Optimization of Southeastern Forest Biomass Crop Production: Watershed Scale Evaluation of the Sustainability and Productivity of Dedicated Energy Crop and Woody Biomass Operations

May 22, 2013

Principle Investigators:

George Chescheir
N. C. State University

Jami Nettles
Weyerhaeuser Co.

Goal Statement

Develop and disseminate science-based information for sustainable production of forest biofuel feedstock in the Southeast.

Quad Chart Overview

Timeline

- Start date – Sept. 30, 2010
- End date – Sept. 30, 2015
- Percent complete – 50%

Barriers

- Barriers addressed
  - **Ft-B. Sustainable Production**
  - **St-C. Sustainability Data across the Supply Chain**
  - **St-E. Best Practices for Sustainable Bioenergy Production**
  - **St-G. Representation of Land Use**

Budget

Funding FY11 - $417,426/$541,453

Funding FY12 - $400,947/$533,320

Funding FY13 - $442,073/$521,954

Project funded for 5 years

Avg. Annual Funds - $418,578

$542,982

Partners

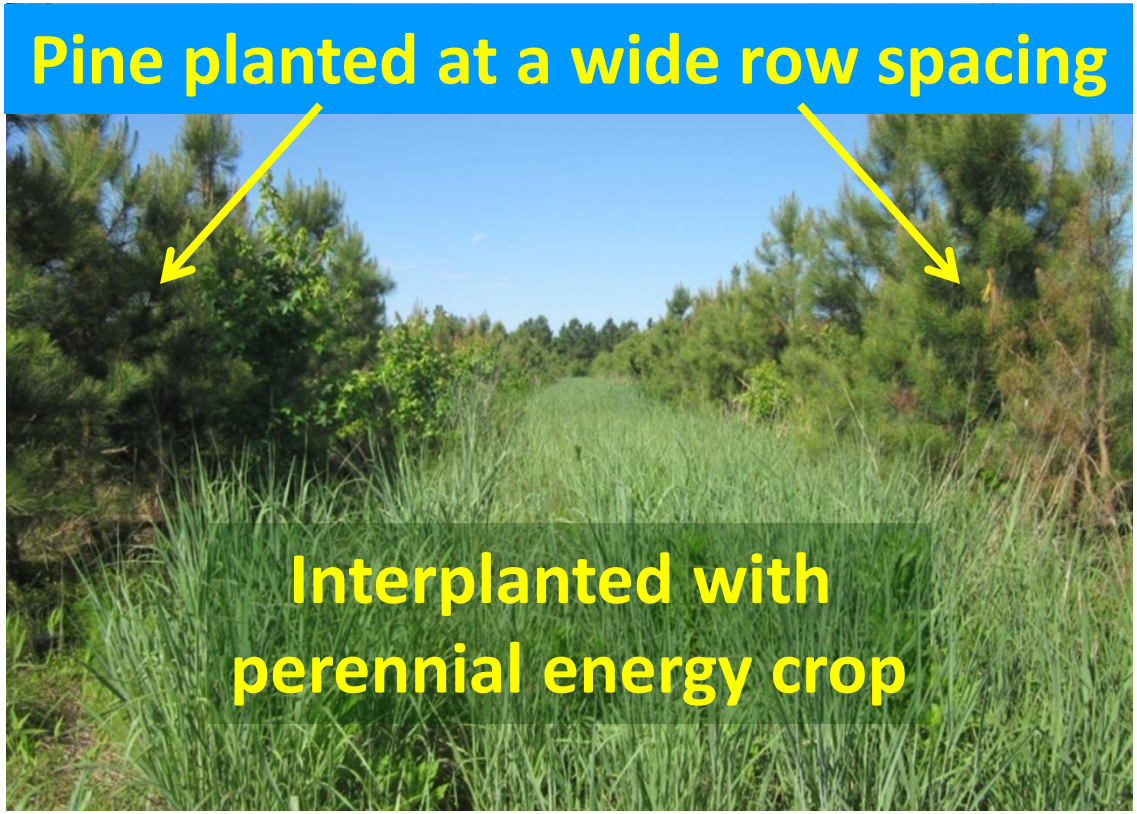
- N. C. State University
- Weyerhaeuser Company
- Catchlight Energy LLC (CLE)
- Virginia Tech
- US Forest Service
- National Council for Air and Stream Improvement (NCASI)

NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

Project Overview

Evaluation of forest-based biofuel crop compatible with high-value timber production:



NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

NC STATE UNIVERSITY

Project Overview

Needs

Outreach
- Science and tech transfer
- Economic guidance
- Operational practices – BMPs/Safety

Broad Models
- Landscape scenarios
- Operational scale effects
- Plant processes

Sustainability Analysis
- Water quality
- Hydrology
- Nutrients
- Soil
- Biodiversity

Field research
- Watershed treatments
- Plot scale measurements
- Southern landscapes

NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

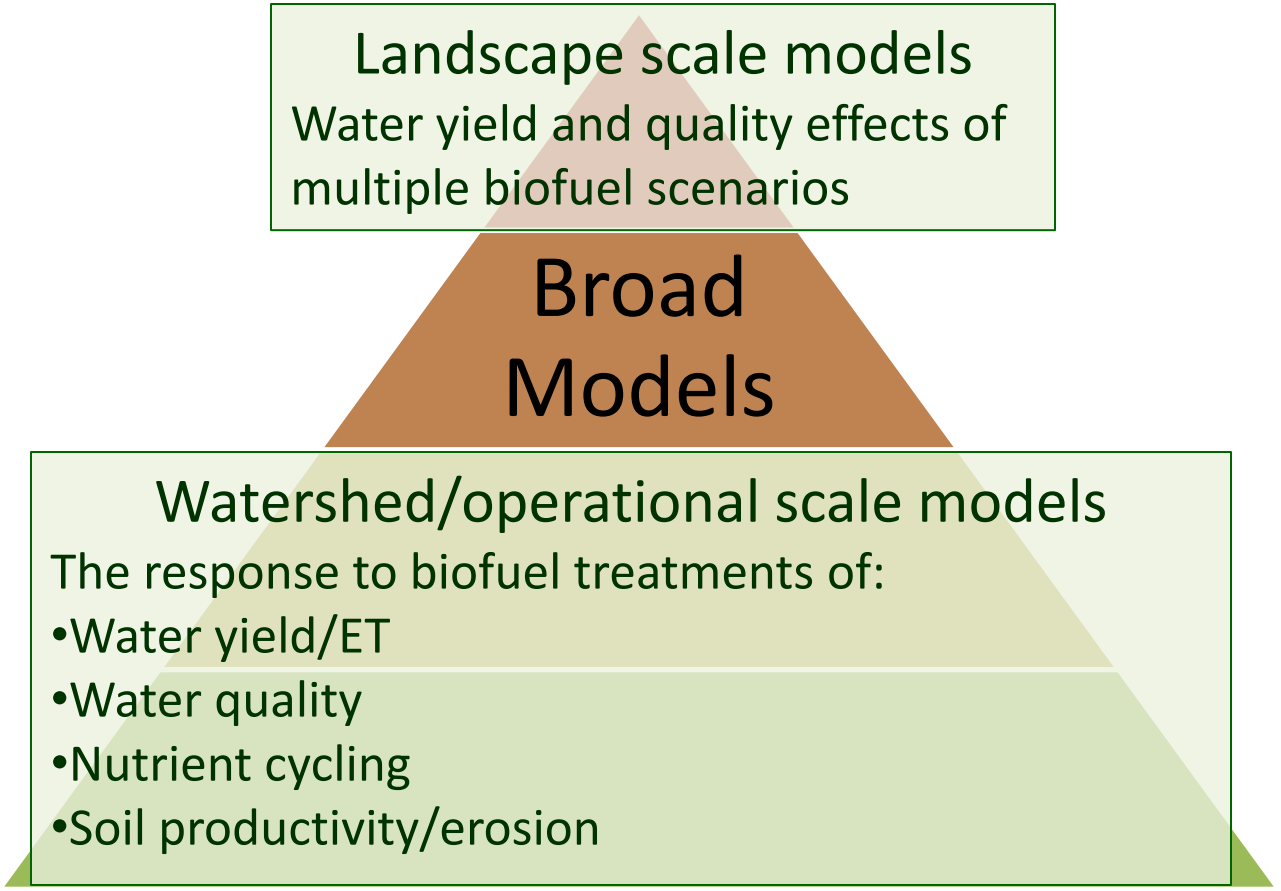
High Level Objective
Knowledge Transfer

Outreach

Disseminate results through publications, presentations, and cooperation with scientists and operators

Develop and evaluate Best Management Practice (BMP) guidelines that ensure environmental sustainability

