DOE Bioenergy Technologies Office (BETO) 2017 Project Peer Review

Optimization of Southeastern Forest Biomass Crop Production:

Watershed Scale Evaluation of the Sustainability and Productivity of Dedicated Energy Crop and Woody Biomass Operations

March 9, 2017

Sustainability and Strategic Analysis

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Weyerhaeuser Company

Goal Statement

Develop and disseminate science-based information for sustainable production of biofuel feedstock in a forestry setting in the Southeast

Relevance to goals of BETO

Evaluate the environmental and economical sustainability of a potentially viable biomass production technology that:

- Will not compromise availability of food, fiber, and water
- Can utilize over 15 million ha of pine plantation forests in the southeast

Quad Chart Overview

Timeline

- Start date - Sept. 30, 2010
- End date - Sept. 30, 2016
- Percent complete – 100%

Budget

	Total Costs FY 10 –FY 14	FY 15 Costs	FY 16 Costs	Total Planned Funding FY 17- End Date
DOE Funded	1446 k	282k	248 k	
Cost Share				
NCSU	132 k	17 k	16 k	
Weyer	992 k	355 k	373 k	
Catchlight	780 k			
V-Tech	65 k			

Barriers

- **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

Partners

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

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Project Overview

Is intercropping switchgrass between pine trees a sustainable method for bioenergy production?

Pine planted at a wide row spacing

However,

- **Converting conventional forestry to intercropping is a land use change**
- **Is this land use change sustainable?**
  - **Environmentally**
  - **Economically**

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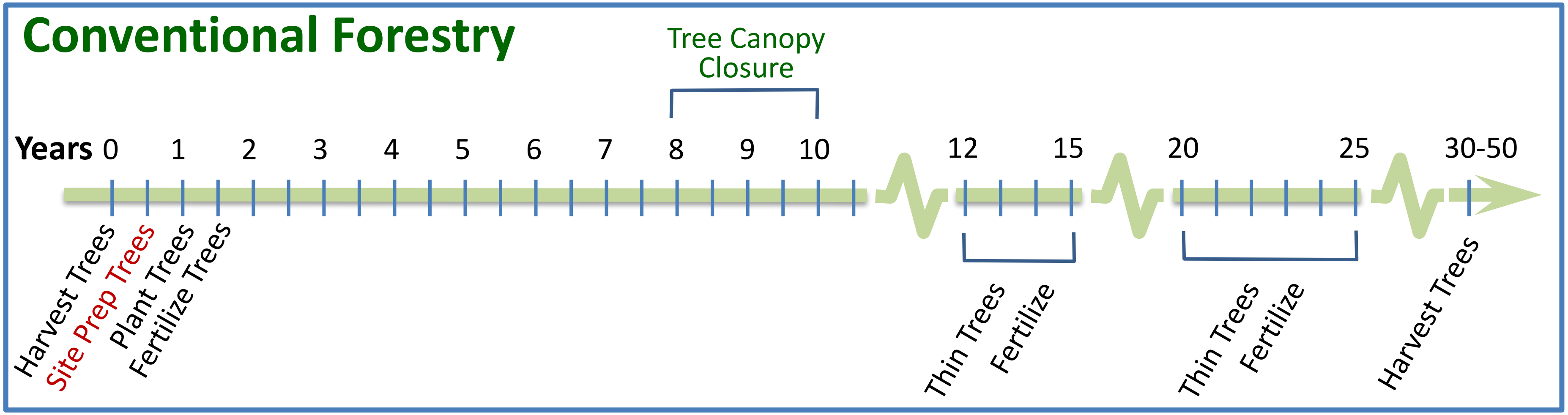
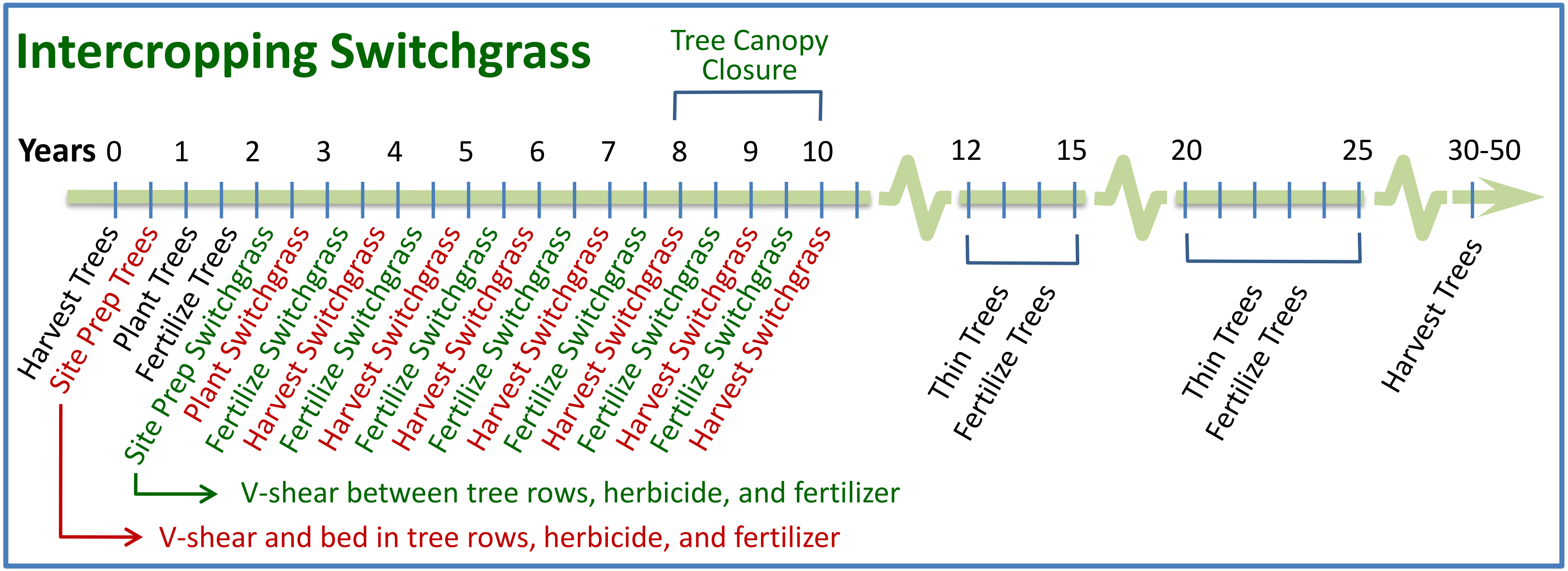
Entry Events for Intercropping Switchgrass Compared to Conventional Forestry





Operations for Seedbed Preparation for Switchgrass

Objectives

Evaluate the sustainability of large-scale forest biofuel feedstock production in the southeastern United States.

1. Quantify the hydrology of different energy crop production systems in watershed scale experiments on different landscapes in the southeast.
2. Quantify the nutrient dynamics of energy crop production systems in watershed scale experiments to determine the impact of these systems on water quality.
3. Evaluate the impacts of energy crop production on soil structure, fertility, and organic matter content.

Project Overview

Objectives

4. Evaluate the response of flora and fauna populations and habitat quality to energy crop production systems.
5. Develop watershed and regional scale models to evaluate the environmental sustainability and productivity of energy crop and woody biomass operations.
6. Quantify the production systems in terms of bioenergy crop yield versus the energy and economic costs of production.
7. Develop and evaluate best management practice guidelines to ensure the environmental sustainability of energy crop production systems.

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Approach (Management)

Project Structure and Team Responsibilities

1. Quantify hydrology - NCSU, Weyer, USFS.
2. Quantify the nutrient dynamics - NCSU,Weyer, USFS
3. Evaluate soil structure and fertility - NCSU, Weyer, V-Tech
4. Evaluate flora and fauna and habitat quality - Weyer
5. Develop watershed and regional models - NCSU, V-Tech
6. Quantify production in terms of crop yield versus the energy and economic costs of production – Weyer, NCSU
7. Develop and evaluate BMPs – NCASI, Weyer

Approach (Management)

Critical success factors – Appropriate and consistent data analysis and management, unrestricted flow of information and ideas between collaborators

Structure - Quarterly meetings:

Present results Review protocols Discuss logistics

Advisory board meetings with outside advisors:

Review results Evaluate progress Strategic planning

Share resources with outside colleagues:

Other Forest Service studies Other university studies

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Approach (Technical)

- Conduct watershed and plot scale experiments to provide data for watershed scale models
- Develop watershed scale models to simulate performance of energy crop production systems over a range of climatic and landscape conditions
- Use results of field and modeling studies to develop best management practices.

