – DWD absent from switchgrass monocultures
- **Plant community**
  – Intercropping initially increased coverage, richness of forbs
  – At 2 years, horizontal cover similar
  – Deer forage lower in intercropped vs. pine stands by year 2

Loman et al. 2013, IJFR
Iglay et al. 2012, Sun Grant Proceedings
Wheat, unpublished.

## BIOMASS HARVESTING GUIDELINES RESEARCH IN NORTH CAROLINA AND GEORGIA






## BIODIVERSITY RESPONSES

- **Field work and analyses on-going**
- **Nearing end of study**
- **Preliminary results:**
  - **Few negative responses of species richness to treatments**
  - **Only eastern narrowmouth toad abundance associated with DWM in 2 years in GA, not in NC**

## WHAT WE KNOW

- Harvesting of residual woody biomass <u>initially</u> has few effects on small vertebrates
- Initial effects of intercropping switchgrass is often similar to pine forest or intermediate between pine and switchgrass only
- Species-specific responses to changes in vegetation structure associated with biofuels production



## WHAT DO WE NEED TO KNOW

- Does intercropping extend the period of abundant herbaceous understory vegetation associated with open canopy pine plantations?
- Will effects of residual woody biomass harvesting intensify as debris decays and becomes limited?
- Can we scale-up stand-level data to the landscape scale?
- What are the effects of landscape composition and spatial scale on diversity and abundance of wildlife in intercropped systems?
- Does the intercropped feedstock matter? Are effects from other perennial grasses or fast-growing woody crops similar to those from switchgrass?

## Soil moisture, water and groundwater results, Julian Cacho, NC State University

### Introduction

Water resources worldwide are under stress even at present water demands (Vörösmarty et al., 2000). The current condition is predicted to intensify in the coming decades as demands for fresh water increase due to population growth and increasing demand for food and bioenergy. Providing food for 9.2 billion by 2050 (UN Secretariat, 2006) is expected to increase agricultural water use, which at present accounts for about 86% of freshwater use around the world (Hoekstra and Chapagain, 2007; Hoekstra and Chapagain, 2008). Increased urbanization and suburban growth as well as intensive industrial activities particularly in developed countries will also require water resource allocation. Rapidly expanding global production of biofuel is putting additional pressure on already constrained freshwater resources. Large-scale bioenergy production has the potential to supply large quantities of $CO_2$ neutral energy in the future (Lemus and Lal, 2005); however, its effects on fresh water availability are still uncertain and thereby need to be investigated. The main objective of this section is to discuss the impacts of loblolly pine-switchgrass intercropping on soil water content, shallow groundwater table, and shallow groundwater quality. Additionally, the effects of the proposed land use on soil physical properties and soil nitrogen availability will be discussed.

### Materials and Methods

Experimental treatments for this study are shown in Fig. 3 of the introductory material (p. 7). They include traditional pine (PINE), pine-switchgrass intercropped (PSWITCH), switchgrass only (SWITCH), and a 38-year old loblolly pine stand (REF). Each treatment is replicated three times on 0.8 ha plots drained by parallel ditches that are 1.0 to 1.2 m deep and 100-m apart.

The effect of the proposed land use on the soil water distribution within the vadoze zone was studied using a hand-held soil moisture probe AP 827 (AquaPro) to measure relative saturation ($S_r$) at least once a week from June 30, 2011 to January 15, 2013 at six depths (15, 22.5, 30, 45, 60, and 75 cm) from ground surface (g. s.) across three locations in each plot including middle, quarter point, and near the ditch. At each location, the $S_r$ was measured near a tree (NT), between two trees on the same bed (BT), between two trees of two adjacent beds (B2T), and in the middle of four trees of two adjacent beds (M4T). NT and BT were grouped as “BED,” while B2T and

M4T were lumped together as "INTERBED." The effect of the proposed land use on shallow groundwater dynamics was studied by measuring and recording the water table depth ($d_{gw}$) using U20 HOBO water logger (Onset Computer Corp.) on a 15-minute interval from September 10, 2009 to January 15, 2013. The loggers were placed in a 5.08 cm (I.D.) polyvinyl chloride (PVC) pipes installed approximately 2.4 m from the g. s.

The impact of pine-switchgrass intercropping on shallow groundwater quality was determined by collecting shallow groundwater samples from groundwater sampling wells located in the middle of the plot and near the ditch. At each location, three wells were spaced at approximately 1 m and were installed at three depths: 0.75-1.0 m, 1.25-1.5 m and 1.75-2.0 m. Water samples were collected monthly or more frequently after fertilizer application (depending on rainfall events) from fall of 2009 to fall of 2012 in PSWITCH, PINE, and SWITCH, and from winter of 2011 to fall of 2012 in REF and were analyzed for total Kjeldahl nitrogen (TKN), ammonium nitrogen ($NH_4^+$ - N), nitrate + nitrite nitrogen ($NO_3^-$ + $NO_2^-$ - N), orthophosphate phosphorus (OP), total organic carbon (TOC).

The effects of pine-switchgrass intercropping on soil physical properties, including bulk density, total porosity, saturated hydraulic conductivity, soil water characteristic, and drainable porosity, were investigated by collecting intact soil cores (7.62 x 7.62 cm) during the third harvesting operation (December 2011) from three random points within each plot and at three depths per sampling point: 0-15, 15-30, and 30-45 cm. In PSWITCH, intact soil cores were collected before and after harvest from the center of the interbed and at the portion of the interbed that is likely traversed by the equipment. In PINE and REF, intact soil cores were only collected once at the MIDDLE after post-harvest soil core collection from PSWITCH. Standard procedures were used to measure and calculate soil the soil physical properties. Lastly, the effect of the proposed land use on soil N availability, assessed in terms of net mineralization and net nitrification rates, was investigated using both field and laboratory measurements. Sequential in-situ incubation technique was used to field measure net mineralization and net nitrification for the top 20 cm soil layer. Four and five field measurements were done in 2011 and 2012, respectively. Laboratory measurement was done by incubating soil samples at optimum conditions and measuring net mineralization and nitrification potential after one, two, eight, and thirteen weeks of incubation.

**Summary of Results and Conclusions**

Intercropping did not significantly affect the soil water distribution in the vadoze zone nor did it affect shallow water table fluctuation. SWITCH had consistently shallower water table among the treatments throughout the study period. This observed trend supports the hypothesis that loblolly pine trees and the understory vegetation have higher evapotranspiration than switchgrass due to their higher leaf area indices and deeper rooting system. Shallow groundwater quality was not significantly affected by intercropping. Nutrient (especially $NO_3^- + NO_2^-$ - N) concentrations were elevated within two years (2009-2010) of tree harvest and plot establishment, but reverted back to background levels as early as the third year (2011) relative to REF. The spike in nutrient concentrations during the first two years after establishment is a typical response of poorly drained forest soils (Shepard, 1994) and can be attributed to a suite of factors including assart effect (Kimmins, 1987), pre-plant fertilizer application, and low nutrient plant uptake.

Soil physical properties were significantly affected at the top layer. The results indicate that the initial site preparation for switchgrass planting has a larger impact on soil physical properties than annual harvesting operations. Soil N availability was not significantly affected by the intercropping. Laboratory results suggest that litter quality differences did not significantly affect net N mineralization and nitrification rates. Field data indicate that PSWITCH and SWITCH tend to confine soil mineral N in ammonium form relative to PINE. This has a positive implication on water quality as ammonium is less mobile in the soil than nitrate, while maintaining productivity since the overall soil N availability was not significantly affected.

**References:**

Hoekstra, A. Y., & Chapagain, A. K. (2007). Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resources Management, 21*(1), 35-48.

Hoekstra, A. Y., & Chapagain, A. K. (2008). Globalization of water: Sharing the planet's freshwater resources. Blackwell Publishing, Oxford, U.K.

Kimmins, J. P. (1987). *Forest ecology.* New York, NY: MacMillan Publishing Co.

Lemus, R., & Lal, R. (2005). Bioenergy crops and carbon sequestration. *Critical Reviews in Plant Sciences, 24*(1), 1-21.

Shepard, J. P. (1994). Effects of forest management on surface water quality in wetland forests. *Wetlands, 14*(1), 18-26.

United Nations Secretariat. (2006). World population prospects: The 2006 revision. New York, N.Y., USA.

Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: Vulnerability from climate change and population growth. *Science, 289*(5477), 284-288.

## **Loblolly pine-switchgrass intercropping for sustainable timber and biofuels production in the southeastern United States,** John King, NC State University

*Investigators*: J King, JC Domec, Z Leggett, E Sucre, K Johnsen, C Maier, J Stape, J Seiler, B Strahm, T Fox

*Collaborating institutions*: North Carolina State University, Virginia Tech University, USDA Forest Service, Weyerhaeuser NR Company, Catchlight Energy LLC

*Funding*: Weyerhaeuser NR Company, Catchlight Energy LLC, USDA NIFA Sustainable Bioenergy Program (NIFA/AFRI 2011-67009-20089)

*Rationale*: Diversifying the nation's energy portfolio with pine-switchgrass intercropping may yield economic and environmental benefits

- Economic:
  - Convert the cost of herbaceous competition control to a revenue stream
  - Resulting biomass amenable to a variety of products: energy, hay, etc.
  - Promote diversified industries associated with pine plantations
- Environmental:
  - Enhanced landscape scale C storage in soils
  - Displacement of fossil energy $CO_2$ emissions
  - Increased resource use efficiencies: water and nutrients
  - Enhancement of biodiversity

*Hypotheses*:

- Asynchronous physiology of $C_3$ trees/$C_4$ grass = greater temporal capture of site resources
- Exploitation of different soil layers = greater spatial capture of site resources (SWG shallow, pine deep)
- Higher utilizable biomass yield per unit water transpired = greater WUE
- Higher utilizable biomass yield per unit N uptake = greater NUE
- Soil organic carbon (SOC) will increase from enhanced litter inputs (chiefly, SWG fine root production and turnover)

*Methods:*

- Field operations (Leggett, Sucre –WeyCo)
    - Covered by others on tour

- Biomass and NPP*(USDA FS – Johnsen & Maier; WY – Sucre & Leggett)*
    - Trees
        - Monthly height and diameter measurement all trees
        - Annual destructive harvest subset of trees for allometric equations
        - Some soil coring for roots
    - Switchgrass
        - Establishment year: monthly quantification of tiller number, H, LAI, biomass in 1 $m^2$ quadrats
        - All years: end of year harvest/baling/green weight scaling
        - Some soil coring for roots in cooperation with SOC studies