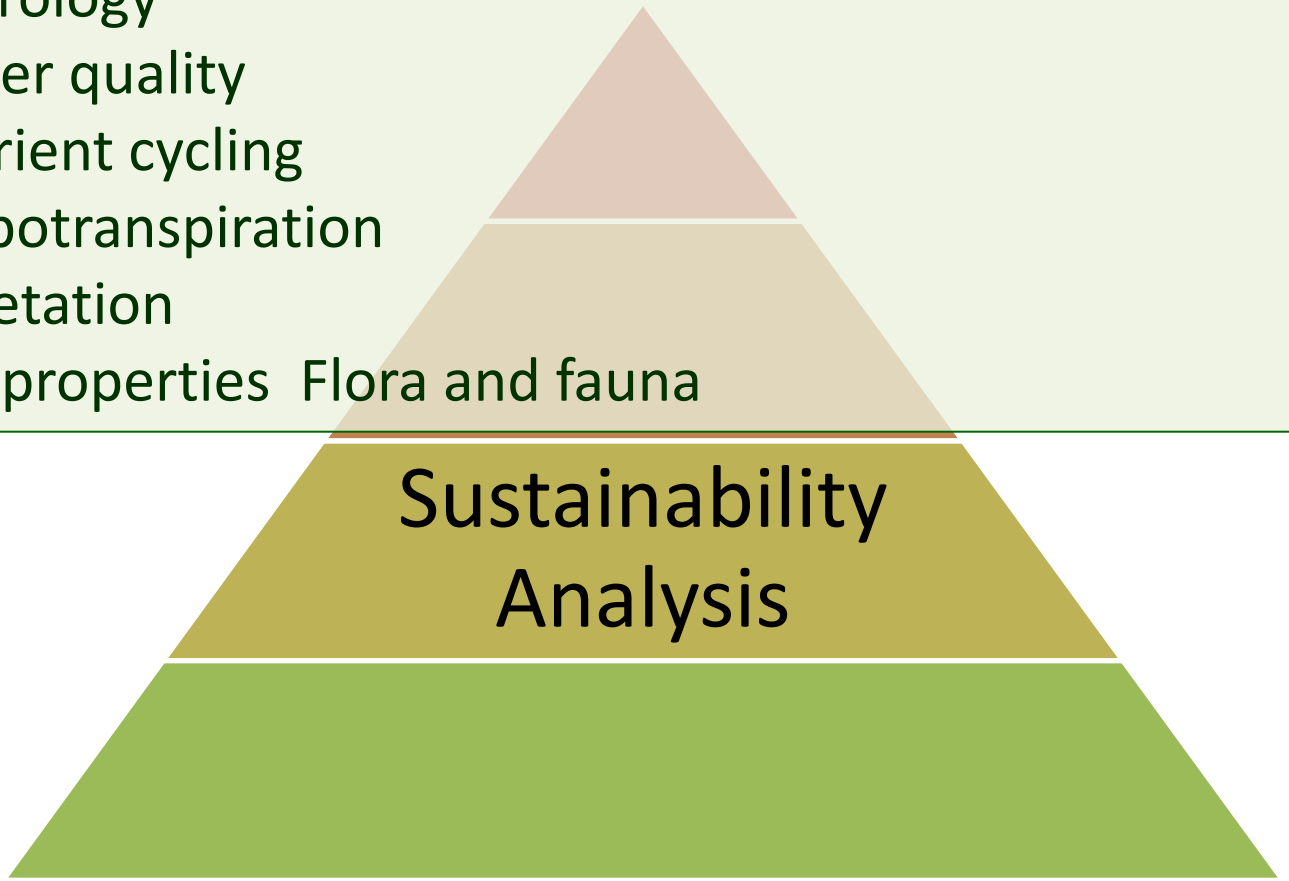
High Level Objective
Generalize Results



High Level Objectives

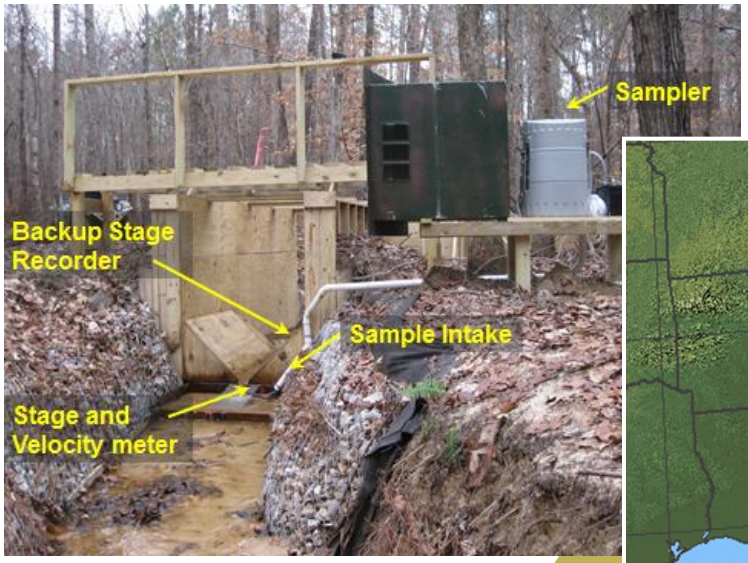
Understand results

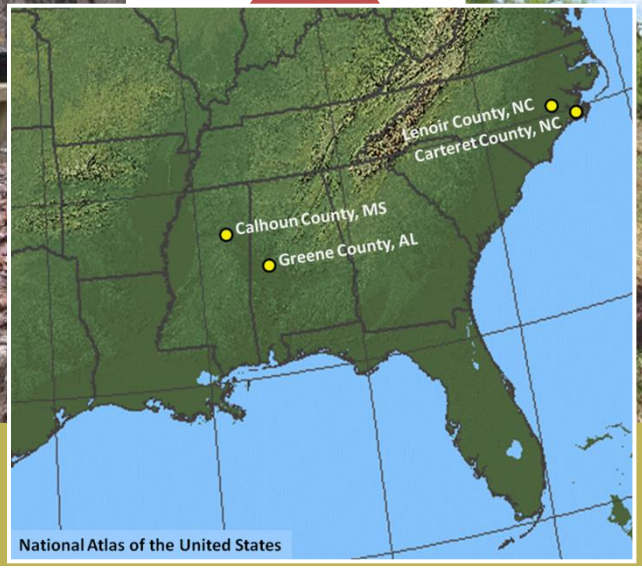
Hydrology
Water quality
Nutrient cycling
Evapotranspiration
Vegetation
Soil properties Flora and fauna



High Level Objective

Perform field experiments and collect data





Field Research

NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

Treatments

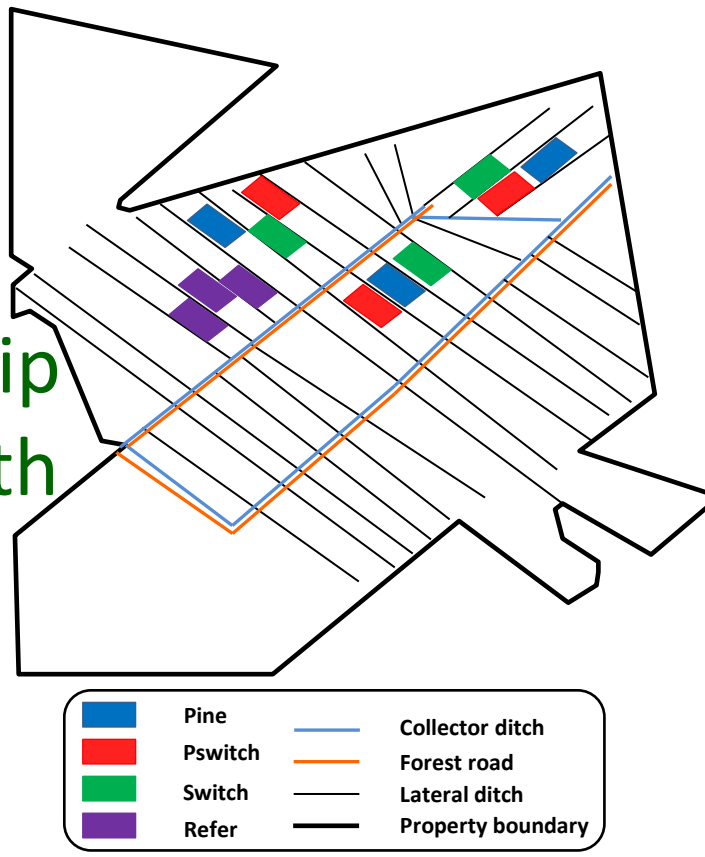
Plot Scale Experiments

Plot size – 2 ha

3 Replicates

Measurements

- Continuous Climate and Precip
- Continuous Water Table Depth
- Soil Moisture
- Soil Physical Properties
- Groundwater Quality
- Soil N and C cycling