Critical success factors – Establish treatments, High quality field data, Appropriate and effective models

Challenges – Establishment of Treatments

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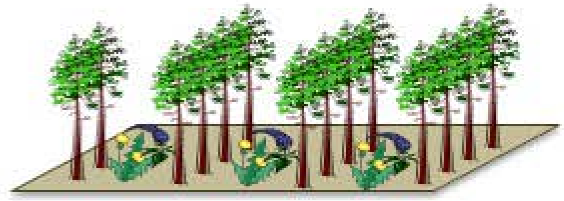
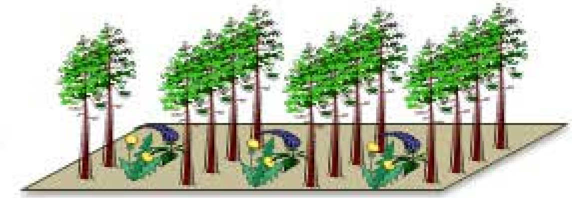
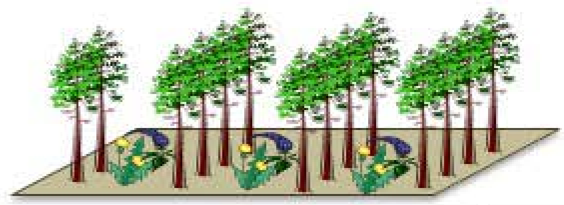
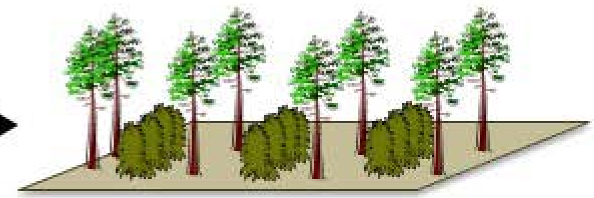
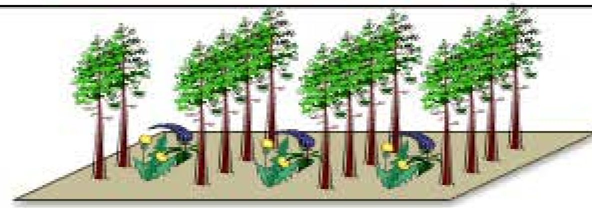
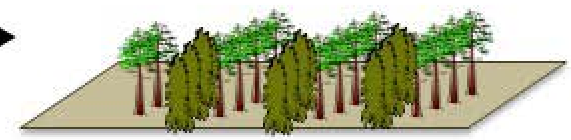
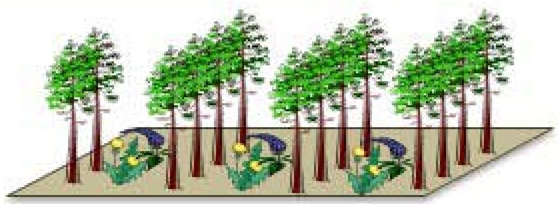
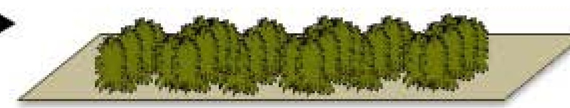
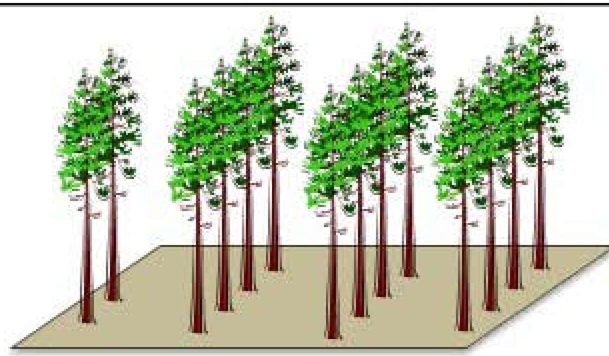
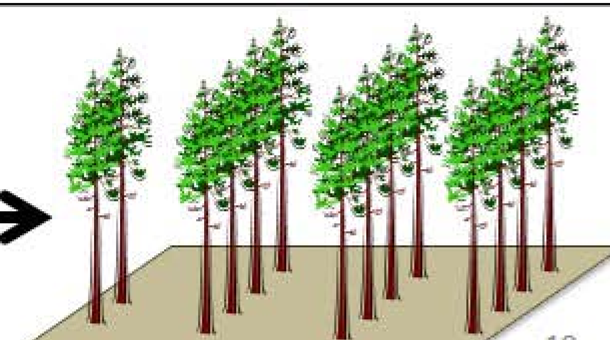
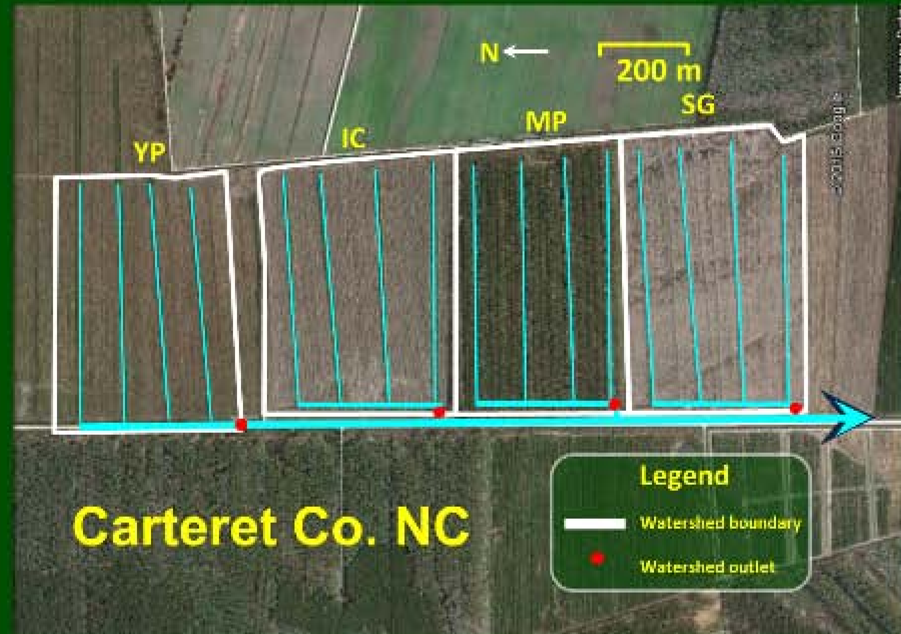
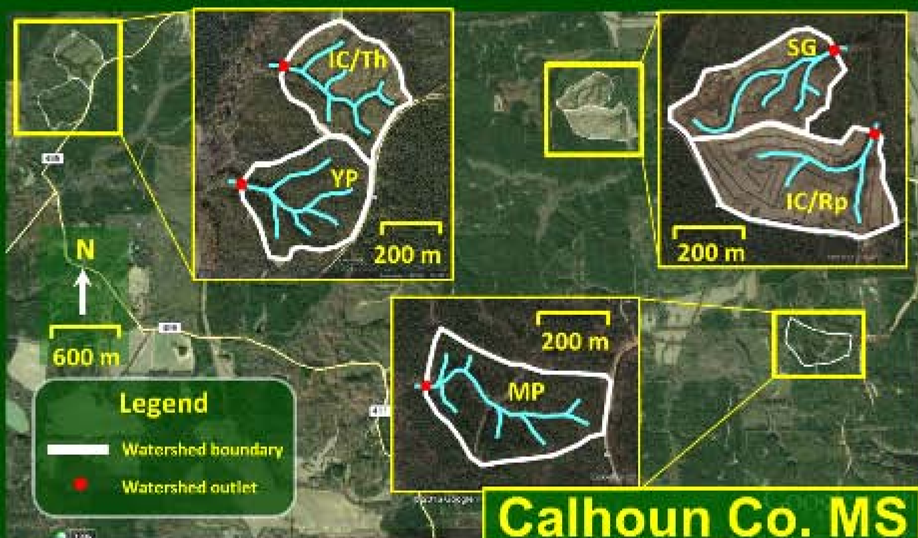
	Pre-Treatment	Post-Treatment
YP **Young Pine**		→ 
IC/Th **Intercrop Thin**		→ 
IC/Rp **Intercrop Replant**		→ 
SG **Switchgrass Only**		→ 
MP **Mature Pine**		→ 

Approach (Technical)

Watershed Experiments





Approach (Technical)

Watershed Experiments

Watershed size – 11 to 27 ha

Measurements (Hydrology)

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

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Approach (Technical)

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

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Approach (Technical)

Watershed Experiments

Measurements (other)

- Soil Physical Properties
- Vegetation Characteristics
- Aquatic Macroinvertebrates
- Diversity of Flora and Fauna
- N and C cycling