- Soil quality, GHG emissions, nutrient cycling (VA Tech – Strahm, Seiler & Fox; NCSU – Stape; WY – Sucre & Leggett)
    - Six week campaigns for SOC, microbial biomass, organic acids
    - Field/ lab ammonification/nitrification rates
    - Soil respiration
    - Isotopic analyses of SOC fractions

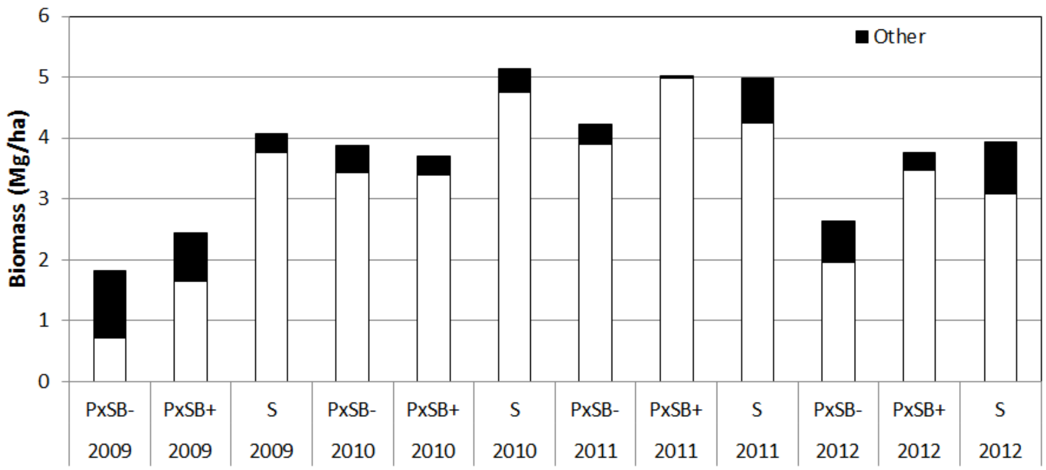
- Soil-plant water relations *(NCSU – Albaugh, Domec, King; WY – Sucre & Leggett)* *(Drainage modeling Youssef & Tian (NCSU))*
    - Leaf-level physiology of grass and trees
    - On site meteorology
    - Groundwater table depth (WTD) monitoring
    - Granier style sapflow sensors
    - Ecosystem models SPA (Soil-Plant-Atmosphere) and DrainMod-Forest to scale water fluxes and compute site water balance

- Federally-mandated LCA requirement for renewable fuels *(WY – Sucre & Leggett)*

*Results to date:*

**Establishment!**

**Yield!**



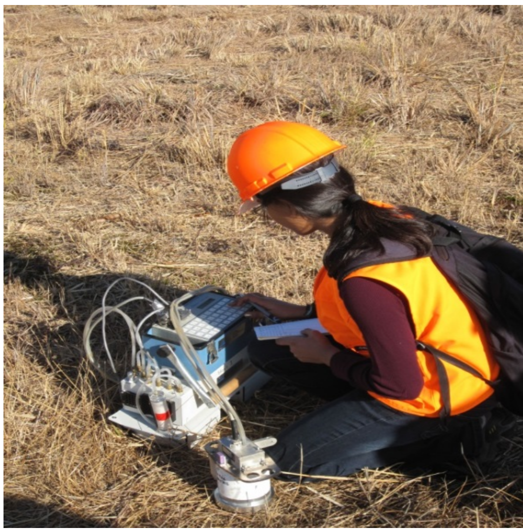

Compares to:

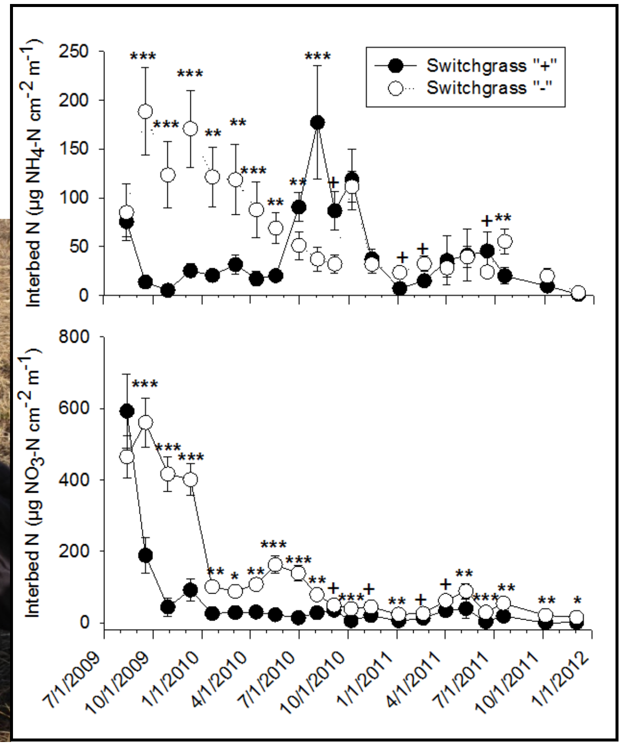
-2.2 Mg $ha^{-1}$ $y^{-1}$ Burley tobacco

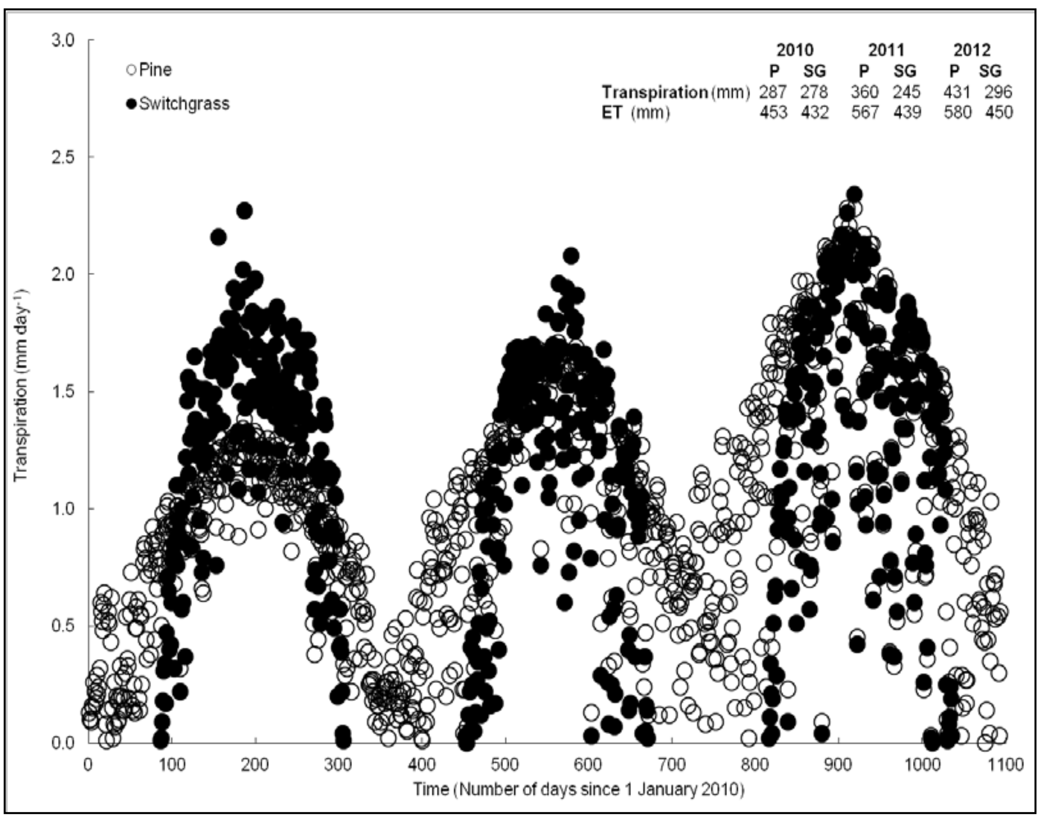
-7.1 Mg $ha^{-1}$ $y^{-1}$ hay

Only 760 ha of hay in Lenoir County, 276,000 ha hay in all of NC.

GHG and nutrient dynamics






Ecosystem estimates of water use (SPA model)

Table1. Physiology, productivity and water use of grass species considered for ligno-cellulosic bioenergy from a summary of the literature. Adapted from King et al. (2013).

| Taxa | Avg Ps (umol $m^{-2}$ $s^{-1}$) | Avg gs (mmol $m^{-2}$ $s^{-1}$) | Avg WUEi£ (µmol $mmol^{-1}$) | $\delta^{13}C$ | Avg ANPP (Mg $ha^{-1}$ $y^{-1}$) | Avg Stand ET (mm $y^{-1}$) | Avg Stand WUE* (kg $mm^{-1}$) | Bioenergy WUE ** (MJ $m^{-3}$) | Avg MAT (°C) | Avg MAP (mm) | MAP/AET # (mm) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Warm-season (C4) | | | | | | | |
| *Miscanthus* | 26.0 | 220 | 0.118 | - | 21.7 | 537 | 29.8 | 54.7 | 17.2 | 493 | 0.9 | A |
| *Panicum v.* | 17.5 | 210 | 0.083 | -13.5 | 10.1 | 457 | 22.8 | 42.2 | 20.1 | 461 | 1.0 | B |
| *Pennisetum* | 20.2 | 296 | 0.068 | - | 12.4 | 495 | 27.5 | 44.3 | 9.1 | 424 | 0.8 | C |
| *Spartina* | 18.4 | 227 | 0.081 | -13.0 | 10.6 | - | - | - | 13.0 | 775 | - | D |
| | | | | | Cool-season (C3) | | | | | | | |
| *Arundo* | 22.8 | 180 | 0.126 | -26.2 | 25.6 | 632 | 40.5 | 71.2 | 16.5 | 859 | 1.3 | E |
| *Phalaris a.* | 10.3 | 200 | 0.051 | - | 8.4 | 708 | 19.6 | 34.5 | 9.9 | 693 | 1.0 | F |
| *Phragmites* sp. | 15.2 | 235 | 0.064 | - | 10.1 | 800 | 12.6 | 23.7 | 11.1 | 812 | 1.0 | G |
| HD mixed praire | 17.1 | 455 | 0.037 | -28.0 | 4.6 | 488 | 9.5 | 16.7 | 13.4 | 859 | 1.7 | H |