Watershed Experiments

Watershed size – 11 to 27 ha

Measurements (Hydrology)

- Continuous Climate and Precip
- Continuous Outflow
- Continuous Water Table Depth
- Continuous Soil Moisture

Watershed Experiments

Measurements (Water Quality)

- Flow Proportional WQ Samples
  - NO_3, NH_3, TKN, TP, OP, DOC, TOC, TSS
- Continuous WQ samples at NC site
  - NO3, DOC, Turbidity
- Groundwater Quality
  - NO_3, NH_3, TKN, TP

Watershed Experiments

Measurements (other)

- Soil Physical Properties
- Aquatic Macroinvertebrates
- Vegetation Charateristics
- N and C cycling

Watershed Experiments

ET determination using Remote Sensing

ET measurements (during satellite flyover)

- LAI
- Stomatal Conductance
- Soil Moisture and Weather Parameters

Satellite image analysis

Correlation and ET modeling using

- Neural Networks
- Multivariate Analysis

Watershed Scale Modeling

Use process based models to simulate:

- Hydrology
- N and C cycling
- Vegetation Growth
- Water Quality

Using DRAINMOD-FOREST for watersheds in flat high water table soils and APEX for upland conditions.

1 - Approach

Watershed Scale Modeling

Develop module to simulate competitive interaction between Pine and understory (can be natural, switchgrass, or other biofuel feedstock)

Models will be calibrated and validated using field collected data. Sensitivity and uncertainty analyses will be conducted on the models

1 - Approach

Landscape Scale Modeling

Use SWAT model to simulate the impact of biofuel production on the hydrology and water quality at the landscape scale (such as Tombigbee Watershed (47,600 km^2))

Use watershed scale models to create realistic representations of biofuel production landuse

Calibrate & validate modified SWAT model using publically-available baseline data

Develop BMPs

Use measured data and models to develop BMPs for biofuel feedstock production.

1 - Approach

NC STATE UNIVERSITY
Bio&Ag ENGINEERING

Team of very bright researchers

Weyerhaeuser

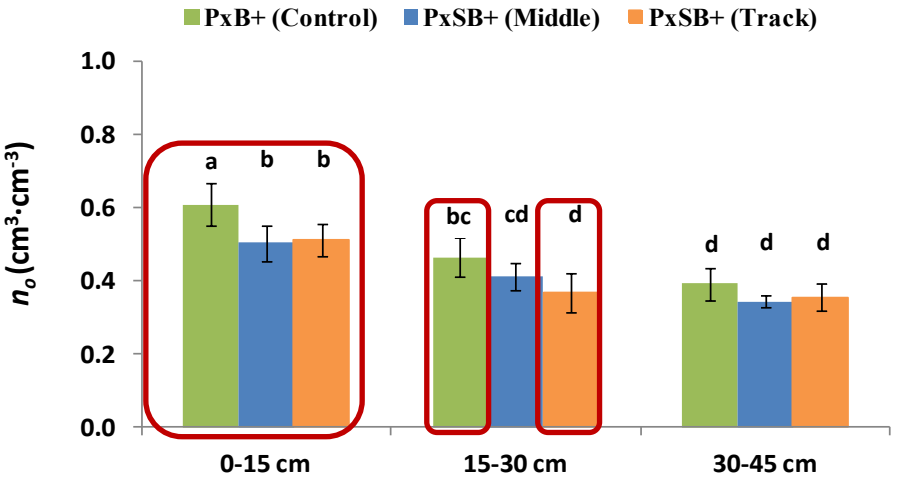
Plot Scale Experiments

- Instrumentation of all sites completed
- High quality data collection completed
- N and C cycling experiments completed
- Water table monitoring continues

Plot Scale Experiments

Site preparation for interplanting caused some changes in soil physical properties

Example of observed changes in soil porosity (η_o)



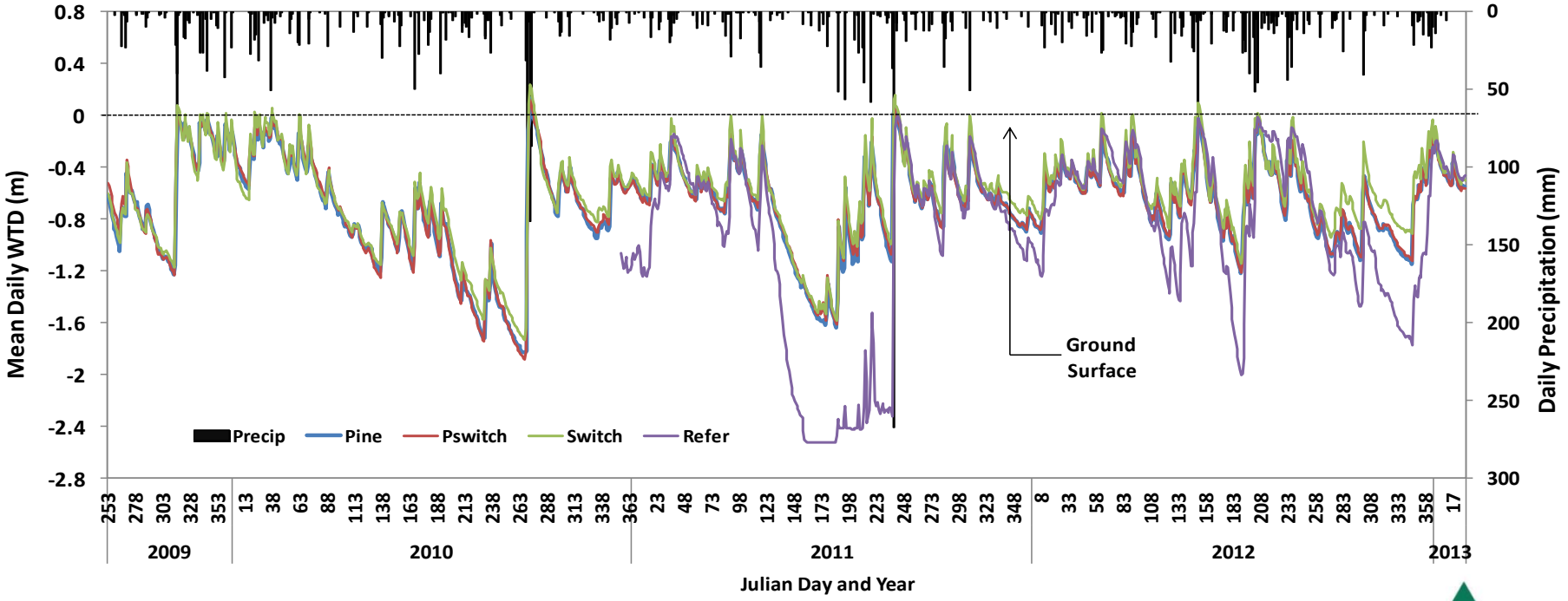
Harvesting operations did not significantly affect soil physical properties

NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

Plot Scale Experiments

No significant changes in water table depths between treatments. Water table significantly deeper in the 38 year old reference stand