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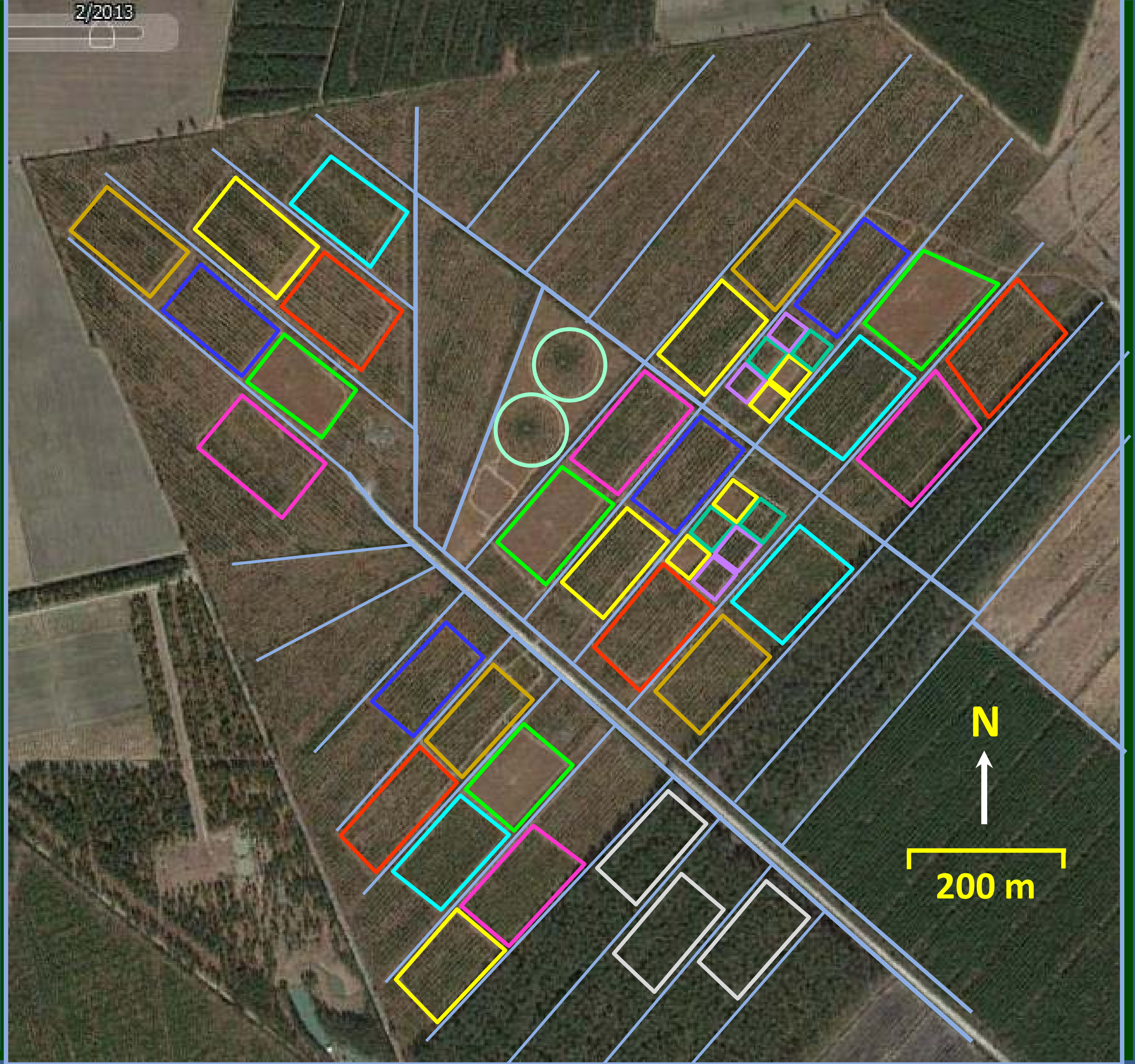
Lenoir County Site, NC



Legend

- Pine Only
- Pine, Biomass
- Switchgrass only
- Pine, Switchgrass
- Pine, Switchgrass, Biomass
- Extra row Pine, Biomass
- Extra row Pine
- Reference, Pine P.D. 1975
- Miscanthus
- Pine, Miscanthus, Biomass
- Nelder Plots
- Drainage Ditch

Approach (Technical)

Plot Scale Experiments

Plot size – 0.8 ha

3 Replicates

Measurements

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

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Approach (Technical)

Plot Scale Experiments

Plot size – 0.8 ha

3 Replicates

Measurements

- Diversity of Flora and Fauna
- Crop growth
- Crop Competition
- Crop Water Use Efficiency
- Crop Root dynamics

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Approach (Technical)

Watershed Modeling

Watershed Scale

Use process based models to simulate:

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

DRAINMOD-Intercrop for flat high water table soils

APEX for upland conditions

Landscape Scale

DRAINMOD-Intercrop with GIS interface and **SWAT** model to simulate the impacts of biofuel production on the hydrology and water quality of large watersheds

Approach (Technical)

Best Management Practices

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

- Compare water quality, hydrology, and aquatic biology across treatments to determine practices that led to sustainability issues
- Use sediment survey data to pinpoint settings where BMPs were inadequate to protect water resources
- Collect and summarize applicable literature on forest bioenergy practices
- Develop operationally feasible BMP guidelines
- Publish guidelines and distribute through grower networks

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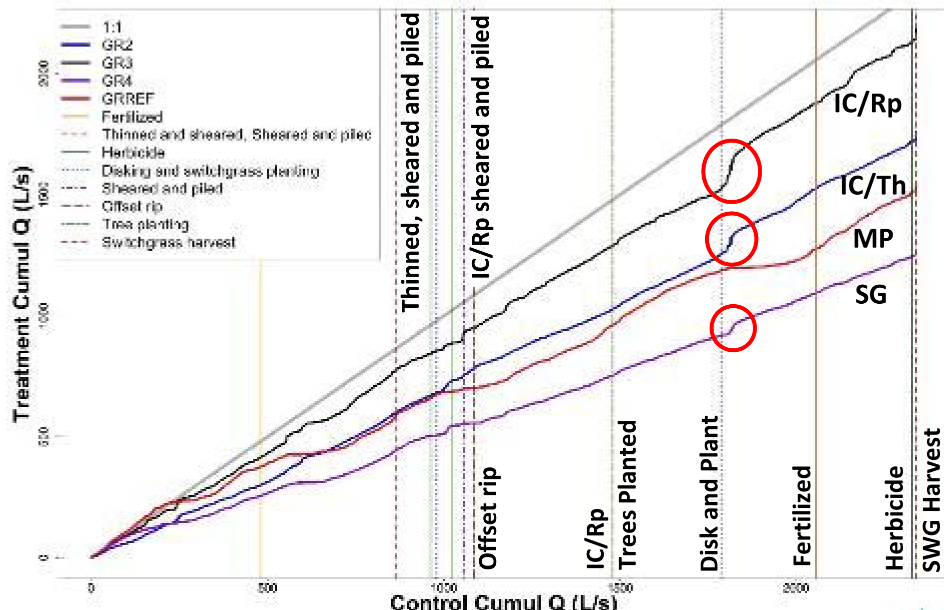
Technical Accomplishments

1. Effect of energy crop production on hydrology

Although hydrology changes due to conversion of conventional forest to switchgrass interplanting or switchgrass monoculture were difficult to observe in the paired watershed studies, we found evidence that water yield increased from watersheds with intercropped switchgrass and monoculture switchgrass when compared to conventional forestry.

Relative to conventional forestry, water yield increased in the inter cropped and switchgrass sites after the sites were disked and replanted.

Cumulative Flow at Greene Co. AL watersheds



Dobbs, N.A. (2016). Hydrology and Water Quality Dynamics Dynamics in Coastal Plain and Upland Watersheds with . . . Intercropping in the southeastern United States, PhD Dissertion, North Carolina State University

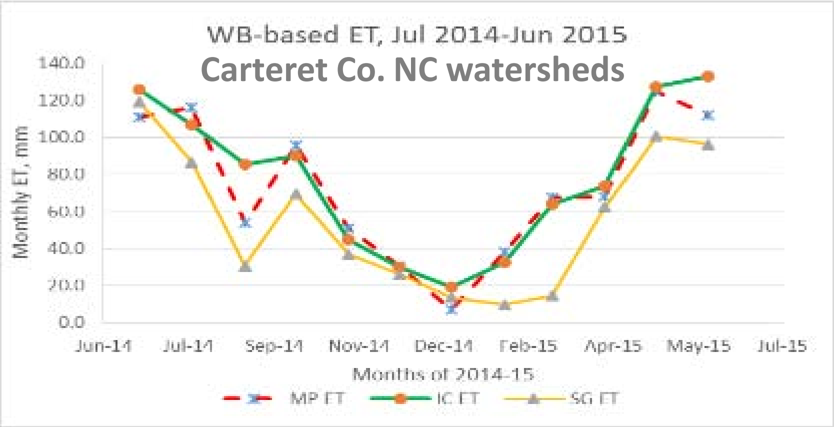
Technical Accomplishments

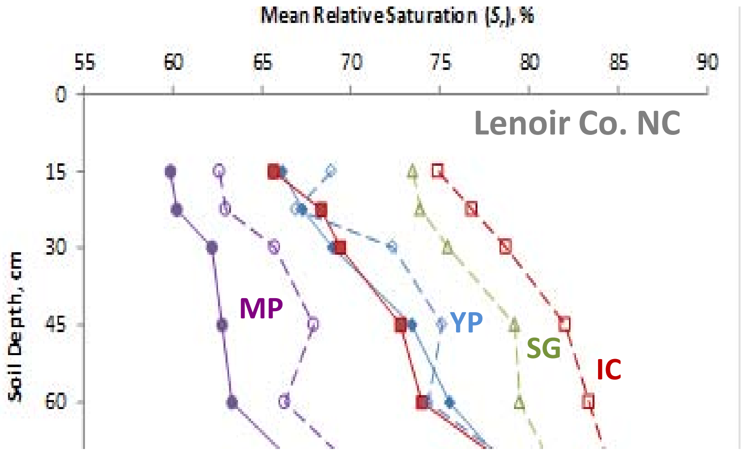
1. Effect of energy crop production on hydrology