## Results from this study suggest mean SWG:

Ps - 28 *u*mol $m^{-2}$ $s^{-1}$

gs – 196 mmol $m^{-2}$ $s^{-1}$

$WUE_i$ – 0.14 *u*mol $mmol^{-1}$

ANPP – 4.1 Mg $ha^{-1}$ $y^{-1}$

Stand WUE – 15.1 kg $mm^{-1}$

Bioenergy WUE – 27.9 MJ $m^{-3}$

*Project outputs to date*:
Students/Theses

- Nichols, L.K. 2013. *Soil CO2 Efflux, Dissolved Organic Carbon, Root Exudates and Microbial Community Dynamics in a Loblolly Pine and Switchgrass Intercropped System Located on the North Carolina Coastal Plain*. MS Thesis, Department of Forest Resources and Environmental Conservation, Virginia Tech University

- Shrestha, P. 2013. *Greenhouse Gas Fluxes And Root Productivity In A Switchgrass (Panicum virgatum L.) And Loblolly Pine (Pinus taeda L.) Intercropping System*. MS

Thesis, Department of Forest Resources and Environmental Conservation, Virginia Tech University

- Approximately 15 undergraduate students (5 per year) gain first-hand research experience as technicians

Publications

- Albaugh J, Domec J-C, Maier C, Sucre E, Leggett Z, King J. 2014. Gas exchange and stand-level estimates of water use and gross primary productivity in an experimental pine and switchgrass intercrop forestry system on the Lower Coastal Plain of North Carolina, U.S.A. *Ag For Meteorol*, in review.
- Albaugh J, Albaugh T, Heiderman R, Leggett Z, Stape J, King K, O'Neill P, King J. 2014. Effect of shading on switchgrass physiology, above- and belowground biomass and light-use efficiency. *Biomass and Bioenergy*, in review.
- King JS, Ceulemans R, Albaugh JM, Dillen SY, Domec J-C, Fichot R, Fischer M, Leggett Z, Sucre E, Trnka M, Zenone T. 2013. The challenge of ligno-cellulosic bioenergy in a water-limited world. *BioScience* 63:102-117.
- Albaugh JM, King JS, Sucre EB, Leggett ZH, Domec J-C. 2012. Establishment success of switchgrass in an intercropped forestry system on the Lower Coastal Plain of North Carolina, U.S.A. *Biomass and Bioenergy* 46: 673-682.

Presentations

- King J, Albaugh JM, Domec J-C, Leggett Z, Sucre E, Johnsen K, Maier C, Stape J, Seiler J, Strahm B, Fox T (2013) Loblolly pine-switchgrass intercropping for sustainable timber and biofuels production in the southeastern United States. USDA NIFA AFRI Sustainable Bioenergy Annual Investigators Meeting, Association for the Advancement of Industrial Crops Annual Meeting, Washington D.C., 12-16 October.
- Albaugh JM, Albaugh TJ, Heiderman RR, Leggett Z, Stape JL, King K, O'Neill KP, King JS (2013) Effect of shading on switchgrass physiology, above- and belowground biomass and light-use efficiency. USDA NIFA AFRI Sustainable Bioenergy Annual Investigators Meeting, Association for the Advancement of Industrial Crops Annual Meeting, Washington D.C., 12-16 October.
- Minick, K.J., B. Strahm, T. Fox, E. Sucre, Z. Leggett. Linking Soil Carbon and Microbially Mediated Nitrogen Transformations in a Southern Loblolly Pine Forest. 12th North American Forest Soils Conference, Whitefish, MT. June 16-20, 2013.

- Shrestha, P., J.R. Seiler, B.D. Strahm, E.B. Sucre, Z.H. Leggett. Soil CO2, CH4, and N2O fluxes in a switchgrass (Panicum virgatum L.) and loblolly pine (Pinus taeda L.) intercropping system. 17th Biennial Southern Silvicultural Research Conference, Shreveport, LA. March 4-7, 2013.
- Nichols, L.K., B.D. Strahm, T.R. Fox, J.R. Seiler, Z.H. Leggett, E.B. Sucre. The impact of low molecular weight organic acids and dissolved organic carbon on microbial biomass in a loblolly pine and switchgrass intercropped system. 17th Biennial Southern Silvicultural Research Conference, Shreveport, LA. March 4-7, 2013.
- Minick, K.J., B.D. Strahm, T.R. Fox, E.B. Sucre, Z.H. Leggett. Carbon and nitrogen dynamics in a southern loblolly pine forest managed for simultaneous wood and bioenergy production. 17th Biennial Southern Silvicultural Research Conference, Shreveport, LA. March 4-7, 2013.
- Nichols, L., B.D. Strahm, J.R. Seiler, T.R. Fox, E.B. Sucre, Z. Leggett. The impact of dissolved organic carbon on microbial biomass and activity. Weyerhaeuser Lenoir I Sustainability Study Research Meeting, New Bern, NC. November 13-14, 2012.
- Albaugh JM, Domec J-C, King JS, Maier CA, Sucre EB, Leggett ZH. Water relations and water use in a pine-switchgrass intercropping stand grown for biofuel production on the Lower Coastal Plain of North Carolina, field presentation at Lenoir 1 Intercropping Sustainability Study Research Meeting, November 13–14, 2012.
- King JS, Domec J-C, Albaugh J, Stape J, Leggett Z, Sucre E, Johnsen K, Maier C, Seiler J, Fox T, Strahm B. Pine-Switchgrass Intercropping for Sustainable Timber and Biofuels Production, poster presented at NIFA/AFRI Project Director's Meeting on Sustainable Bioenergy and Bioproducts, October 24–26, 2012, OH.
- Albaugh JM, Domec J-C, King JS, Maier CA, Sucre EB, Leggett ZH. Water relations and water use in a pine-switchgrass intercropping stand grown for biofuel production on the Lower Coastal Plain of North Carolina, field presentation at Forest Productivity Cooperative Annual Research Meeting, October 18, 2012.
- Albaugh J, Domec J-C, Maier C, Sucre E, Leggett Z, King J. Water relations and productivity in an intercropped pine-switchgrass study examining biofuel production in North Carolina, USA. Sun Grant Initiative National Conference for Biomass Feedstock Production and Utilization, New Orleans, 9–12 October, 2012.

- Albaugh J, Domec J-C, Maier C, Sucre E, Leggett Z, King J. Water relations in an intercropped pine-switchgrass study examining biofuel production in North Carolina, USA. World Bioenergy Conference, Elmia, Sweden, 29–31 May, 2012.
- Albaugh JM, Domec J-C, King JS, Maier CA, Sucre EB, Leggett ZH. Water relations and water use in a pine-switchgrass intercropping stand grown for biofuel production on the Lower Coastal Plain of North Carolina, field presentation at Lenoir 1 Intercropping Sustainability Study Research Meeting, Nov 17–18, 2011.
- King JS, Domec J-C, Albaugh J, Stape J, Leggett Z, Sucre E, Johnsen K, Maier C, Seiler J, Fox T, Strahm B. Pine-Switchgrass Intercropping for Sustainable Timber and Biofuels Production, poster presented at NIFA/AFRI Project Director's Meeting on Sustainable Bioenergy and Bioproducts, October 24–26, 2011, VA.
- Albaugh JM, King JS, Sucre EB, Leggett ZH, Domec J-C. Switchgrass establishment success and photosynthesis in an intercropped forestry system in North Carolina. 12th North American Agroforestry Conference - Agroforestry: A Profitable Land Use, Athens, GA, 4–9 June, 2011.

*Future activities*:

- Grass fine root production/turnover (2014)
    - Sequential coring to 35 cm depth
- Deep (2 m) soil processes (2014-2015)
    - Seasonal fluctuation of WTD → soil properties
    - Tree and grass root depth distributions, phenology, biochemistry
- Tree productivity estimates → total stand-level performance (2014-2016)
- Parameterize Drainmod-Forest for pine-SWG and compare to SPA (2014-2016)
    - Complete site water balance and bioenergy water use efficiency
- Soil carbon sequestration potential ($\Delta^{13}C/^{12}C$) (2014)
- Harvesting of pine 'extra row' treatment with Bio-Baler (Fall 2014)
- Cradle-to-grave LCA at end of study (2016)

## History of research at Carteret, Chip Chescheir, NC State University

The long term research study at Carteret 7 was initiated in 1986 with initial field data collection beginning in 1987 and continuous hydrologic data collection beginning in 1988. The overall objective of the study was to quantify the effects of different water management and silvicultural treatments on the hydrology and water quality of drained pine plantations in the coastal plain. The different water management practices were the timing and levels weirs that control the drainage rates from the forest watersheds. At that time, recent research had shown that controlled drainage reduced the amount of water flowing from agricultural fields as well as reducing the nitrogen export from those fields. Well managed controlled drainage could also increase crop yields. Although the amount of water and nitrogen flowing from managed forest watersheds was less than from agricultural watersheds, controlled drainage could have significant environmental and economic benefits for forest production in the coastal plains. The silvicultural treatments considered during the study were harvesting, site preparation, planting, fertilization, and thinning.

Installation of the research watersheds involved dividing a 75 ha stand into three separate 25 ha watersheds and installing riser structures with V-notch weirs to control water levels and measure water flow from the watersheds. An expensive pump station needed to be installed at the outlet of the entire research area to prevent weir submergence and insure accurate flow measurements. Water level recorders and water quality samplers were installed at each control structure to quantify flow rates and automatically collect water quality samples. A weather station was installed to measure and record rainfall, temperature, relative humidity, solar radiation, net radiation, and wind speed and direction. Other equipment and instruments were installed and used to measure water table depth, soil moisture, tree growth, leaf area index, stomatal conductance, throughfall and stem flow. The funds and logistic support for the installation of this research site was provided by Weyerhaeuser Co.