Bio&Ag ENGINEERING

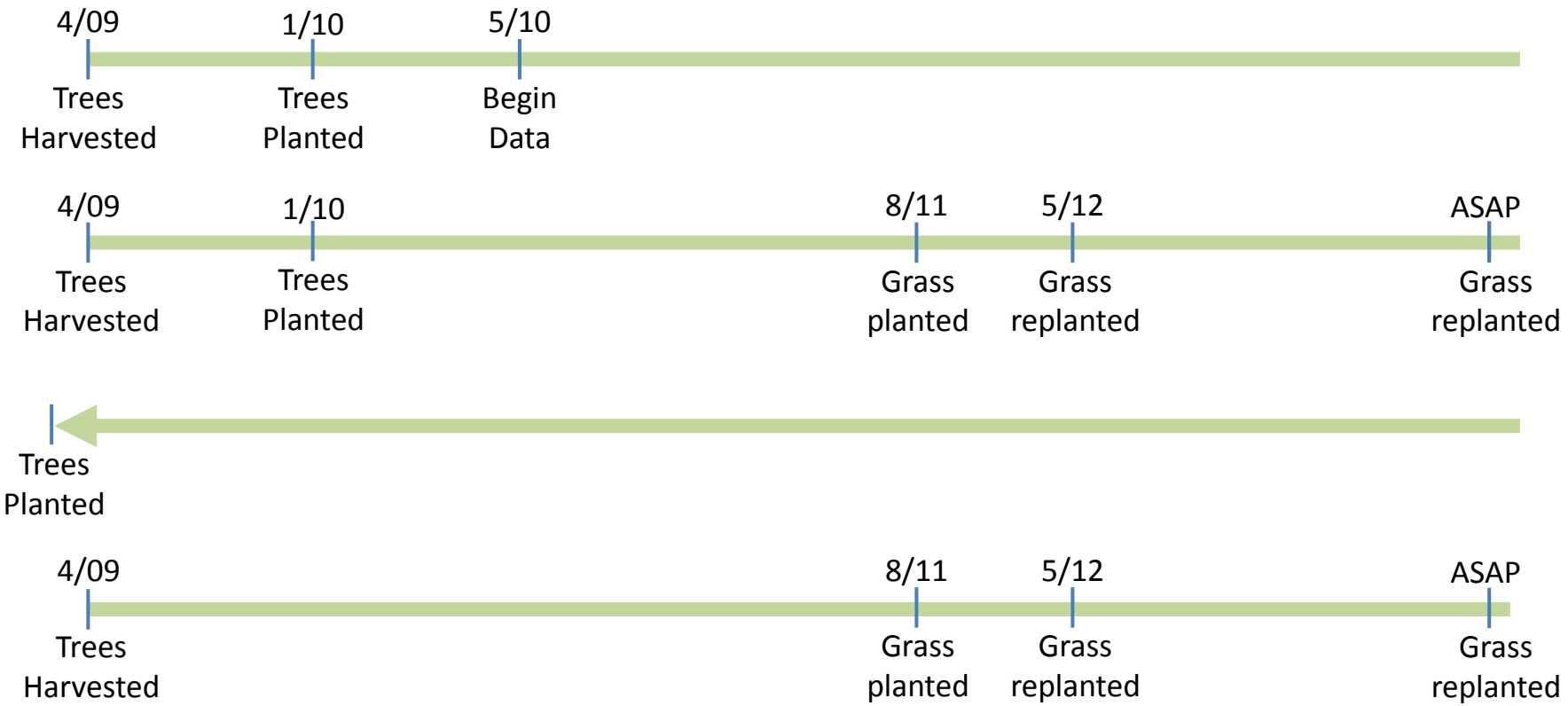
Weyerhaeuser

Watershed Experiments

- Instrumentation of all sites completed
- High quality pretreatment data collected
  - 1 yr at NC and 2 yr at MS/AL
- Treatment installation completed
- High quality treatment data collected
  - 2 yr at NC and 1 yr at MS/AL

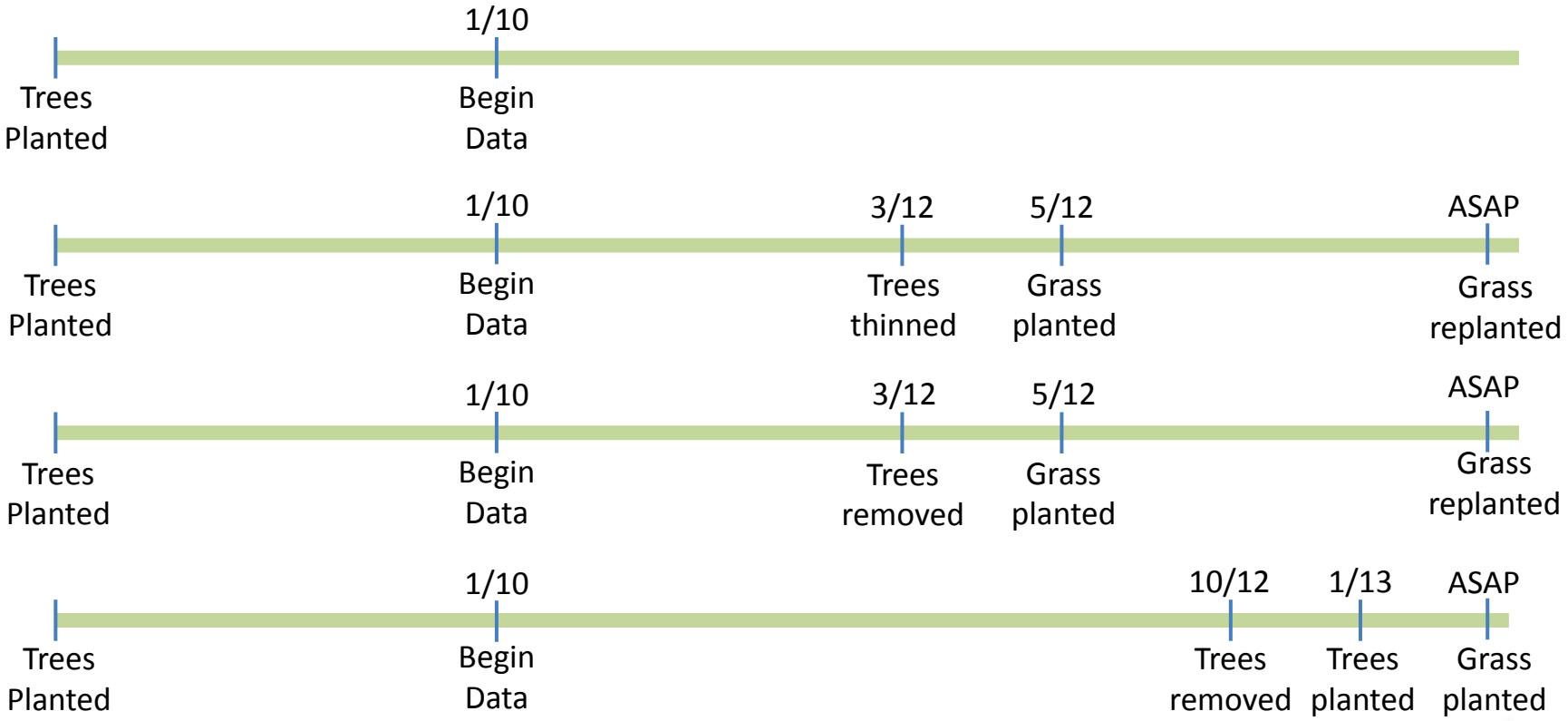
Watershed Experiments

Installation of Treatments Completed (NC)