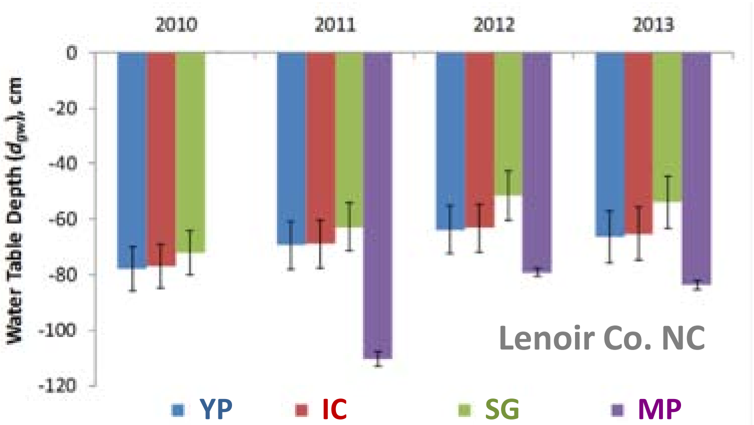
ET calculated by water balance lower for switchgrass monoculture

Relative saturation greater for intercropping and SG

Water table shallow for SG







Amatya, D.M., et.al. 2016. Estimating PET and ET of Switchgrass and Its Inter-cropping in Young Pine Stands on NC Coastal Plain. ASABE 2016 Int'l meeting.

Cacho, J. F. (2013), Impacts of Bioenergy Feedstock Production on Soil Physical Properties, Soil Water and Nitrogen Dynamics . . ., PhD Dissertion North Carolina State University.

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Technical Accomplishments

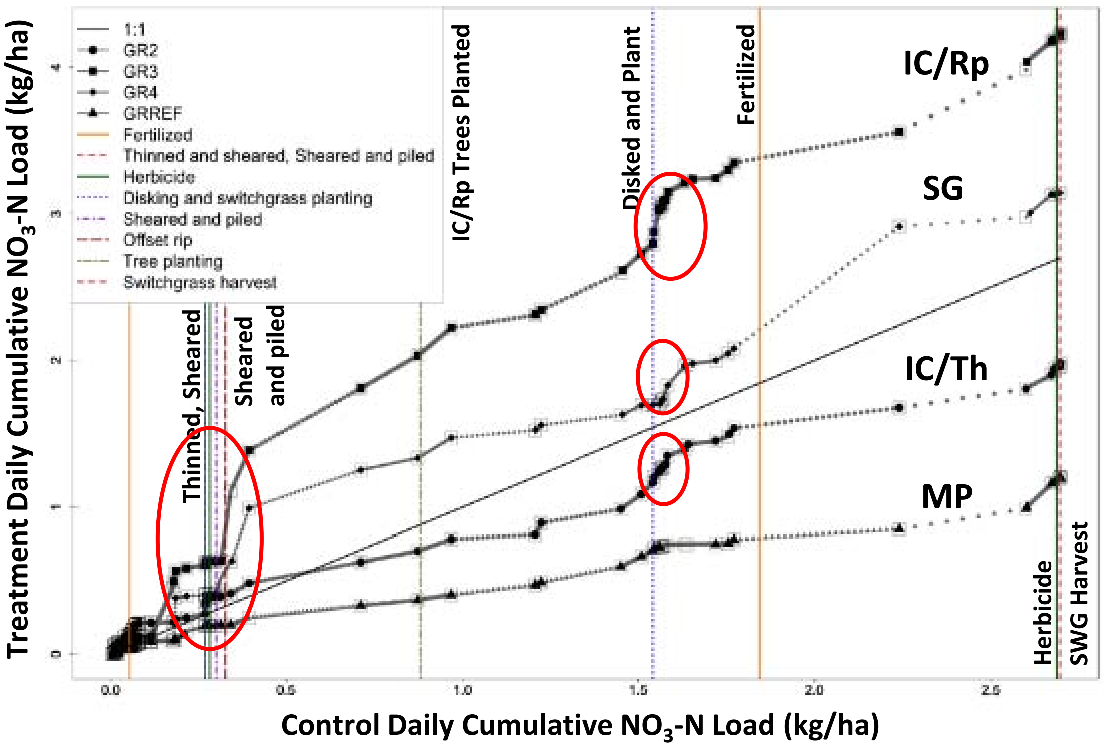
2. Effect of energy crop production on water quality

Annual NO_3-N loads from all watersheds were less than 2.5 kg/ha. Consistent with managed forestry

Some field operations caused short term increases in NO_3-N loadings.

	NO_3-N Load kg/ha/yr				
Year	YP	IC/Th	IC/Rp	SG	MP
2	0.18	0.15	0.61	0.36	0.17
3	0.49	0.38	1.02	0.84	0.19
4	0.82	0.76	1.15	0.63	0.37
5	0.93	0.46	0.90	1.08	0.43

Cumulative NO_3-N loads at Greene Co. AL watersheds



Dobbs, N.A. (2016). Hydrology and Water Quality Dynamics Dynamics in Coastal Plain and Upland Watersheds with . . . Intercropping in the southeastern United States, PhD Dissertion, N. C. State University

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Technical Accomplishments

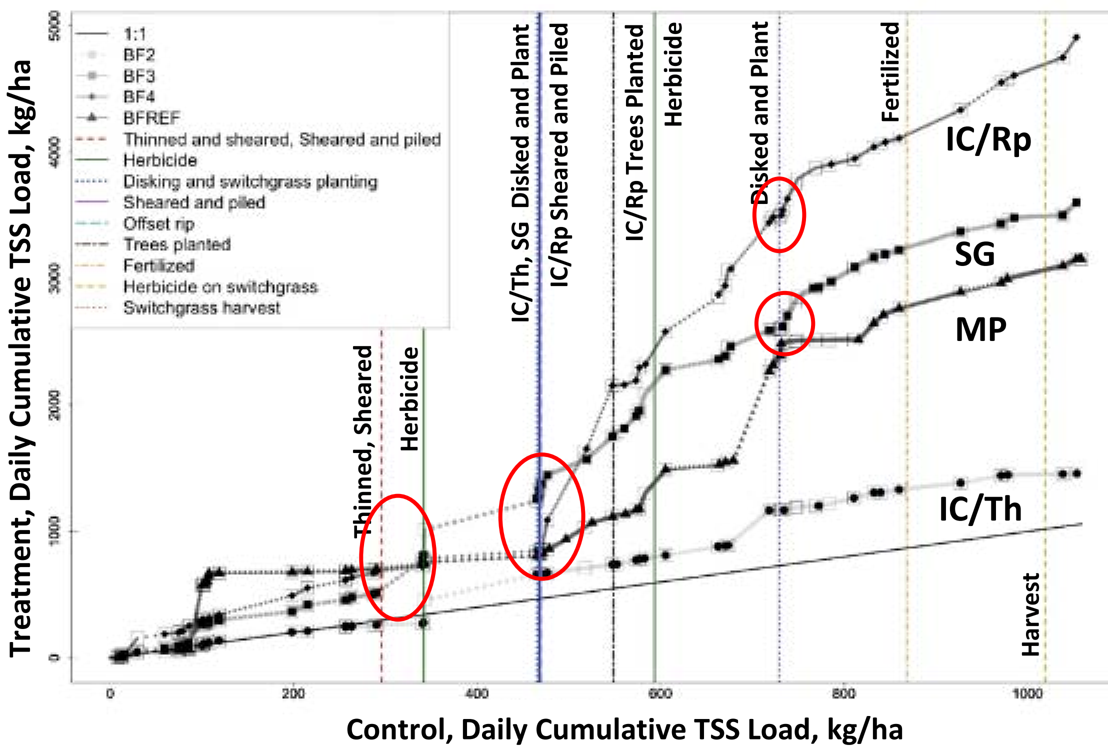
2. Effect of energy crop production on water quality

Annual TSS loads from upland watersheds were less than 2.5 t/ha. They were less than 0.04 t/ha from NC watersheds. Consistent with managed forestry

Some field operations caused short term increases in TSS.

	TSS Load kg/ha/yr				
Year	YP	IC/Th	IC/Rp	SG	MP
2	263	241	672	586	861
3	354	712	2256	1938	668
4	270	537	1716	1083	1402
5	199	128	801	379	394

Cumulative TSS loads at Calhoun Co. MS watersheds



Muwamba, A. et al. (2015), Effects of site preparation for pine forest switchgrass intercropping on water quality, J. Environ. Qual., 44(4), 1263-1272

Carter, T.M. (2016). Impacts of Established Loblolly Pine and Switchgrass Intercropping . . . on Hydrology and Water Quality, MS Thesis, N. C. State Univ.