The long-term study began in 1988 with a two year calibration period to determine the characteristics of the watersheds before treatments began. Controlled drainage treatments were then implemented on watersheds D2 and D3 in 1990. One treatment (D2) was managed to promote tree growth while the other treatment (D3) was managed to minimize offsite impacts. Watershed D1 remained in free drainage as the control watershed with no management practices until 2009. In 1995, watershed D2 was harvested to study the impacts of harvesting, site preparation and regeneration on hydrology and water quality. At the same time, an orifice weir was installed on watershed D3 to study the performance of a weir with an orifice to allow low flow rates and reduce peak flow rates. The orifice weir study ended in 2001 and watershed D3 was thinned in 2002 to study the impact of thinning on hydrology and water quality.  Watersheds D2 and D3 were fertilized in 2005 and the effects of fertilization on hydrology and water quality were studied over the next two years.

The research program was extended in 2009, with support from Catchlight Energy, LLC and the US Department of Energy, due to a need to identify second generation biofuel sources from managed forests and to understand the corresponding environmental implications. The treatments were expanded to include a dedicated energy crop, switchgrass (Panicum virgatum). A fourth adjacent 25 ha watershed (D0) was added to the research site and the trees on watersheds D0, D1, and D3 were harvested in 2009.  The sites were prepared for trees, switchgrass, and intercropping switchgrass with trees.  Trees were planted in 2010 and switchgrass was planted in 2011.  The resulting treatments are:

D0 - Loblolly pine with standard forestry practice
D1 - Loblolly pine with switchgrass planted between rows.
D2 - Mid-rotation Loblolly pine reference with standard forestry practice
D3 - Switchgrass only.

Much of the equipment and instrumentation was updated in 2010 to continue accurate monitoring of the hydrology and water quality of the watersheds and to document the impacts of the different treatments.  Similar treatments were installed on more upland sites in Mississippi and Alabama to determine the hydrology and water quality impacts of interplanting switchgrass with loblolly pine over a range of topographies and climates in the southeastern US.

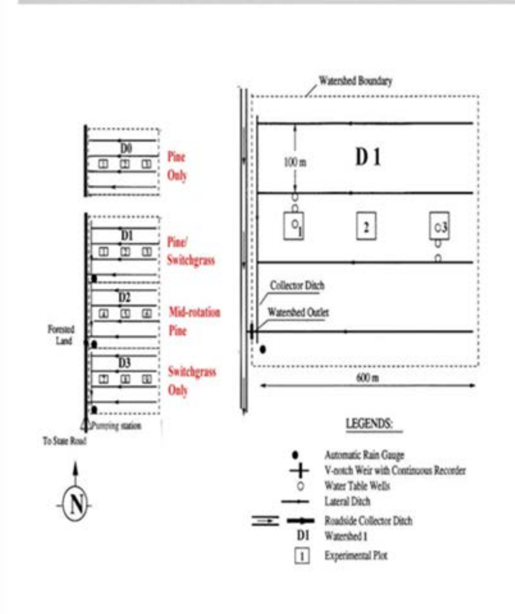
A very important part of the Carteret research effort has been the development of computer models based on the water management model DRAINMOD.  A forest hydrology model (DRAINLOB) was developed and tested using the data collected at the Carteret watersheds. This model added methods to more accurately calculate evapotranspiration from pine forests and to more accurately calculate subsurface drainage resulting from the widely spaced ditches. DRAINLOB was modified so that it could be used to simulate the hydrology of coastal plain forests on a watershed scale.   More recently, the DRAINMOD-FOREST model was developed which predicts hydrology, soil C and N cycles, and tree growth in drained forests under various climate conditions and silvicultural practices.   The model was evaluated using the 21-year dataset collected from the intensively managed loblolly pine plantations at the Carteret County, NC site. The model accurately predicted annual, and monthly drainage, as well as annual and monthly nitrate export values.  A new routine has been developed for DRAINMOD-FOREST that enables the model to simulate growth of switchgrass and the competition of pine trees and switchgrass in intercropping treatments.  These DRAINMOD based models are valuable tools for extending our research to consider different management practices and changing climatic conditions.

Chronological List of Water and Silvicultural Treatments at the Carteret County Watersheds

| Management | Date | D0 | D1 | D2 | D3 | Notes |
|---|---|---|---|---|---|---|
| Trees Planted | 1974 | | Y | Y | Y | 2100 trees ha1 |
| Thinning | 1980 | | Y | Y | Y | Thinned to about 1000 trees ha-1 |
| Fertilization | 1981 | | Y | Y | Y | Aerial applied 169 kg N ha-1 |
| Commercial thinning | 1988 | | Y | Y | Y | Thinned to about 370 trees ha-1 |
| Fertilizer application | 1989 | | Y | Y | Y | Ground applied 225 kg N ha-1 |
| Control drainage | 1990–1994 | | | Y | Y | Raised outlet weir levels |
| Harvesting | 1995 | | | Y | | Whole tree harvesting |
| Orifice control drainage | 1995–1999 | | | | Y | Orifice weir installed |
| Site preparation | 1996 | | | Y | | Bedding |
| Trees Planted | 1997 | | | Y | | 2100 trees ha-1 |
| Thinning | 2002 | | | | Y | Thinned to about 185 trees ha-1 |
| Fertilization | 2005 | | | Y | Y | Applied 115 (D2) and 172 (D3) kg N/ha |
| Harvesting | 2009 | Y | Y | | Y | Whole tree harvesting, D0 added |
| Site preparation | 2009 | Y | | Y | | Bedding |
| Trees Planted | 2010 | Y | | Y | | 2100 trees ha-1 |
| Switchgrass Planted | 2011 | | Y | | Y | Interplant D1, Switchgrass only D3 |
| Switchgrass overseeded | 2012 | | Y | | Y | Interplant D1, Switchgrass only D3 |

## Carteret site and instrumentation, Cliff Tyson, Weyerhaeuser Co.

# Site layout and History




D0 was added in 2009. It is 64 acres under normal operations. Site history: harvested in 2009.1, bedded and pines planted 2009.4.

D1 is 65 acres with an intercropping of switchgrass. Site history: 1988 – 2009 control for hydrology study. 2009.1 harvested, 2009.4 bedded and pines planted. Switchgrass was planted in 2012.2 and 2013.2

D2 was thinned to 140 trees per acre in 2009.1. Site history: 1988 till 2009 hydrology treatments applied. It has no new treatment in place and serves as a connection to the original hydrology study.

D3 is 67 acres and was clear-cut from 2009.4 till 2010.2. Site history: 1988 till 2009 hydrology treatments. It was planted in switchgrass in 2012.2 and 2013.2.

## How do we collect the data?

All stage data is collected by In-situ 500's.


Water samplers collected by Sigma 900 are run at NCSU lab's.

Campbell CR200 software and loggers are used to convert stage data into flow weighted samples.

Rain data is collected at each outlet using a Hobo rain gauge.

Weather data is Collected by a Hobo U30 weather Station.

## Results from silviculture and bioenergy research, Devendra Amatya

Research Hydrologist, US Forest Service, Cordesville, SC

Following are the major findings/results based on a long-term (1988-2008) study to determine effects of silvicultural and water management treatments on pine forest hydrology and drainage water quality:

- ET was the dominant component of the water budget (~70% of annual rainfall (P)) followed by drainage (McCarthy et al., 1991; Amatya et al., 1996; Amatya and Skaggs, 2011; Tian et al., 2012). Interception and lateral seepage were estimated to be 15% and 4%, respectively, of the average annual P. Seasonal ET loss was as much as 96% of the rainfall depending on the season.
- Controlled drainage (CD) consisting of a raised weir on a flashboard riser during the summer-fall period on treatment watershed D2 helped store the water in the soil profile for periods of high tree growth and ET (Amatya et al., 2000a). Spring time CD on treatment watershed D3 also substantially reduced freshwater outflows, minimizing off-site water quality impacts (Amatya et al., 1998). Similarly, use of orifice-weir as an alternative CD at ditch outlet significantly reduced outflows compared to free drainage from control watershed D1 (Amatya et al., 2003).
- CD water management on D2 and D3 reduced the export of N, P, and sediment, primarily by reducing reduced drainage (Amatya et al., 1998). CD with an orifice-weir reduced the P and sediment export, but despite the reduced outflows, N did not decrease (Amatya et al., 2003).
- Blanton et al. (1998) found that the 1995-96 harvesting, bedding, and site preparation for regeneration on treatment watershed D2 reduced drainable porosity in the top 60 cm of the profile by approximately 50%, resulting in a significant change in storm outflow hydrographs.
- Amatya et al. (2006a) found the increase in average water table elevation, drainage (by about 20 cm and 260 mm, respectively) and water quality parameters soon after harvesting in 1995 returned to baseline levels approximately 6 years (by 2004) after planting of pine trees in 1997 for regeneration on treatment watershed D2.
- Sun et al. (2002) concluded that streamflows from flatwoods watersheds like the one at the Carteret site generally are discontinuous in more years than are streamflows from upland watersheds. The stormflow peaks in these low-gradient coastal watersheds were smaller than those in the upland watersheds except under extremely wet conditions.
- Using data from control (D1) and many other sites in the southern US, Lu et al. (2003) concluded that a long-term annual ET model they developed with four independent variables – annual precipitation, latitude, elevation, and forest coverage, can adequately predict the long-term annual ET to examine the spatial variability and effects of land use change on water availability.
- Using weather data from the Carteret site and two other coastal stations to evaluate five methods of estimating PET, Amatya et al. (1995) found the Turc method was the best using the Penman-Monteith method as a reference for the humid coastal plain. Amatya et al. (2000b) found the effects of vegetation type on measured net radiation ($R_n$) with the most $R_n$ absorbed by the pine canopy and the least by the grass canopy with the emerging vegetation in between.
- Using long-term hydro-meteorologic data from 36 stations including D1 at the Carteret site, Lu et al. (2005) concluded that the Priestlay-Taylor, Turc, and Hamon methods were better predictors of PET than other methods they evaluated using the water balance.
- Skaggs et al. (2006) found 20-30 times higher effective hydraulic conductivity for the top 90 cm of the Deloss fine sandy loam soil compared to the data published by NRCS Soil Survey at the harvested site (D2), primarily due to site preparation including bedding for regeneration than due to the harvesting itself.