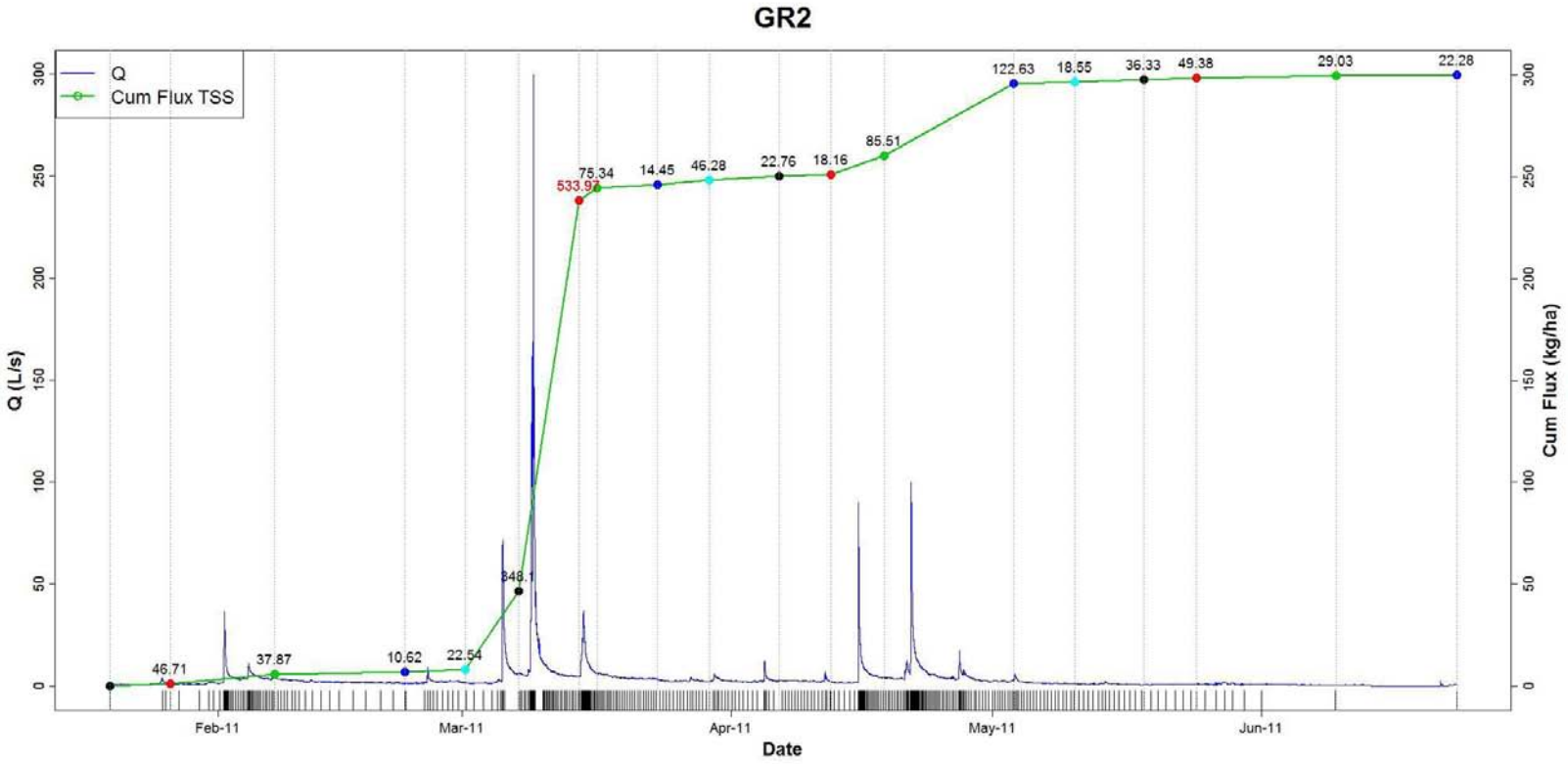
Watershed Experiments

Installation of Treatments Completed (MS/AL)

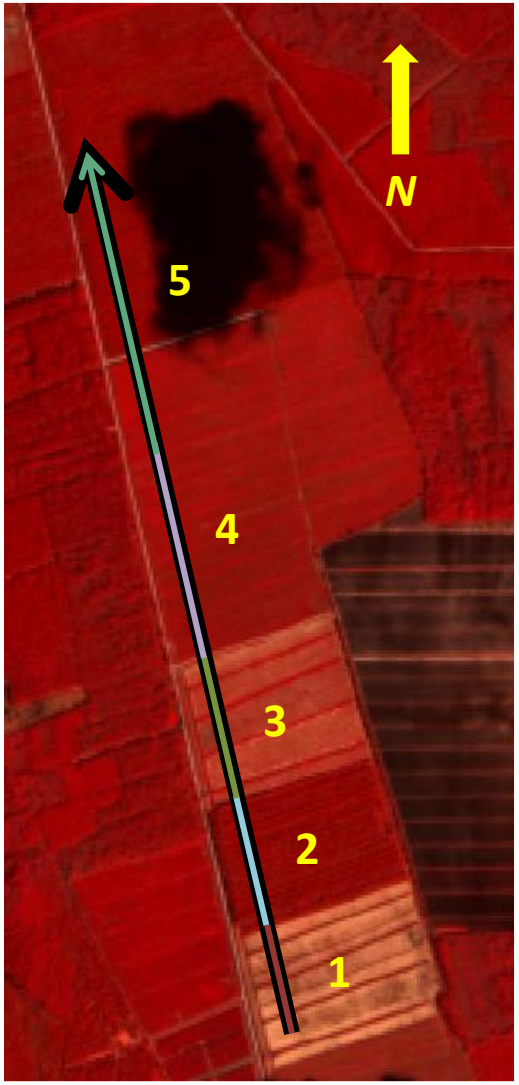


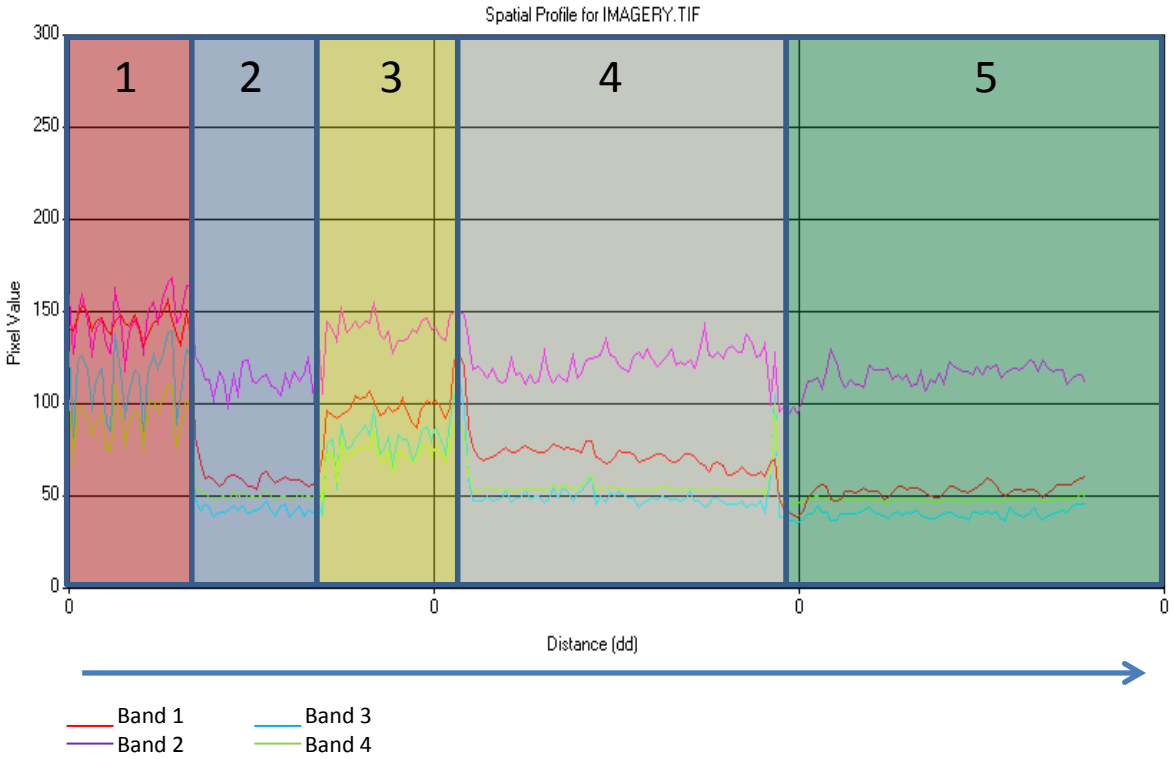
Watershed Experiments

Sample of data sets collected



2 – Technical Accomplishments/ Progress/Results





Transect of Leaf Area Index density running from South to North. Each chart line represents a particular wavelength of reflected light. Differences between these lines will be used to create an index value for stomatal conductance and canopy temperature.

SPOT 5 Image of Carteret, NC
March 2013

Bio&Ag ENGINEERING

Weyerhaeuser

2 – Technical Accomplishments/ Progress/Results

Scintillometer installation on Switchgrass site

Carteret, NC – April 01, 2013

Measures intensity fluctuations of eddies between the laser light source and receiver

NC STATE UNIVERSITY Bio&Ag ENGINEERING

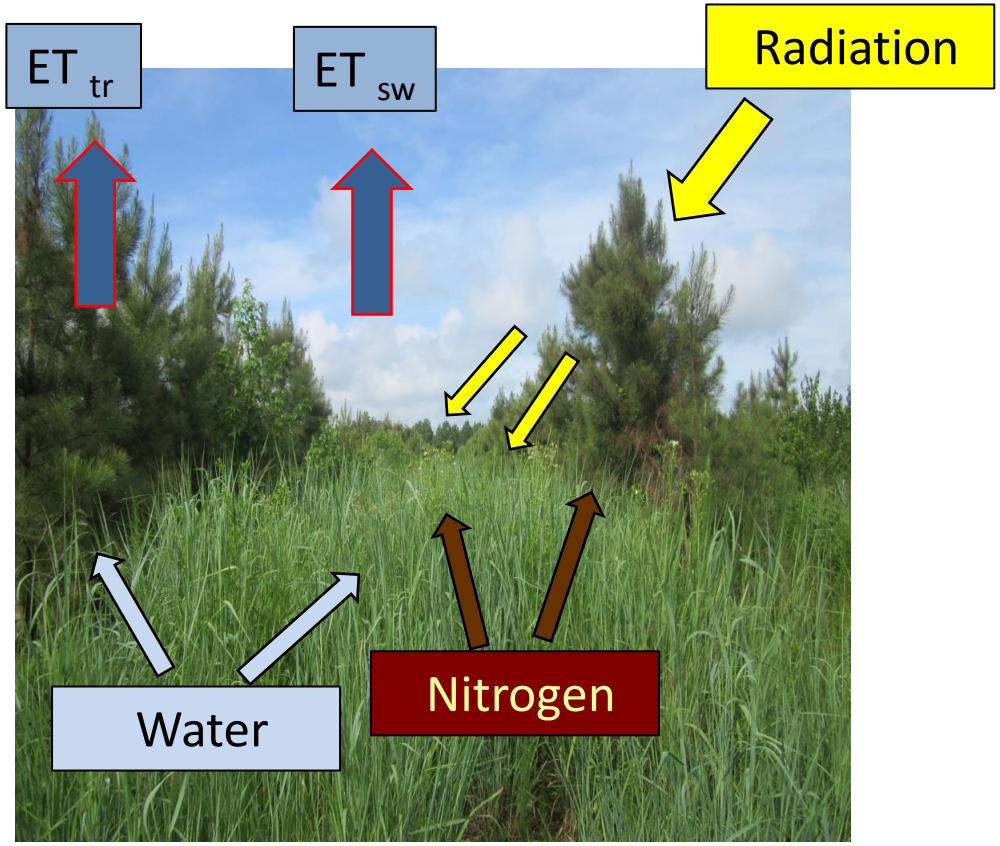
Weyerhaeuser

Watershed Scale Modeling

DRAINMOD-Forest was successfully calibrated and validated for its ability to simulate the hydrology and C and N cycling in managed forest conditions at the NC site.