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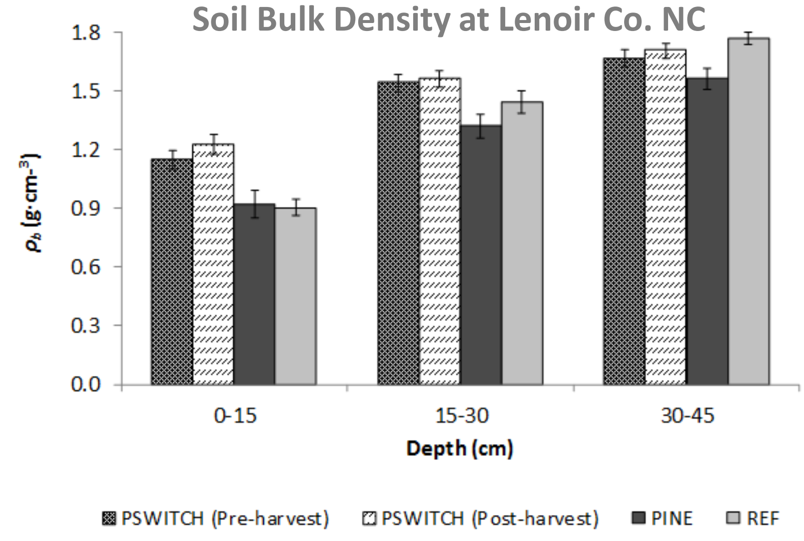
Technical Accomplishments

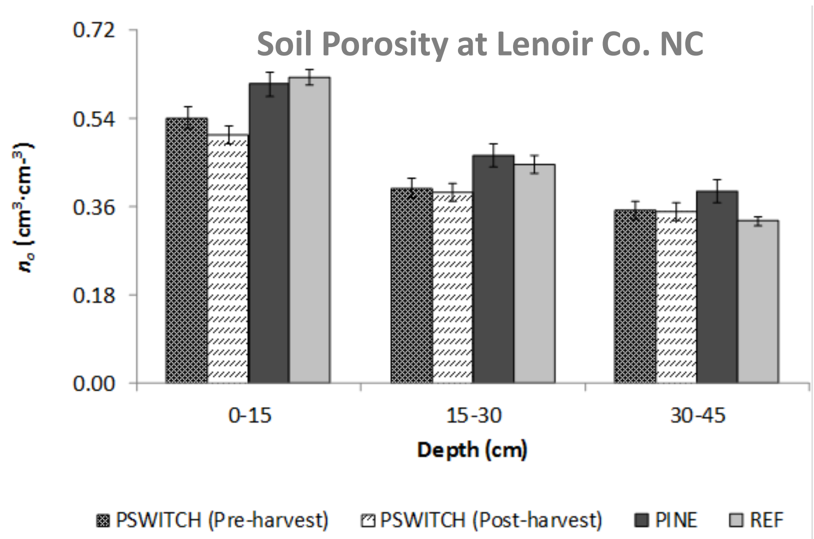
3. Effect of energy crop production on soil properties

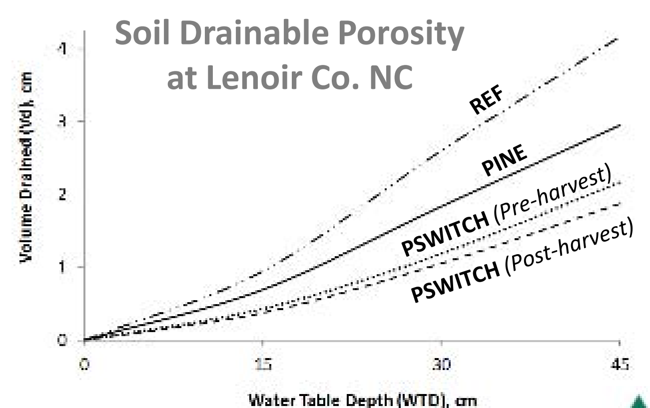
Soil bulk density was higher and soil porosity was lower at 0-15 cm and 15-30 cm depths at interplanted site.

Soil drainable porosity was lower at interplanted site.

Soil properties were not affected by third switchgrass harvest.







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Cacho, J. F. et al. (2015), Impacts of Switchgrass-Loblolly Pine Intercropping on Soil Physical Properties of a Drained Forest, Transactions of the ASABE, 58(6), 1573–1583

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Technical Accomplishments

4. Effect of energy crop production on biodiversity

a) Bird species associated with pine-grassland conditions were less on intercropped stands than pine controls for the first 2 years after stand establishment, but then communities were similar.

Loman, Z. G. et al. (2014) Breeding bird community response to establishing intercropped switchgrass in intensively-managed pine stands. Biomass and Bioenergy 67:201-211.

b) Differences in browse for white-tailed deer were only evident in the first 2 years after stand establishment. Overall, carrying capacity for white-tailed deer was not affected by intercropping.

Greene, E. J. (2016) Plant community and white-tailed deer nutritional carrying capacity response to intercropping switchgrass in loblolly pine plantations, Master of Science, Mississippi State University.

c) Switchgrass intercropping within managed loblolly pine did not affect wild bee communities.

Campbell, J. W. et al. (2016) Switchgrass (Panicum virgatum) intercropping within managed loblolly pine (Pinus taeda) does not affect wild bee communities. Insects 7, 62.

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Technical Accomplishments

4. Effect of energy crop production on biodiversity

d) Intercropping appeared sufficient to maintain rodent communities. although communities were less diverse in intercropped stands primarily due to increased dominance by cotton rats (Sigmodon hispidus) at the MS sites and by increased numbers of an invasive species, the house mouse (Mus musculus) at the NC sites.

King, K. L. et al. (2014) Response of rodent community structure and population demographics to intercropping switchgrass within loblolly pine plantations in a forest-dominated landscape. Biomass and Bioenergy 69:255-264.

Marshall, M. M. et al. (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.

e) Detection, diversity, and relative abundance of the herpetofaunal community were generally not affected by biomass removal or switchgrass interplanting.

Homyack, J. A. et al. (2013) Initial effects of woody biomass removal and intercropping of switchgrass (Panicum virgatum) on herpetofauna in eastern North Carolina. Wildlife Society Bulletin:1-9.

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Technical Accomplishments

5. Crop system in terms of yield vs. energy and economy

Yields of switchgrass interplanted with pine trees was below levels needed for economic feasibility.

Costs per bale for field operations was about double those for agriculture.

a) Additional site preparation (disking before planting) increased cost of production.
b) Increased need for equipment maneuverability slowed field operations.
c) Limitations of equipment and concerns about erosion limited production to lower slopes. Reduced planted area by approximately 25%
d) Competition for light between switchgrass and trees limited production to a 5 to 7 year window.
e) Switchgrass yields were reduced in low pH and high water table conditions.

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Nettles, J. et al. (2015). Sustainable Production of Bioenergy Feedstock from the Industrial Forest: Potential and Challenges of Operational Scale Implementation, Curr Sustainable Renewable Energy Rep, 2(4), 121–127

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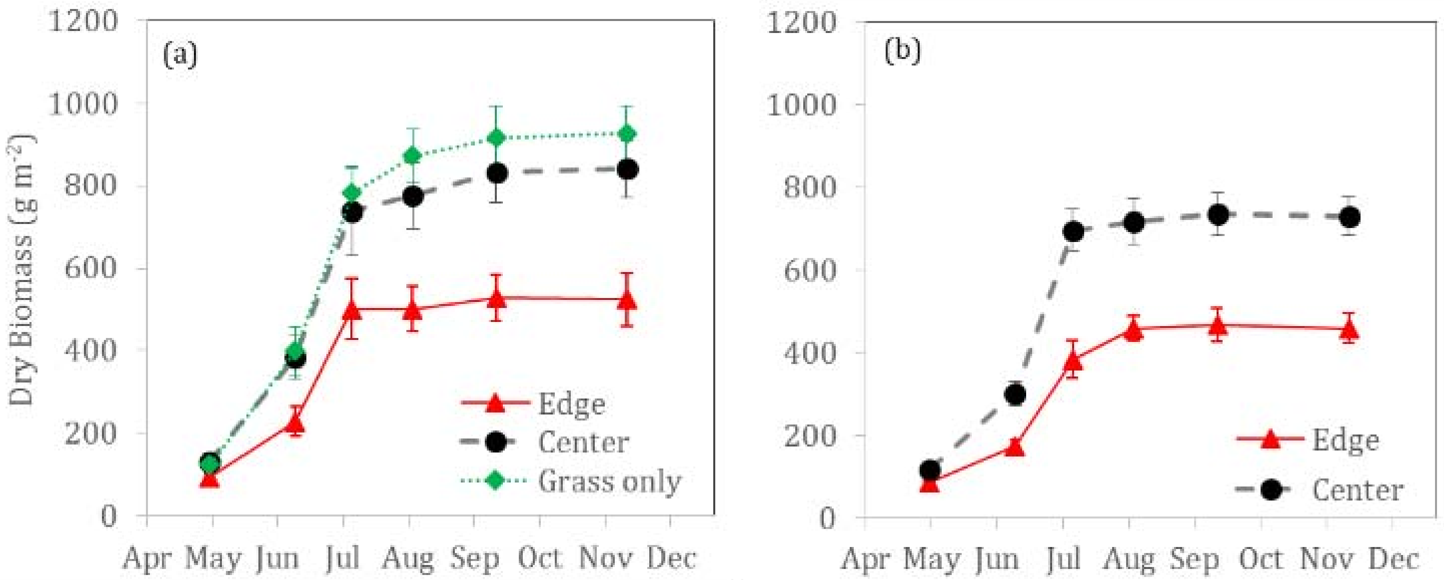
Technical Accomplishments

5. Crop system in terms of yield vs. energy and economy

Effect of tree shading on switchgrass productivity

Dry Biomass (g m²)	Lenoir		Carteret	
	2014	2015	2014	2015
Edge	598±58	523±65	577±98	459±37
Center	843±70	839±70	800±121	732±47
Edge/Center	0.71	0.62	0.72	0.63



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Tian, S. et al. (2016). Switchgrass growth and pine-switchgrass interactions in established intercropping systems, GCB Bioenergy, doi:10.1111/gcbb.12381.