- Amatya et al. (2008) found a short term effect of 2002 thinning of D3 pine on its increased water table & outflow which seems to have recovered within three years after thinning possibly due to rapid canopy increase; no substantial effects, however, were, found on nutrient levels.
- Zhou et a. (2008) developed and successfully tested an empirical climate driven model, also sensitive to vegetation, to estimate ET of forests at multiple time scales using long-term hydro-meteorologic data from five different sites including the Carteret control (D1)
- Skaggs et al. (2011) found two orders of magnitude higher effective hydraulic conductivity for top 70 cm of soil layers than the corresponding agricultural site. Drainable porosity was also higher for the drained Carteret pine forest than the agricultural site.
- Sampson et al. (2011) reported four years post-harvest maximum $LAI_{CLIP}$ exceeded 8 $m^2$ $m^{-2}$ (projected area basis). $LAI_{PCA}$ underestimated $LAI_{CLIP}$; Corrected $LAI_{PCA}$ estimates exceeded simulated pine LAI ($LAI_{SIM}$) for ~4.5 years post-planting.
- The recent fertilization study (Beltran et al., 2010) determined that peak nutrient concentrations soon after fertilization were much higher than the average concentrations. The effect of fertilization on both the nutrient concentrations and loading rates was short lived e.g. only up to three months after fertilization. The average nutrient increase on the thinned stand was higher than on the young stand as a result of a higher fertilizer rate applied.
- McCarthy et al. (1992) and Amatya and Skaggs (2001) used data from this study to develop and test the forest hydrologic model (DRAINLOB) based on DRAINMOD (Skaggs 1978) for forest hydrologic balance, particularly ET and drainage. The model was applied for various water and silvicultural management practices. (McCarthy and Skaggs 1992; Richardson and McCarthy 1994; Amatya and Skaggs 1997; Amatya et al., 1999). DRAINLOB was modified for use at the watershed scale (Amatya et al., 1997) and was successfully applied to data on large coastal watersheds with pine forest cover (Amatya et al., 2004; 2006b; Kim et al., 2012; 2013).
- Recently, a fully integrated hydrology, nutrients, and productivity model DRAINMOD-FOREST was developed and successfully tested with 21-year data from this site (Tian et al., 2012; 2013).
- Using a PnET-II ecosystem process model, Sun et al. (2000) predicted a significant increase of drainage (6%) and forest productivity (2.5%) for a pine forest on the control (D1) as a result of future climate change scenarios predicted by the General Circulation Model HADCM2.
- The study at the Carteret site, together with a large watershed-scale experimental study near Plymouth, NC, resulted in a long-term database and hydrologic and water quality models for evaluating the cumulative impacts of various agricultural and silvicultural management practices on a lower Coastal Plain watershed (Amatya et al., 1998; 2002; 2004; Chescheir et al. 1998; Fernandez et al., 2002; 2005; 2006; 2007; Diggs, 2004; Shelby et al., 2005; Skaggs et al., 2003;).

*In 2009, due to a need to identify second generation biofuel sources from managed forests and to understand the corresponding environmental implications, the research program was extended by support from Catchlight Energy, LLC. The treatments were expanded to include a dedicated energy crop, switchgrass (Panicum virgatum), by monitoring an additional adjacent 25 ha watershed. Similar treatments were installed on sites in Mississippi and Alabama. These multiple watersheds are being monitored for collecting hydrology, water quality, vegetation, and soils data to evaluate the hydrologic and water quality effects of switchgrass alone, young pine with natural understory, and young pine with switchgrass intercropping compared to the control (pine stand with a natural understory) using a paired watershed approach. We are also developing methods for estimating evapotranspiration for these treatment watersheds using remote sensing based spatial high resolution multispectral satellite imagery data with ground truthing, where possible, together with sensor technology. We have completed* *monitoring for a 3-year (2009-2012) calibration when the switchgrass was established and currently monitoring for the 2^nd^ year just before harvesting the switchgrass sometime in 2014 is going on.*

After detection of periods with unstable and weak regression coefficients due to various management operation effects during the calibration period, stable, significant, and predictive pairwise calibration equations have been developed to use with treatment data (after May 2012) to quantify the effects on water table, soil moisture, flow, and nutrients and sediment.

The longest calibration period with stable predictive regression coefficients for each watershed pair for both the hydrology and nutrients varied depending on timing for management practices imposed for the switchgrass establishment.

Preliminary results from the calibration period have indicated highest outflow from the watershed with young pine and understory and the least from the mature pine as a control, consistent with the observed average soil moisture and water table data. Both the average soil moisture and water table for the switchgrass intercropped watershed was very similar to the switchgrass only treatment in 2012-13 period, although the later consistently yielded higher outflow than the switchgrass intercropped since after raking of the former for switchgrass seeding in April 2012. As expected, observed soil moisture on pine beds was consistently higher than the rows for switchgrass for the calibration period when the switchgrass has not yet been germinated well in the intercropped watershed.

Results of outflow and evapotranspiration were somewhat complicated by the management operations undertaken for switchgrass establishment on the intercropped and switchgrass only treatment watersheds. Detailed hydrologic analysis for evaluation of all treatment effects is still underway.

Seasonal variations in rainfall affected temporal dynamics of nutrients levels, with higher values during the wet winter and after large summer storms, particularly the events of September 2010 and August 2011.

Water table elevation affected magnitude and temporal variation of nutrient concentrations in all watersheds. Exponential increase in N and P loads with increase in water table elevation was also observed. Nitrogen and phosphorus concentrations decreased with increase in volume of water flowing out of the sites, possibly due to dilution effects.

## **Water quality results from silviculture and bioenergy**, Francois Birgand, NC State University

First compiled results of water quality impacts from the silcultural practices from this project are available from the five watersheds in Alabama. The results presented herein are extracted from Ms. Erin Bennett's MS thesis (Bennett, 2013) and ensuing article in preparation.

Five watersheds (8.0 – 26.7 hectares) were established in a paired approach with five different land cover treatments in Greene County, AL. These land cover treatments include: 18 year reference pine stand (GRREF), switchgrass only (GR4), thinned pine with switchgrass intercropping (GR2), newly established pine with switchgrass intercropping (GR3), and young pine stand with normal undergrowth (GR1). Data for two pretreatment years and one establishment year were available for analysis. A suite of indicators were used to detect and quantify impacts using continuous flow data and flow proportional composite sampling.

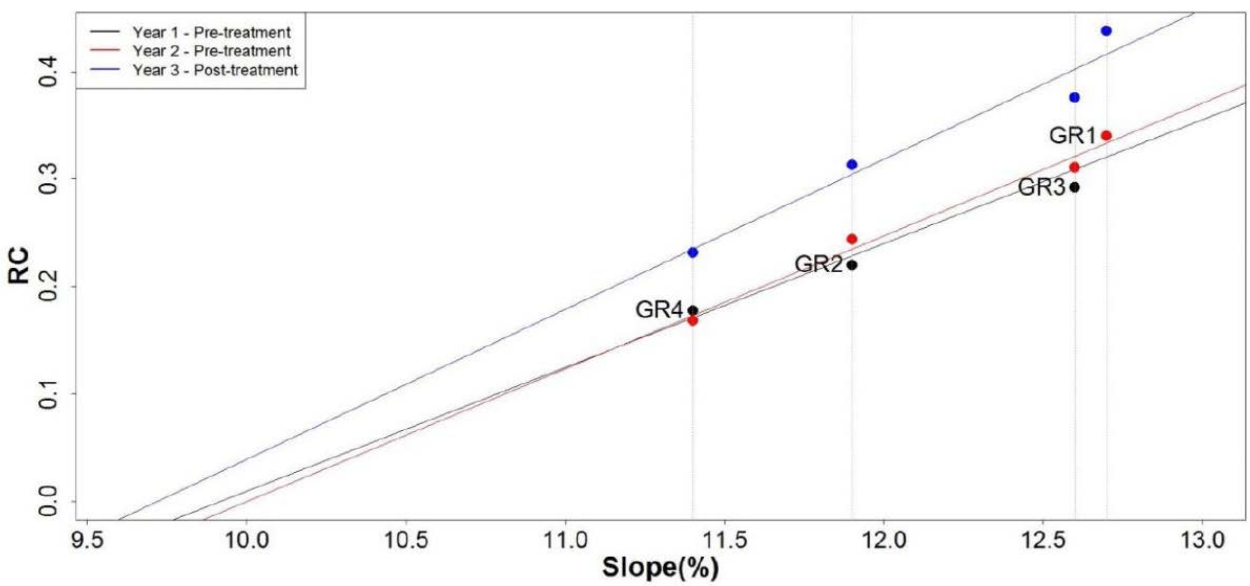



**Figure 4: Relationship between the runoff coefficient (Percentage of the annual rainfall) and the average topographical slope in the watersheds**

**Method:** The key to all the results were very careful methods to quantify the nutrient loads at the outlets of the watersheds. The monitoring techniques were continuous flow measurements (on a two minute-basis) and flow proportional composite sampling. A short explanation of the latter might be helpful. For each field visit interval (2-weeks) one sample composited over the interval was collected. The water in the composite bottle contains the addition of many subsamples which are strategically sampled, specifically proportionally to volume flowed at the station. In the end, the final concentration at the end of each field visit interval, the concentration of all parameters in the bottle is a very close approximation to the one needed to calculate the load (Between two bimonthly field visits, the load is calculated by multiplying the flow proportional concentration with the volume flowed in that period).

The results of the flow and load monitoring techniques are 1) continuous flow values, which gives access to the fine dynamics of flow in the watersheds, which can be compared from one watershed to the next, and 2) cumulative values for flow and loads. From the 2-week load values, it is actually possible to describe the short term dynamics, such that a sudden increase in load could be related back to management in the watersheds. This is essentially the approach which we took to draw our conclusions.

**Hydrology Results:** The first striking result was that we were not able to detect significant treatment hydrological effects, other than at the event cumulative and maximum flows, despite quite a variety of tools used. This was attributed to a combination of factors: 1) the hydrology before and after treatment was not significantly different, and/or 2) the tools used to make the differences apparent were not powerful enough, and/or 3) the nature of the extremely flashy hydrology (over 50% of the flow could occur in less than 10% of the time) which renders the statistical comparison between ephemeral flow peaks difficult. The watersheds in Alabama exported a relatively small percentage of the annual rainfall (less than 30% for most year and watersheds; Figure 4), but all the more so with the higher hillslope, which was expected. The results were that soil management and crop establishment would be more visible in the watersheds which exported more water and with higher slopes.

**Water Quality results:** Cumulative 2-week nutrient loads were calculated for each watershed and plotted as a function of time (Figure 5), and as a function of cumulative volume(Figure 6). Management timings were plotted vertically in the graphs.