An uncertainty analysis was conducted using the generalized likelihood uncertainty estimation (GLUE) methodology.

Watershed Scale Modeling



Concepts for Plant Competition

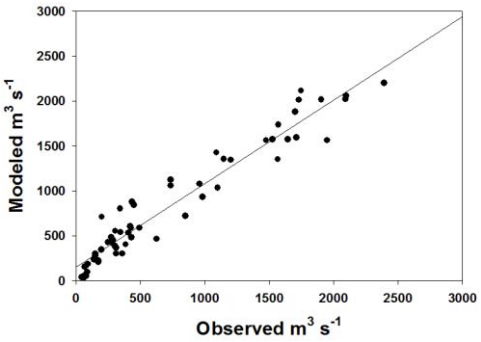
Partitioning of solar radiation is a function of canopy fraction and leaf area;

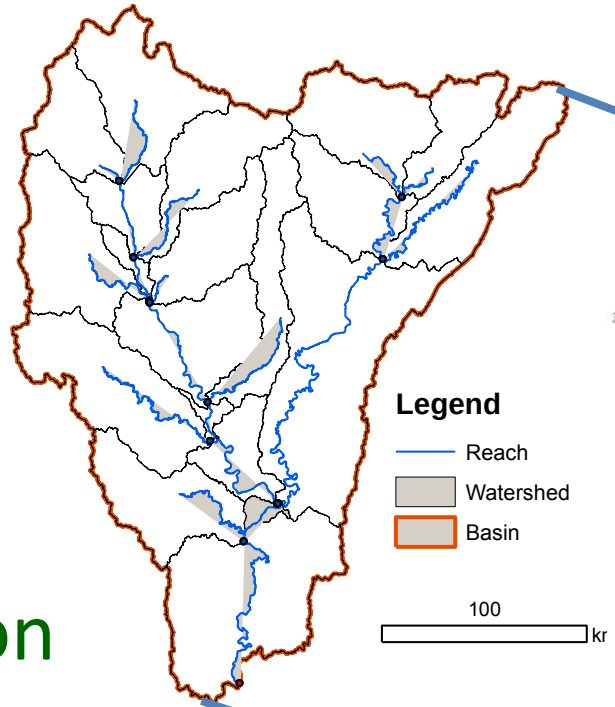
Partitioning of soil water and nitrogen is a function of roots distribution;

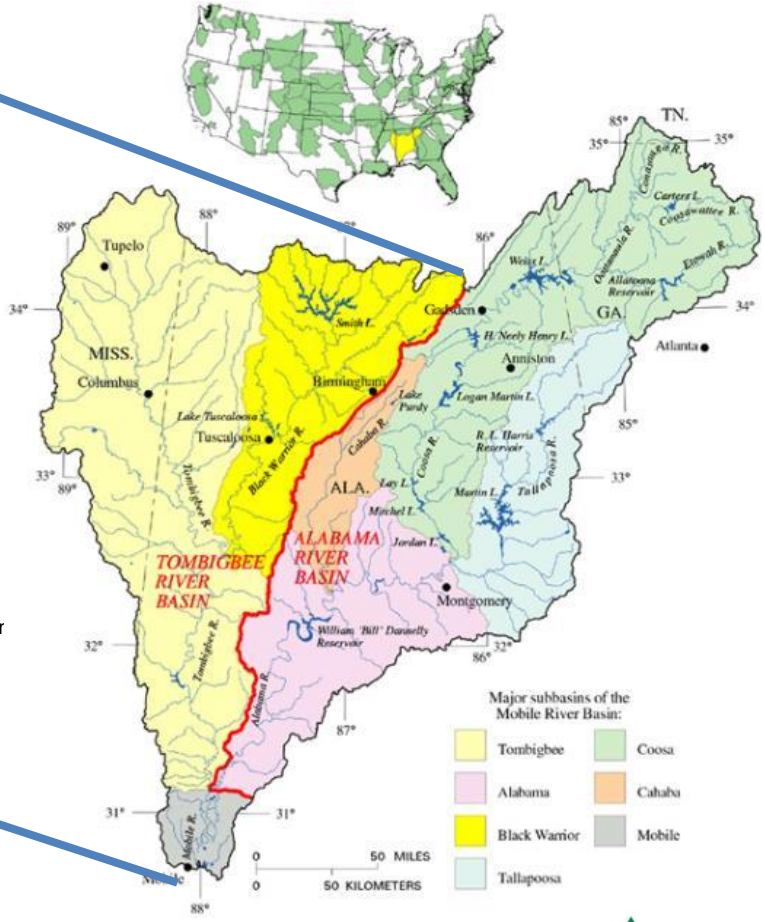
Partition ET into two portions: up-story trees and understory bio-energy grasses.

2 – Technical Accomplishments/ Progress/Results

Landscape Scale Modeling







Calibration and validation of SWAT for the Tombigbee Watershed

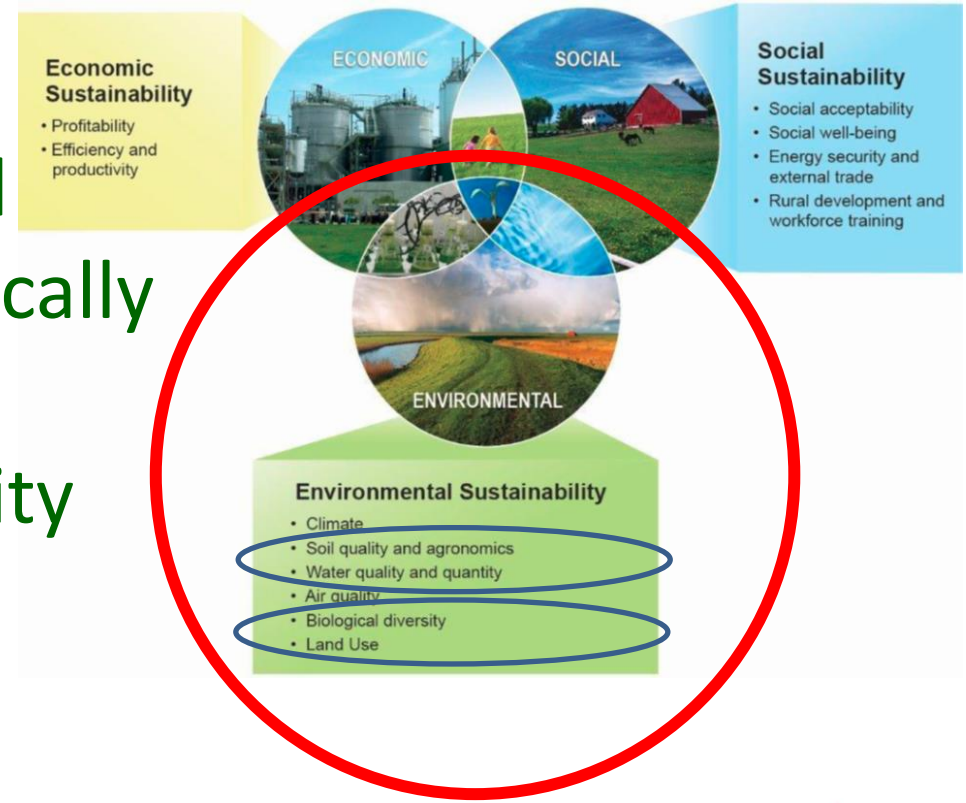
NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