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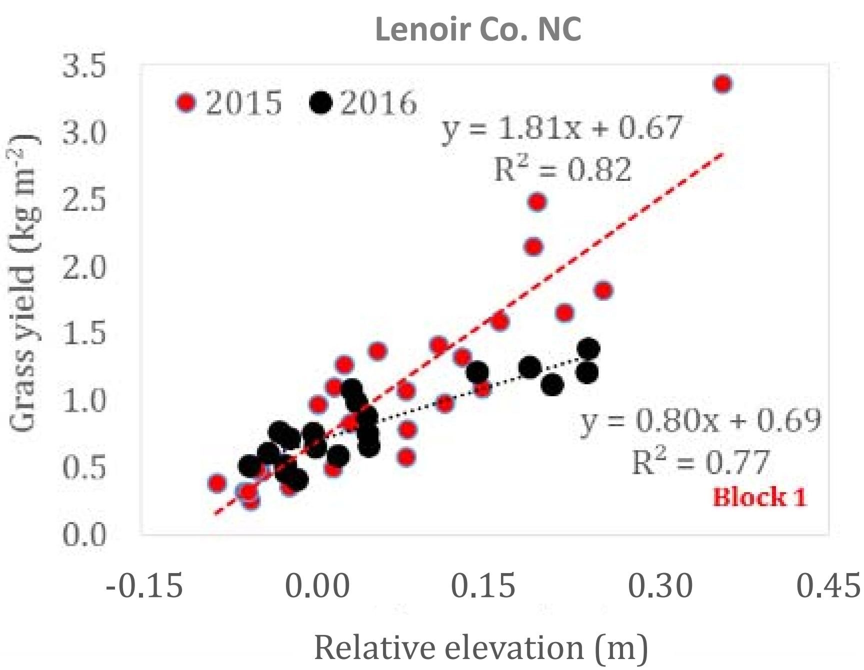
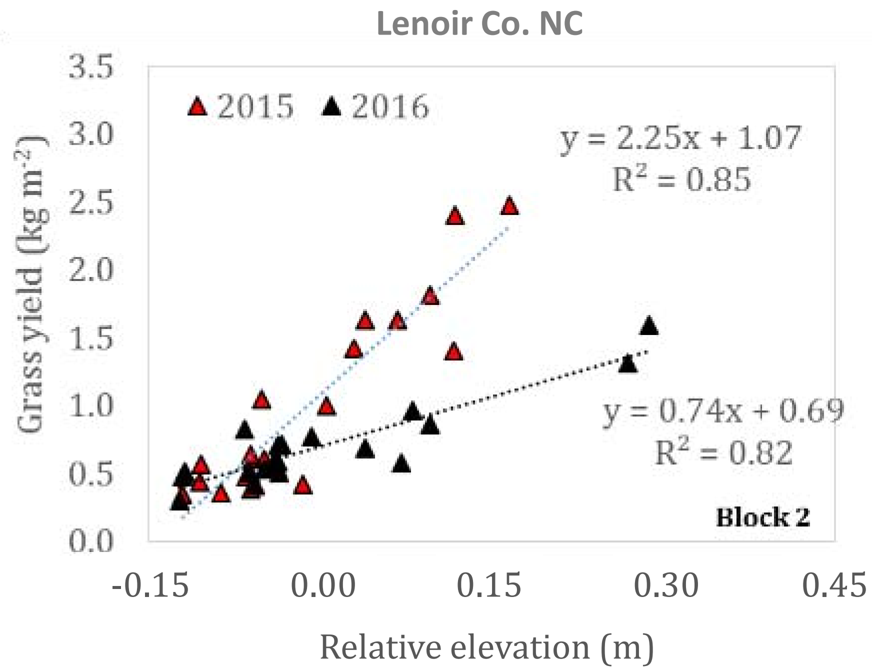
Technical Accomplishments

5. Crop system in terms of yield vs. energy and economy

Effect of topography induced excess water stress on switchgrass yield





Tian, S. et al. (2017). Effects of micro-topography induced water-logging on switchgrass (Alamo) growth in lowland areas. Submitted to GCB Bioenergy

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Technical Accomplishments

6. Develop watershed and regional scale models

DRAINMOD Forest
Tian et al., 2012, Journal of Environ. Quality

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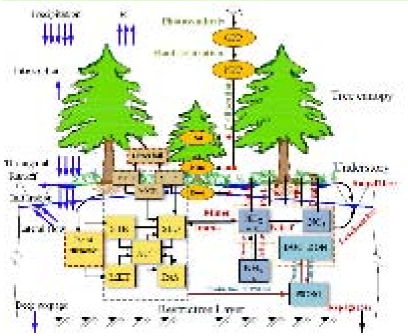
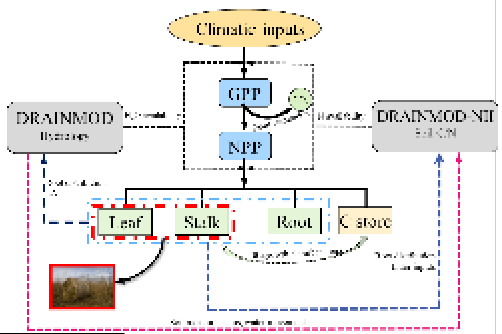
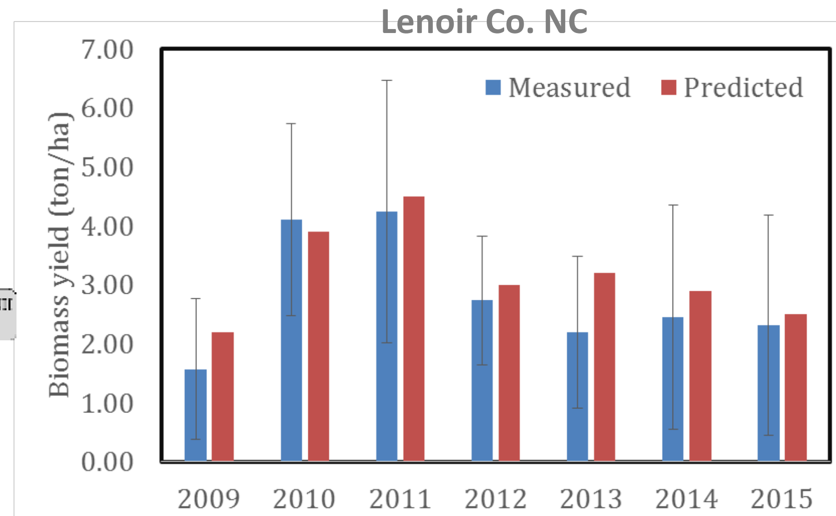
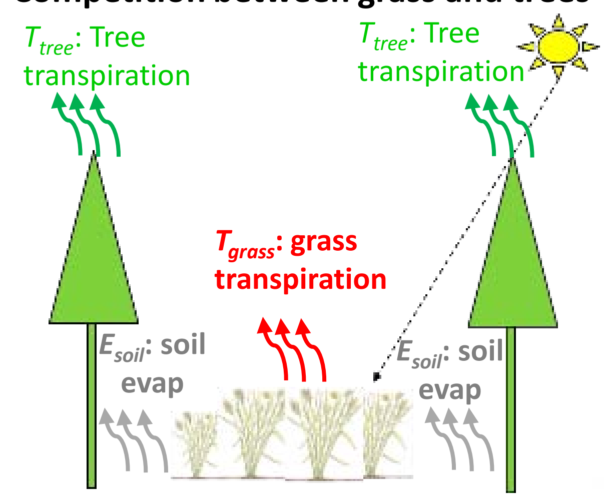
DRAINMOD Grass
Tian et al., 2016, Environ Modelling & Software