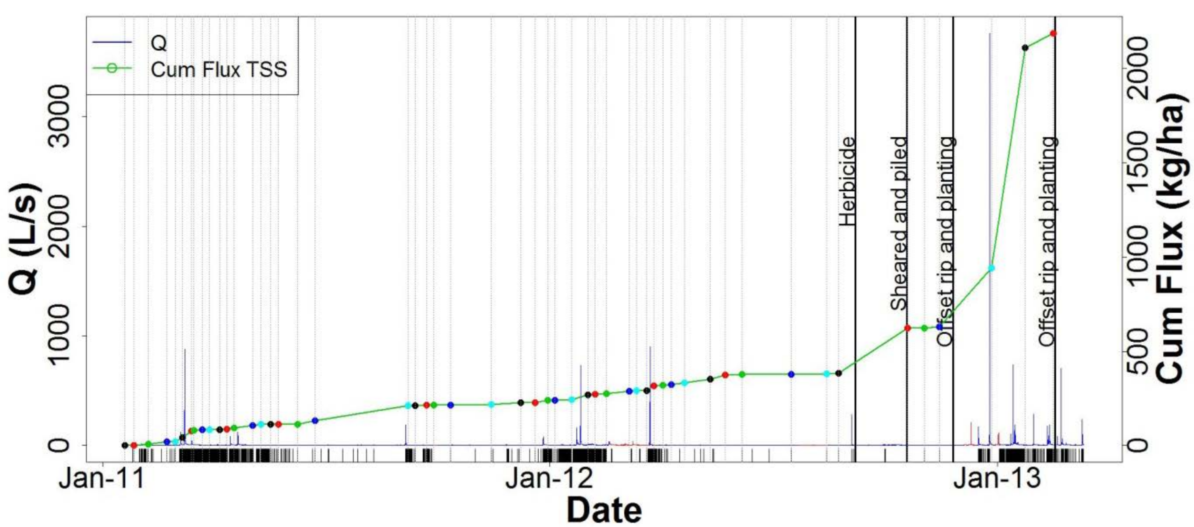



**Figure 5: Hydrograph, times of sampling (rug at the bottom) and cumulative load of Total Suspended Solids for GR3**

Contrary to the hydrology results, material loadings showed clear indication of soil management and site preparation impacts. The switch grass only and the newly established pine with switchgrass intercropping showed the most exportation compared to the other watersheds. There was a TSS loading increase from pre- to post- treatment (Table 9). To eliminate the bias of increased cumulative flow volumes increasing the cumulative loading from the watersheds, the cumulative loading versus cumulative volume graphs for TSS showed that there were increases in the flow-weighted concentrations (increases in slope) from pre- to post-treatment (Figure 7). ***These relatively sudden increases appeared to be closely correlated in timing with identified site preparation operations on the ground. This correlation was taken as strong evidence that the observed material load increases were due to site preparation operations during crop establishment***.

**Table 1: Cumulative loading of water quality parameters for all study watersheds for year 2 and year 3 (separated by a comma)**

| WS | TSS Cumul Load ($kg.ha^{-1}$) | TP Cumul Load ($kg.ha^{-1}$) | DOC Cumul Load ($kg.ha^{-1}$) |
|---|---|---|---|
| GR1 | 394,681 | 0.933,1.68 | 38.5,63.8 |
| GR2 | 497,1435 | 0.234,0.869 | 23.9,38.4 |
| GR3 | 252,1899 | 0.372,1.36 | 21.3,58.4 |
| GR4 | 96,814 | 0.214,0.353 | 17.1,22.0 |
| GRREF | 109,389 | 0.283,0.164 | 21.4,20.7 |

This allowed us to conclude that there were some measurable impacts of these practices. This reemphasizes the vulnerability during the crop establishment period in these watersheds, regardless of their slopes. Actual site preparation for establishment of switchgrass intercropping in Southern forests of the USA will likely be a hybrid between the treatments at GR2 (thinned pine with switchgrass intercropping), and GR3 (newly established pine with switchgrass intercropping). Switchgrass will probably be sowed after trees have been established for one to two years, thus the thinning of an older (6 year) stand will not occur like at GR2 nor will removing and replanting the trees shortly (2 months) before planting switchgrass will occur like in GR3.

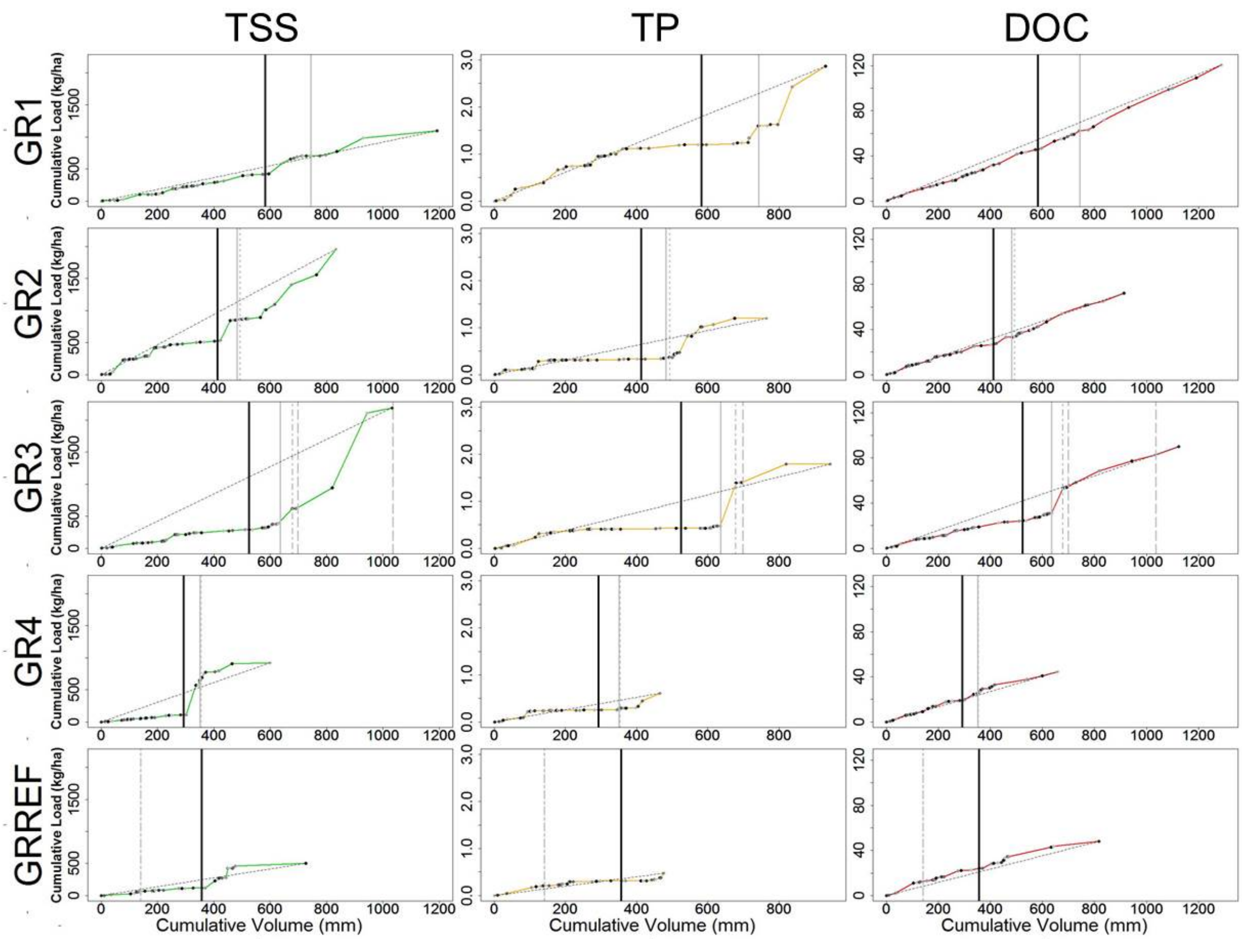



Figure 6. Cumulative TSS, TP and DOC loads versus cumulative volume for all study watersheds

**Discussion:** The observed effects on GR2 and GR3 suggest that in all cases, site preparation has the potential to have a detectable and significant impact on TSS exports. This corresponds to previously reported results relating bare ground and increased sediment loading (Butler et al., 2006), but also more generally to common knowledge that erosion potential increases with decreasing soil coverage as predicted by the USLE family models (e.g., Wischmeier and Smith, 1978; USDA ARS, 2008; reviewed by Kinnell, 2010). With stormwater in trafficked, residential and commercial areas with impermeable surfaces the event mean concentrations have been found to range from 19-937 mg/L which is comparable to max concentrations seen during implementation of the biomass treatments in the project of 800-1000 mg/L.

Effects on N, P and C are not as clear. For nitrogen, there were great uncertainties from the concentration values coming from the lab, which explain why no values could be reported. However, despite relative uncertainties, the absolute values suggest that the level of dissolved inorganic exports were low. For TP and DOC, the exports seemed to have been discorrelated to those of TSS, which was unexpected. Definite increases in TP and DOC loads were observed for the intercropped treatments but their magnitude was less than that of the undisturbed young pine reference. Our results suggest that there is potential for export of TP and DOC associated with site preparation for switchgrass intercropping, but the exports may not be strongly correlated to those of TSS.

The crop establishment period is clearly sensitive and needs to be taken into account for all efforts (including modeling) predicting the impacts of biomass production and in our case biomass intercropping. The fact that the switchgrass may be slow to establish needs to be considered and more extensive best management practices should be used to alleviate these potential water quality impacts. Stream buffers are currently considered as an adequate best management practice for pine plantations and intercropped systems, and they were implemented in all studied watersheds. Our results show that this may not be enough, particularly when switchgrass is slow to establish. Additional BMPs such as temporary sediment fences should be considered to further protect the water quality of these watersheds.

**Conlusion:** no clear statistically significant hydrological differences between treatments could be detected. This was attributed to the difficulty of detecting treatment effects within the general 'hydrological noise' associated with intrinsic physical differences between watersheds, rainfall variability between treatment years, and low sensitivity of the indicators chosen to detect changes. In contrast, there were clear effects on TSS exports associated with soil disturbance and with the low vegetation cover during the establishment of the switchgrass treatments. The loading magnitude and the dynamics of the loading increases were taken as indicators of water quality impacts, which may explain the discrepancy between the lack of statistically significant effect on hydrology and the definite effects on TSS exports. Treatment effects on TP and DOC exports were observed although were not as clear since their export mechanisms appeared to be different than those of TSS.