3 – Relevance

Contribution to Goals of Biomass Program MYPP

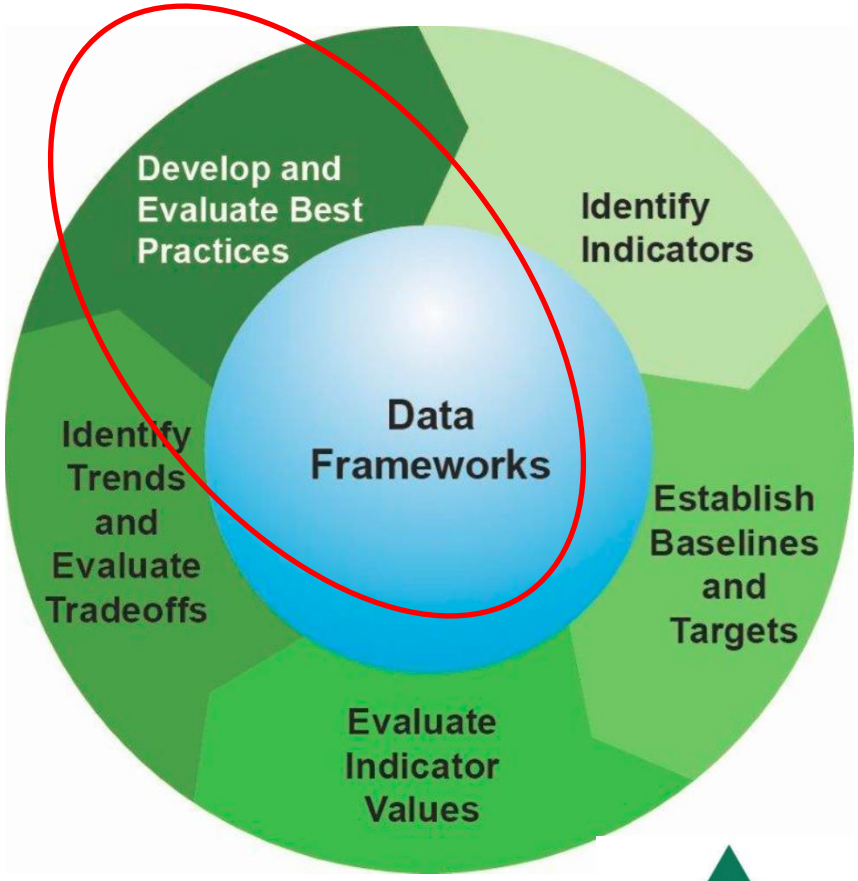
Our project is directly related to Environmental Sustainability and specifically to: Soil quality
Water quality/quantity
Biological diversity
Land use



3 – Relevance

Contribution to Goals of Biomass Program MYPP

The sustainability activity addressed by our project: "Develop and evaluate best practices based on monitoring, field data, and modeling results."



4 – Critical Success Factors

Success of this project will depend on:

- High quality data collection, and management
- Appropriate data analysis and interpretation
- Development and use of appropriate and effective models
- Presentation and publication of research results
- Development and dissemination of effective Best Management Practices

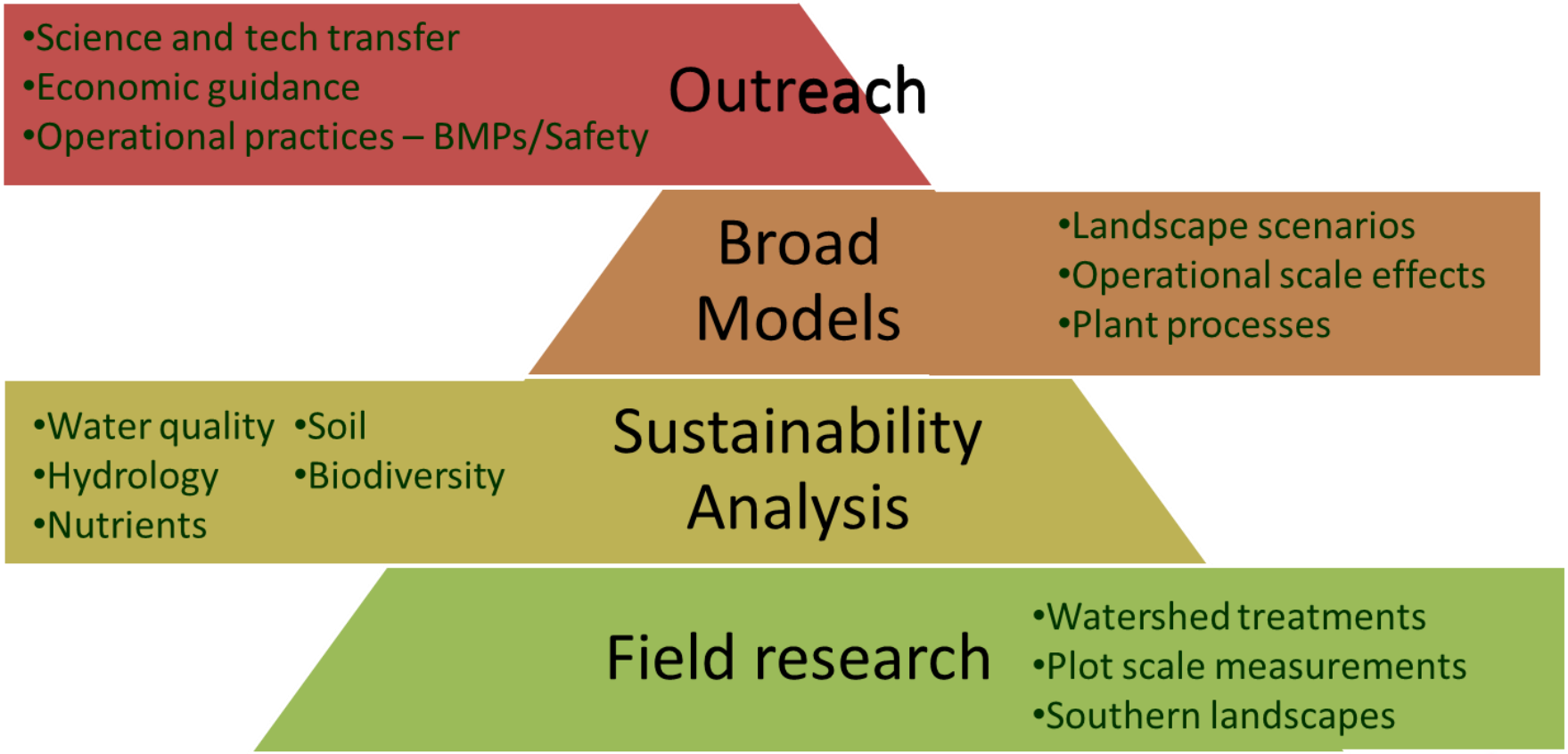
5 – Future Work

Tasks

- Complete data collection (watershed studies)
- Complete data analyses (watershed studies)
- Calibrate and validate watershed scale models
  - Go/No Go decision point on model validation
- Simulate multiple biofuel scenarios (watershed scale)
- Develop land use representations for SWAT
- Simulate multiple biofuel scenarios (landscape scale)
- Develop Best Management Practices
- Develop Life Cycle Analysis
- Co-host an External Conference
- Publish and disseminate results

Summary

Goal: **Develop and disseminate science-based information for sustainable production of forest biofuel feedstock in the Southeast.**



NC STATE UNIVERSITY Bio&Ag ENGINEERING

Weyerhaeuser

Responses to Previous Comments

How is site variability being handled?

- We have a total of 14 sub-watersheds in 3 states, across a range of soils and climate conditions but with similar forest conditions and treatments. Within each set, we selected watersheds with similar soils, slopes, site characteristics, and locations adjacent or very close to each other. We are quantifying site and climatic variation that does occur in the field. The Before/After, Control/Impact setup should also allow us to quantify variability.

Have you thought enough about generalizing the results?

- Modeling is a major component of our effort, and is being used to extend our watershed-scale studies to larger landscapes. We have already published innovative methods that link multi-scale models, from plant growth through rainfall runoff. These process-based models will help us evaluate where generalizations are appropriate and what kind of errors may come out of generalizations. We put a lot of effort into balancing broad applicability with likely environmental and economic conditions necessary for feedstock growth.

Responses to Previous Comments

Do you have a plan to deliver BMPs and land management strategies to non-industrial forest landowners?

- We plan several methods of outreach. Scientific publications with research data and models will be very important for ongoing research, but we recognize the importance of more practical outreach and plan to use existing networks to transfer our results. Weyerhaeuser Company is part of several grower networks, and regularly provides outreach material to loggers and small private landowners. More popular publications will reach extension agents and consultants. Our outreach will include information on the biofuel treatments as well as BMP guidance and safety-related material.

Will a sensitivity analysis be performed on the data used in the modeling?