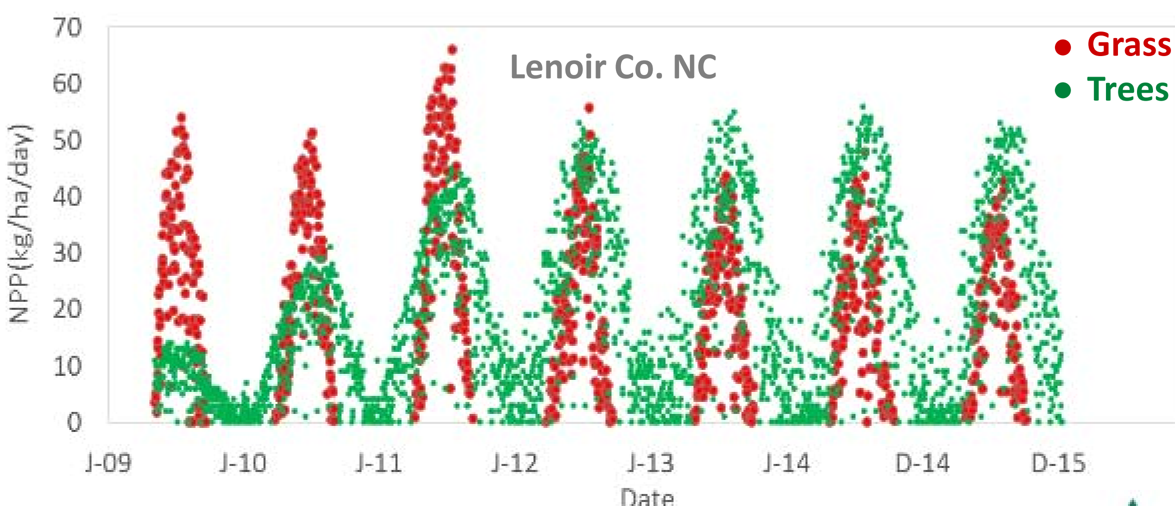






Competition between grass and trees





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Tian, S. et al. (2016) Development and field testing of an integrated process-based model for pine-switchgrass intercropping systems. 10th International Drainage Symposium.

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Technical Accomplishments

6. Develop watershed and regional scale models

DRAINMOD-Intercrop simulations with GIS interface of the Lower Tar Pamlico River Basin

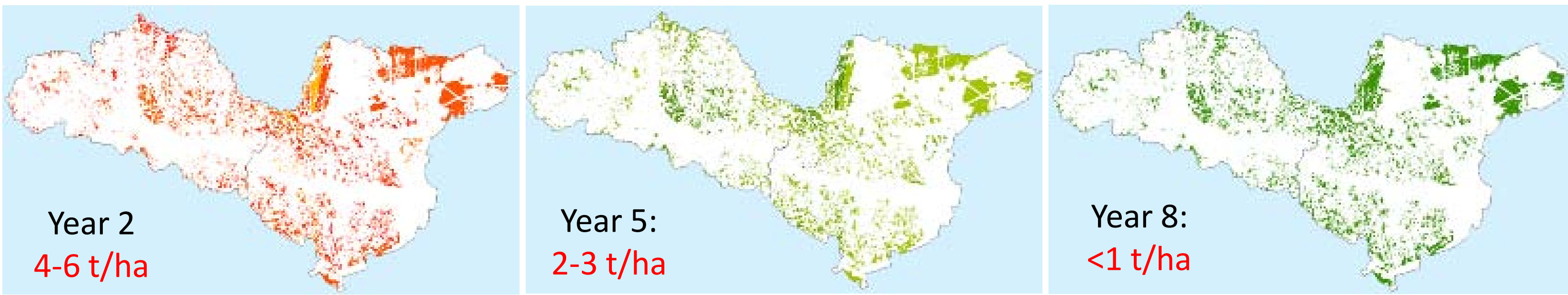
(kg/ha)

- 0 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 2500
- 2501 - 3000
- 3001 - 3500
- 3501 - 4000
- 4001 - 4500
- 4501 - 5000
- 5001 - 5500
- 5501 - 6000
- 6001 - 6500

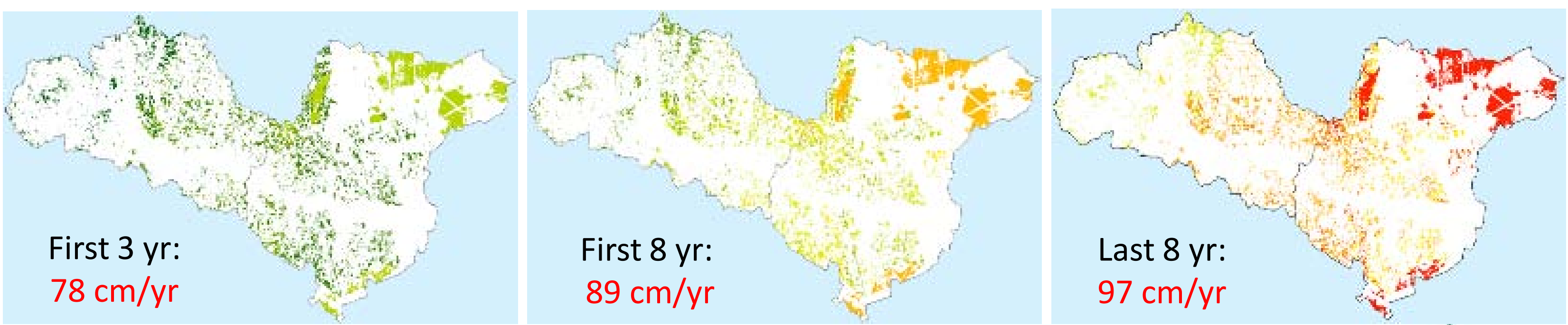
(cm/yr)

- 0 - 70
- 71 - 75
- 76 - 80
- 81 - 85
- 86 - 90
- 91 - 95
- 96 - 100
- 101 - 105
- 106 - 110
- 111 - 115

Predicted Average Switchgrass Yield for Different Time Periods



Predicted Average Water Use for Different Time Periods



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Tian, S. et al. (2017) Evaluation of environment impacts and economic outputs of switchgrass-pine intercropping at a regional scale. Internal Review.

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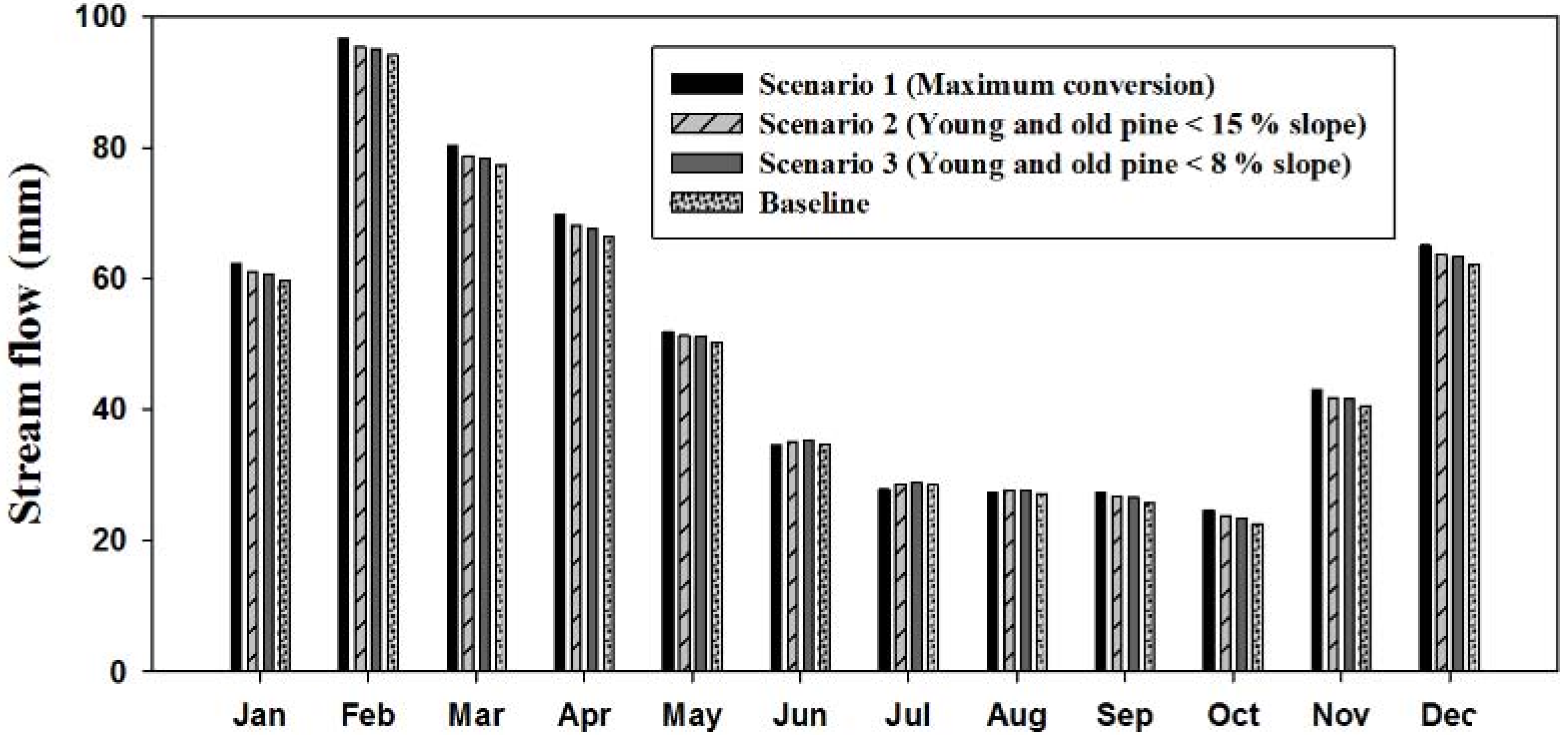
Technical Accomplishments