We conclude that the site preparation work and the ensuing periods of low vegetation cover, make switchgrass intercropping susceptible to increased TSS loads at the small watershed scale. The results from this study will be compared to the other paired watershed studies in upland Calhoun County, MS watersheds and coastal plain watersheds in Carteret County, NC to see if differences in hydrology and water quality can be detected during site preparation. Research will continue on all three watershed studies to analyze the hydrology and water quality dynamics as the treatments grow through time.

**References**

Bennett, E.M. 2013. Hydrology and Water Quality Impacts of Site Preperation for Loblolly Pine (Pinus taeda) and Switchgrass (Pancium virgatum) Intercropping in Upland Forested Watersheds in Alabama. Dissertation of Master of Science, North Carolina State University. 250pp.

Butler, D.M., D.H. Franklin, N.N. Ranells, M.H. Poore, and J.T. Green. 2006. Ground cover impacts on sediment and phosphorus export from manured riparian pasture. 35: 2178-2185.

Kinnell, P.I.A. 2010. Event soil loss, runoff and the Universal Soil Loss Equation family of models: a review. Journal of Hydrology. 385:384-397.

USDA ARS (Agricultural Research Service). 2008. Draft Science Documentation, Revised Universal Soil Loss Equation Version 2. Washington, DC: USDA Agricultural Research Service

Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses a guide to conservation planning. Agric. Handb 537. U.S. Gov. Print. Office, Washington, DC. 537.

**Development and testing of an integrated model for bioenergy grass ecosystems,**

Shiying Tian, NC State University

**Purposes** :To develop and test an integrated, process-based whole-ecosystem model to simulate the hydrology, biogeochemistry and vegetation growth for grass-based biomass production systems (Figure 1).

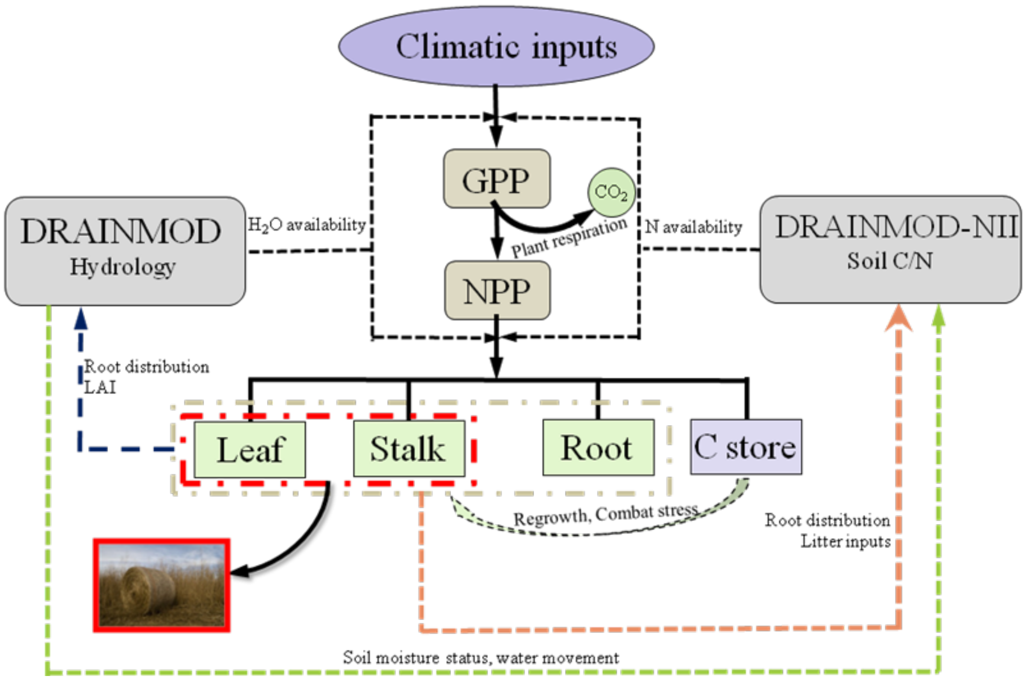



Figure 1: Schematic diagram of the integrated model for bioenergy grass.

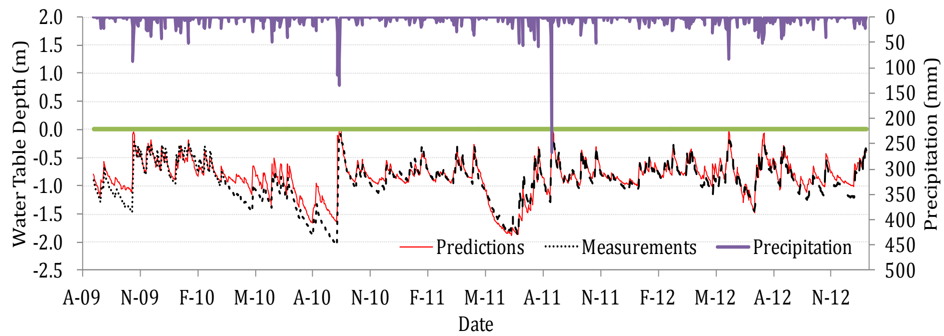
## Applications

1. Predict the productivity of bio-energy crop under different site conditions and management practices; e.g. fertilizer amount and timing; harvesting scheme;

2. Evaluate the impacts of bio-energy crop cultivation on hydrological and biogeochemical (mainly carbon and nitrogen) cycling.

   e.g. Will the land use change alter the hydrological processes, if so, how much? Will the land use change lead to water quality problems? Will the land use change affect the carbon sequestration?

**Preliminary testing:** the newly developed model has recently been applied successfully for simulating hydrology (Figure 2), nitrogen cycling (Figure 3), and biomass yield(Figure 4) in Lenoir.

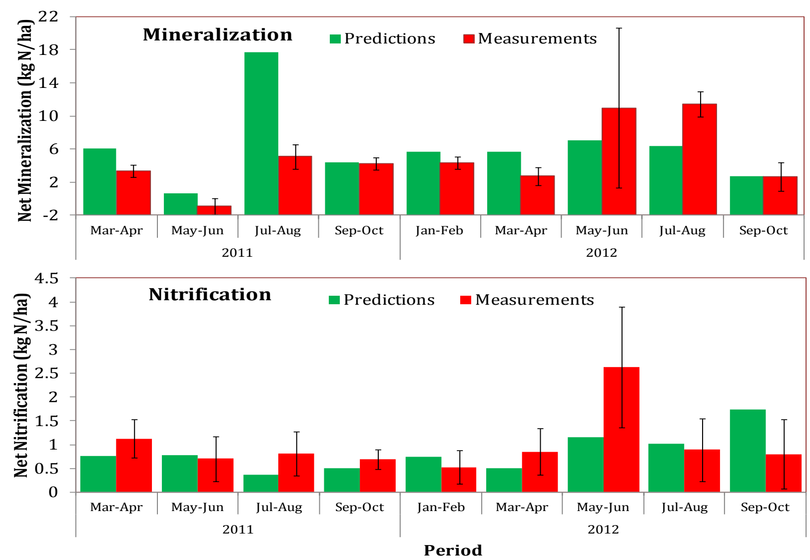



*The model accurately predicted the daily fluctuations of water table depth as showed in Figure 2*

Figure 2: comparison between predicted and measured water table depth.

Figure 3: Predicted vs. measured N cycling

*The model successfully captured the seasonal changes of nitrogen cycling as showed in Figure 3*



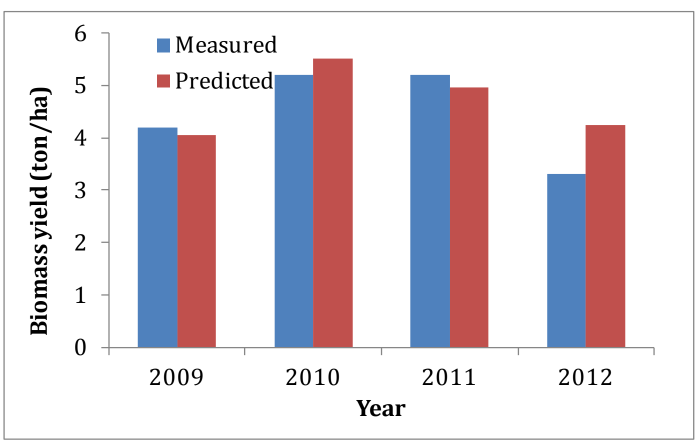




Figure 4: Comparison between predicted and measured annual yield.

*The model accurately predicted the annual yield with mean absolute errors less than 0.8 ton year$^{-1}$*

**Future work:** 1) Applying the model for simulating the intercropped pine-switchgrass ecosystem by considering intra-species competition for water, nutrients, and radiation; 2) Upscaling our model results to evaluate hydrological and water quality impacts of this land use change over the southeastern region.

## Tour speaker contact information:

| | |
|---|---|
| Devendra Amatya | damatya@fs.fed.us |
| Francois Birgand | francois_birgand@ncsu.edu |
| Julian Cacho | jfcacho@ncsu.edu |
| Chip Chescheir | cheschei@ncsu.edu |
| Bob Emory | bob.emory@weyerhaeuser.com |
| Jessica Homyack | jessica.homyack@weyerhaeuser.com |
| Bryan Hulka | bryan.hulka@weyerhaeuser.com |
| Gail Johnson | gail.johnson2@weyerhaeuser.com |
| John King | john_king@ncsu.edu |
| Zakiya Leggett | zakiya.leggett@weyerhaeuser.com |
| Jami Nettles | jami.nettles@weyerhaeuser.com |
| Eric Sucre | eric.sucre@weyerhaeuser.com |
| Shiying Tian | stian@ncsu.edu |
| Billy Tucker | billy.tucker@weyerhaeuser.com |
| Cliff Tyson | cliff.tyson@weyerhaeuser.com |
| Andres Villegas | andres.villegas@catchlightenergy.com |
| Jason Watters | jason.watters@weyerhaeuser.com |

## Related Publications

### In Review/In Revision

Albaugh, J.M., J. Domec, C.A. Maier, E.B. Sucre, Z.H. Leggett, and J.S. King. In review. Gas exchange and stand-level estimates of water use and gross primary productivity in an experimental pine and switchgrass intercrop forestry system on the Lower Coastal Plain of North Carolina, U.S.A. Agricultural and Forest Meteorology.