- Sensitivity and uncertainty analyses will be performed on the important model inputs. These analyses have been performed on the DRAINMOD-Forest model and methods and results of those analyses are presented in the publications listed on the next slides. After the plant growth and competition components are added to the models, these same analyses will be performed and presented. The main focus will be on the management and plant growth variables used to simulate the switchgrass, pine trees, and the interactions between them.

Publications and Presentations

Publications:

- Tian, S.Y., M.A. Youssef, R.W. Skaggs, G.M. Chescheir and D.M. Amatya. 2013. Predicting dissolved organic nitrogen export from a drained loblolly pine plantation. Water Resources Research., 49, 1–16, doi:10.1002/wrcr.20157.
- Tian, S.Y., M.A. Youssef, R.W. Skaggs, D.M. Amatya, and G.M. Chescheir. 2012. Modeling water, carbon, and nitrogen dynamics for two drained pine plantations under intensive management practices, Forest Ecol. Manage., 264, 20–36.
- Tian, S.Y., M.A. Youssef, R.W. Skaggs, D.M. Amatya, and G.M. Chescheir. 2012. DRAINMOD-FOREST: Integrated modeling of hydrology, soil carbon and nitrogen dynamics, and plant growth for drained forests, J. Environ. Qual., 41(3), 764–782.
- Tian, S.Y., M.A. Youssef, R.W. Skaggs, D.M. Amatya, and G.M. Chescheir. 2012. Temporal variations and controlling factors of nitrogen export from an artificially drained coastal forest, Environ. Sci. Technol., 46(18), 9956–9963.
- Amatya, D.M. and R.W. Skaggs. 2011. Long-term hydrology and water quality of a drained pine plantation in North Carolina. Transactions ASABE 54(6): 2087-2098.Technology transfer

Presentations:

- Nettles, J. and Z. Leggett. 2012. Extent and distribution of sustainable intensive forest biofuel practices. Abstract accepted to the 2012 National Sun Grant Initiative Conference: “Science for Biomass Feedstock Production and Utilization.” October 2-5, New Orleans, LA.

Publications and Presentations

Presentations:

- Dalton, K.P., S.S. Panda, D. Amatya, R. Jackson, G. Chescheir, and J. Nettles. 2012. Remote estimation of pine forest hydrologic parameters with advanced geospatial technology. Presented at the International American Society of Agricultural and Biological Engineers (ASABE) Conference 2012, July 29 – August 2, 2012, Dallas, TX. Paper # 1337043.
- Nettles, J. and Z. Leggett. 2012. Extent and distribution of sustainable intensive forest biofuel practices. Abstract accepted to the 2012 National Sun Grant Initiative Conference: "Science for Biomass Feedstock Production and Utilization." October 2-5, New Orleans, LA.
- Nettles, J. 2012. Water yield impacts of forest-based biofuel scenarios. Third annual international conference on forests and water in a changing environment. September 16 – 19, 2012. Fukuoka, Japan
- Panda, S.S., J. Nolan, D. Amatya, K. Dalton, R.M. Jackson, H. Ssegane, and G. Chescheir. 2012. Stomatal conductance and leaf area index estimation using remotely sensed information and forest speciation. Presented as a poster at the 3rd International Conference on Forests and Water in a Changing Environment, Fukuoka, Japan, September 18 –20, 2012.
- Panda, S.S., J. Nolan, and L. Irminger. 2012. Orchard LAI estimation and land-use correlation using geospatial technology. Presented in the Georgia Geospatial Conference 2012, October 16 – 18, 2012, Athens, GA.

Publications and Presentations

Presentations:

- Cacho, J.F., M. A. Youssef, G. M. Chescheir, T. W. Appelboom, R. W. Skaggs. 2012. Impacts of bioenergy feedstock production on the shallow groundwater quality of drained forest lands. Presented at the International American Society of Agricultural and Biological Engineers (ASABE) Conference 2012, July 29 – August 2, 2012, Dallas, TX. Paper # 1337424
- Allen, Elizabeth, François Birgand, Vazken Andréassian, Charles Perrin and G.M. Chescheir. Quantifying the effect of biomass cropping system on hydrology by use of the GR conceptual model. Presented at the International American Society of Agricultural and Biological Engineers (ASABE) Conference 2012, July 29 – August 2, 2012, Dallas, TX. Paper # 1337210
- Tian, S., M. A. Youssef,R.W. Skaggs, G.M. Chescheir, D.M. Amatya. 2012. Predicting dissolved organic nitrogen export from a poorly drained loblolly pine plantation using modified version of DRAINMOD-NII. Presented at the International American Society of Agricultural and Biological Engineers (ASABE) Conference 2012, July 29 – August 2, 2012, Dallas, TX. Paper # 1338236
- Cacho, J.F., M. A. Youssef, G. M. Chescheir, T. W. Appelboom, R. W. Skaggs. 2012. Effects of Bioenergy Feedstock Production on Soil Physical Properties of Drained Forest Lands. presented at the International American Society of Agricultural and Biological Engineers (ASABE) Conference 2012, July 29 – August 2, 2012, Dallas, TX. Paper # 1337420

Publications and Presentations

Presentations:

- Tian, S., M. A. Youssef, D.M. Amatya, E.D., Vance. 2012. Global sensitivity analysis of the integrated forest ecosystem model, DRAINMOD- FOREST. Presented at the International American Society of Agricultural and Biological Engineers (ASABE) Conference 2012, July 29 – August 2, 2012, Dallas, TX. Paper # 1338234
- Nettles, J., D. Amatya, J. Cacho, G. Chescheir, J. Grace, Z. Leggett and M. Youssef. 2012. The impact of forest-based biofuel practices on riparian buffers and water resources. Oral presentation at the 2012 AWRA Summer Specialty Conference on Riparian Ecosystems. June 25-27, 2012, Denver, CO.
- Nettles, J. and G. Chescheir. 2012. The water footprint of intensive forestry operations. NCASI Southern Regional Meeting, June 11 – 13, Greenville, SC.
- Chescheir, G.M., R.W. Skaggs and D.M.Amatya, D.M,. 2012 Research methods to determine the hydrology and water quality impacts of eucalyptus production in the Southern US. Symposium on the Assessment and Management of Environmental Issues Related to Eucalyptus Culture in the Southern United States. Charleston, South Carolina February 22-24, 2012.
- Amatya,D.M, S. Panda, G. Chescheir, J. Nettles, T. Appelboom, and W. Skaggs. 2011.Evaluating Evapotranspiration of Pine Forest, Switchgrass, and Pine-Switchgrass Intercroppings using Remote Sensing and Ground-based Methods. Abstract submitted to AGU Annual meeting, San Francisco, CA, December 5 – 9,2011.
- Christopher,S., S. Schoenholtz, J. Nettles. 2011. Water resources implications of biofuelproduction at a regional scale. Abstract submitted to AGU Annual meeting, SanFrancisco, CA, December 5 – 9, 2011.

Publications and Presentations

Presentations:

- Nettles,J. 2011. Long term sustainability of forest-based biomass utilization. Biomass to Electricity Workshop, Electric Power Research Institute, Austin, TX,November 8 – 10, 2011.
- Amatya, D.M., R.W. Skaggs, J.E. Nettles, and G.M. Chescheir. 2011. Long-Term Hydrology of a Drained Pine Plantation: A Reference for Land Use Conversion into Bio-energy based Switchgrass Plantation in Coastal North Carolina. Poster Paper # 11-11504, ASABE Annual Int'l Meeting, Louisville, KY, August 7-10, 2011.
- Nettles, J, 2011. Forest biomass growth and harvest: Sustainability indicators and the billion ton update> Workshop, Billion Ton Study, Oak Ridge National Laboratories and the US Department of Energy Biomass Program. September 28 – 30, 2011. Oak Ridge, TN.
- Nettles, J. Z. Leggett, J. Grace. 2011. Water Yield Effects of Biofuel Intercropping in Loblolly Pine Plantations of the Southeastern US. American Fisheries Society Annual Meeting, Seattle, WA, September 4 – 8, 2011.
- Nettles, J., J. Grace, Z. Leggett. 2011. Field survey of riparian sediment delivery in forest biofuel operations. ASABE Annual Meeting, Louisville, KY, August 7 – 10th, 2011.
- 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.

Publications and Presentations

Presentations:

- 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. IUGG 2011, Earth on the Edge, Science for a Sustainable Planet. Melbourne, Australia, June 28 – July 8, 2011.
- Nettles, J., W. Skaggs, D. Amatya, G. Chescheir. The effects of silvicultural and biofuel operations on water quality and quantity: Long term experimental watershed studies in poorly drained pine plantations, North Carolina, US. IUGG 2011, Earth on the Edge, Science for a Sustainable Planet. Melbourne, Australia, June 28 – July 8, 2011.