Albaugh, J.M., T. Albaugh, R. Heiderman, Z.H. Leggett, J. Stape, K. King, K. O'Neill, and and J.S. King. In review. Effect of shading on switchgrass physiology, above- and belowground biomass and light-use efficiency. Agroforestry Systems.

Amatya, D.M., C. Rossi, A. Saleh,Z. Dai, M. Youssef, R. Williams, D. Bosch, G. Chescheir, G. Sun, and W. Skaggs. In revision. Review of nitrogen fate models applicable to forest landscapes in the southern US. Transactions of the ASABE.

Blazier, M.A., T.R. Clason, H.O. Liechty, Z.H. Leggett, E.B. Sucre, S.D. Roberts, K. Krapfl, and E.D. Vance. In review. 2013. Nitrogen and carbon of switchgrass, loblolly pine, and cottonwood biofuel production systems in the southeast United States. Soil Science Society of America Journal.

Homyack, J., Lucia, K., D. Miller, and M. Kalcounis-Rueppell. In review. Rodent population and community responses to biofuels production in intensively managed pine forest in North Carolina. Journal of Wildlife Management.

Lucia, K., J. Homyack, D. Miller, and M. Kalcounis-Rueppell. In revision. Niche overlap of white-footed mice and house mice in an intercropped switchgrass-pine system. Journal of Mammalogy.

Minick, K.J., B.D. Strahm, T.R. Fox, E. Sucre, Z. Leggett, and J. Zerpa. In review. Switchgrass intercropping effectively utilizes excess soil inorganic N in a young loblolly pine plantation located in coastal North Carolina. Forest Ecology and Management.

Nettles, J.E. In review. Water Management and Productivity in Planted Forests. International Association of Hydrological Sciences, Publication

Ssegane, H., D. M. Amatya, E. W. Tollner, Z. Dai, and J.E. Nettles. In review. Estimation of Daily Streamflow of Southeastern Coastal Plain Watersheds by Combining Estimated Magnitude and Sequence. Journal of American Water Resources Association.

Strickland, M., Z. Leggett, E. Sucre, and M. Bradford. In review. Biofuel intercropping effects on soil carbon and microbial activity. Journal of Applied Ecology.

### Published

Albaugh, J.A., E.B. Sucre, Z.H. Leggett, J.C. Domec, and J.S. King. 2012. Evaluation of intercropped switchgrass establishment under a range of experimental site preparation treatments in a forested setting on the Lower Coastal Plain of North Carolina, U.S.A. Biomass and Bioenergy 46:473:482.

Albaugh, J.M., J. Domec, C.A. Maier, E.B. Sucre, Z.H. Leggett and J.S. King, 2012. Water relations and productivity in an intercropped pine-switchgrass study examining biofuel production in North Carolina, USA. Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA. Paper 3.5.
http://sungrant.tennessee.edu/NatConference/ConferenceProceedings/

Beauvais, C. 2010. Coarse Woody Debris in a Loblolly Pine Plantation Managed for Biofuel Production. M.F. Thesis, Duke University, Durham, NC.

Bennett, E.M. 2013. Hydrology and Water Quality Impacts of Site Preparation for Loblolly Pine (Pinus taeda) and Switchgrass (Panicum virgatum) Intercropping in Upland Forested Watersheds in Alabama. MS thesis. North Carolina State University. Department of Biological and Agricultural Engineering, Raleigh, NC.

Blazier, M.A., T.R. Clason, E.D. Vance, Z.H. Leggett, and E.B. Sucre. 2012. Loblolly pine age density affects switchgrass growth and soil carbon in an agroforestry system. Forest Science 58:485-496.

Breland, K.L. 2013. Effects of loblolly pine (Pinus taeda) and switchgrass (Panicum virgatum) intercropping techniques on intermittent stream macroinvertebrate communities. MS thesis. University of Alabama at Birmingham, Department of Biology, Birmingham, AL.

Briones, K., J. Homyack, D. Miller, and M. Kalcounis-Rueppell. 2013. Intercropping switchgrass with loblolly pine does not influence the functional role of the white-footed mouse (Peromyscus leucopus). Biomass and Bioenergy 54: 191-200.

Briones, K. 2011. Effect of intercropping switchgrass with loblolly pine on the diet and trophic position of Peromyscus leucopus. M.S. Thesis. University of North Carolina-Greensboro. Greensboro, NC.

Cacho, J. 2013. Impacts of Bioenergy Feedstock Production on Soil Physical Properties, Soil Water and Nitrogen Dynamics, and Shallow Groundwater Quality of a Drained Forest in Southeastern U.S. Ph.D. Dissertation. North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC.

Heiderman, R. 2013. Managing a Loblolly Pine Stand with Miscanthus × giganteus Intercropping: Exploring Shade Tolerance, Productivity and Sustainability. M.S. Thesis. North Carolina State University. Department of Forestry. Raleigh, NC.

Homyack J., Z. Aardweg, T. Gorman and D. Chalcraft. 2013. Initial effects of biofuels production on abundance and diversity of herpetofauna in eastern North Carolina. Wildlife Society Bulletin. 37: 1-9. DOI: 10.1002/wsb.248

Iglay, R. B., S. K. Riffell, D. A. Miller, and B. D. Leopold. 2012. Effects of switchgrass intercropping and biomass harvesting on plant communities in intensively managed pine stands. Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA. Paper 3.6. http://sungrant.tennessee.edu/NatConference/ConferenceProceedings/

King, J.S., R. Ceulemans, J.M. Albaugh, S.Y. Dillen, J. Domec, R. Fichot, M. Fischer, Z.H. Leggett, E. Sucre, M. Trnka, and T. Zenone. 2013. The challenge of lignocellulosic bioenergy in a water-limited world. BioScience. 63 (2):102-117

King, K. 2013. Landscape-scale effects of intercropping switchgrass (Panicum virgatum l.) and loblolly pine (Pinus taeda) on rodent community structure and population demographics. M.S. Thesis. University of North Carolina Greensboro, Greensboro, NC, USA.

Leggett, Z.H. and E.B. Sucre. 2012. Evaluating the impact of switchgrass intercropping in loblolly pine plantations on long-term soil productivity. Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA. Paper 4.9. http://sungrant.tennessee.edu/NatConference/ConferenceProceedings/

Loman, Z. G., S. K. Riffell, D. A. Miller, J. A. Martin, and F. J. Vilella. 2013. Site preparation for switchgrass intercropping in loblolly pine plantations reduces retained trees and snags, but maintains woody debris. Forestry: An International Journal of Forest Research. 2013: 1-8. doi:10.1093/forestry/cpt004.

Marshall, M., J. Homyack, D. Miller, and M. Kalcounis-Rueppell. 2012. Effect of removal of woody biomass after clearcutting and intercropping switchgrass (Panicum virgatum) with loblolly pine (Pinus taeda) on rodent diversity and populations. International Journal of Forestry Research 2012:1-11. Doi:10.1155/2012/703970.

Marshall, M. 2011. The influence of managing a loblolly pine (Pinus taeda) forest for biofuels production via switchgrass (Panicum virgatum l.) intercropping and woody debris removal on rodents. M.S. Thesis. University of North Carolina-Greensboro. Greensboro, NC.

Minick, K.J., B. D. Strahm, T.R. Fox, E. Sucre, and Z. Leggett. 2013. Soil organic matter fractions in loblolly pine forests of coastal North Carolina managed for bioenergy production. Proceedings of 17$^{th}$ Biennial Southern Silviculture Research Conference.

Nettles, J. E. and Z.H.Leggett. 2012. Extent and distribution of sustainable intensive forest biofuel practices. Proceedings from Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA. Paper 4.11. http://sungrant.tennessee.edu/NatConference/ConferenceProceedings/

Nettles, J., M. Youssef, J. Cacho, J. Grace, Z. Leggett and E. Sucre. 2011. The water quality and quantity effects of biofuel operations in pine plantations of the southeastern US. In N.E. Peters, V. Krysanova, A. Lepisto, R. Prasad, M. Thomas, R. Wilby, S. Zandarya (Eds), Water Quality: Current Trends and Expected Climate Change Impacts. (115-122). IAHS Publication 348, IAHS Press, Oxfordshire, UK.

Nichols, L.K. 2013. Soil CO2 Efflux, Dissolved Organic Carbon, Root Exudates and Microbial Community Dynamics in a Loblolly Pine and Switchgrass Intercropped System Located on the North Carolina Coastal Plain. M.S. Thesis. **Virginia Polytechnic Institute and State University.** The Department of Forest Resources and Environmental Conservation. Blacksburg, VA

Ridley, C.E., H. I. Jager, C. M. Clark, R. A. Efroymson, C. Kwit, D. A. Landis, Z.H. Leggett, and D. A. Miller 2013. Debate: Can bioenergy be produced in a sustainable manner that protects biodiversity and avoids the risk of invaders? Bulletin of the Ecological Society of America. 94:277–290. http://dx.doi.org/10.1890/0012-9623-94.3.277

Riffell, S., J. Verschuyl, D. A. Miller, and T. B. Wigley. 2012. Potential biodiversity response to intercropping herbaceous biomass crops on forest lands. Journal of Forestry 110:42-47.

Riffell, S. K., J. P. Verschuyl, D. A. Miller, and T. B. Wigley. 2011. Relationships between intensive biomass production and biodiversity in U.S. forests – a literature review. National Council for Air and Stream Improvement Technical Bulletin No. 992. Research Triangle Park, North Carolina, USA.

Shrestha, Paliza. 2013. Greenhouse gas fluxes and root productivity in a switchgrass and loblolly pine intercropping system for bioenergy production. M.S. Thesis. **Virginia Polytechnic Institute and State University.** The Department of Forest Resources and Environmental Conservation. Blacksburg, VA.

Ssegane, H., D. M. Amatya, R.W. Skaggs, J.E. Nettles, G.M. Chescheir, and E. W. Tollner. 2013. Consistency of Hydrologic Relationships of a Paired Watershed Approach. American Journal of Climate Change. 2:147-164

Tian, S.Y., M.A. Youssef, D.M. Amatya, and E.D. Vance. 2013. Global sensitivity analyses of DRAINMOD-Forest, an integrated forest ecosystem model. Hydrological Processes, DOI: 10.1002/hyp.9948.