SWAT simulations of Tombigbee Watershed predicted impacts of intercropping on streamflow

Predicted streamflow increases of 2 to 7%

Higher increases predicted in winter



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Christopher, S. F. et al. (2015), Water quantity implications of regional-scale switchgrass production in the southeastern U.S, Biomass and Bioenergy, 83, 50–59

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Technical Accomplishments

7. Develop and evaluate BMP guidelines

The BMPs practiced for interplanting switchgrass were the same as those used for managed forestry - riparian buffers, contour planting, and well-managed roads and road drainage.

The existing BMPs gave a flexible system that could be adapted by allowing contractor judgment to be incorporated into site and riparian buffer layout.

This resulted in riparian buffers being almost doubled where they were most valuable. Higher slope and wetter areas were also avoided as appropriate to soils.

This flexible system provided a solid basis for protecting water quality as well as it does in conventional silviculture.

Additional BMPs could lead to a high energy cost per managed acre and be counter-effective when GHG implications are considered.

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Schilling, E., and J. Nettles. (2017) Best Management Practices in Forest Biomass Operations. Internal Review.

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Technical Accomplishments

Educational and Training Opportunities

University Student Opportunities

5	Post-Doc Fellows	5 Completed
3	PhD students	2 Completed
6	Masters students	6 Completed

14 - Undergraduate assistants

45 - Undergraduate students have participated in a prepared biofuel lecture and field exercise.

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Relevance

Contribution to Goals of BETO Multi-Year Program Plan

Our project is directly related to Environmental Sustainability and specifically to:

- Soil quality
- Water quality/quantity
- Biological diversity
- Land use

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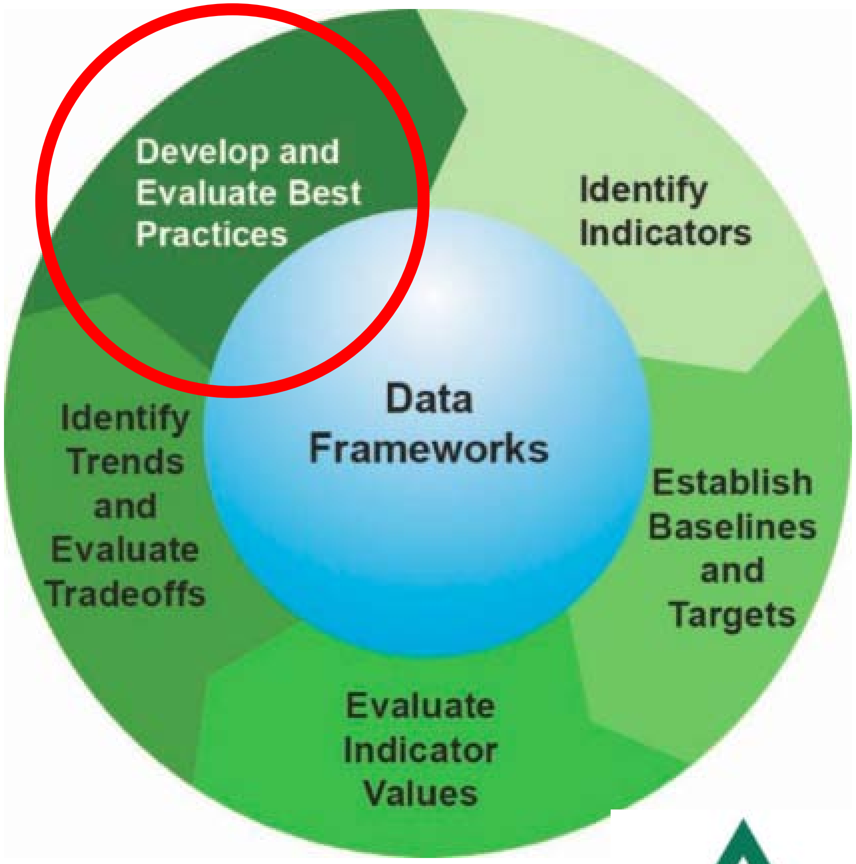
Relevance

Contribution to Goals of BETO Multi-Year Program Plan

The sustainability activity addressed by our project:

"Develop and evaluate best practices based on monitoring, field data, and modeling results"



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Summary

This project produced a very large database documenting the impact of interplanting switchgrass with pine trees on hydrology, water quality, soil quality, and biodiversity. Some impacts were observed, but they were small and short lived.

The project developed models that can simulate switchgrass growth when it is in competition with pine trees as well as the hydrology and nutrient dynamics that result from this interplanted system. The models predicted switchgrass production, water use, and the quality of the water leaving the system over a range of climatological and geographic conditions.

Summary

The project also documented the limitations of switchgrass production in the forestry setting and the challenges and increased costs arising from this practice. These challenges led to the conclusion that intercropping switchgrass with pine trees is not economically feasible in the current economic climate.

Despite the unlikelihood that this system will be utilized in the near future, economic and technological changes may occur that will make this a feasible system for bioenergy production. The data, models, BMPs and experiences documented in publications resulting from this project will be highly valuable to those implementing this system.

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Response to Previous Reviewers' Comments

Are water quality conditions so affected by the areas previously not planted in perennial grasses that such a study was thought to bring about great improvements in water quality? Perhaps the presenter could have made that clearer from the beginning.

We hypothesized that adding switchgrass to a forested system would degrade the typically good water quality from forested lands, since additional operations needed for switchgrass could increase nutrient and sediment loads. These operations include: additional site preparation and planting to establish switchgrass, and the annual fertilization and harvesting of the switchgrass. It is very possible that switchgrass will improve water quality after it gets established, but that may be difficult to determine since the baseline water quality of forests is very good. One of the main questions we will answer is: how long does it take to re-establish good water quality after field operations?

Response to Previous Reviewers' Comments

Without investigating the preparation, harvesting, and transport costs of interplanting switchgrass in pine stands against estimated returns, it is impossible to assess the biomass supply potential from these projects' simulations.

We have collecting economic information about the costs and returns of the system to produce switchgrass in this forested setting. Additional information is also available about the transport and processing of the biomass. This information was used to perform a life cycle analysis of the entire system; however, this analysis depended on productivity data collected in our studies. We needed to collect and analyze the data from the final growing season in order to make the final analyses.

Publications

Amatya, D. M., G. M. Chescheir, and J. E. Nettles (2016), Impacts of Switchgrass Intercropping in Traditional Pine Forests on Hydrology and Water Quality in the Southeastern United States, in Examples of Positive Bioenergy and Water Relationships, pp. 75–80, Global Bioenergy Partnership.

Cacho, J. F., M. A. Youssef, G. M. Chescheir, R. W. Skaggs, Z. H. Leggett, E. B. Sucre, J. E. Nettles, and C. Arellano (2015), Impacts of Switchgrass-Loblolly Pine Intercropping on Soil Physical Properties of a Drained Forest, Transactions of the ASABE, 58(6), 1573–1583, doi:DOI 10.13031/trans.58.11238.

Christopher, S. F., S. H. Schoenholtz, and J. E. Nettles (2015), Water quantity implications of regional-scale switchgrass production in the southeastern U.S, Biomass Bioenergy, 83(C), 50–59, doi:10.1016/j.biombioe.2015.08.012.

Muwamba, A. et al. (2015), Effects of site preparation for pine forest/switchgrass intercropping on water quality, J. Environ. Qual., 44(4), doi:10.2134/jeq2014.11.0505.

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 USA, in Water Quality: Current Trends and Expected Climate Change Impacts, edited by N.E. Peters,V. Krysanova, A. Lepisto, R. Prasad, M. Thomas, R. Wilby, S. Zandarya, pp. (115–122, IAHS Press.

Nettles, J., P. Birks, E. Sucre, and R. Bilby (2015), Sustainable Production of Bioenergy Feedstock from the Industrial Forest: Potential and Challenges of Operational Scale Implementation, Curr Sustainable Renewable Energy Rep, 2(4), 121–127, doi:10.1007/s40518-015-0042-9.

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Publications

Ssegane, H., D. M. Amatya, G. M. Chescheir, W. R. Skaggs, E. W. Tollner, and J. E. Nettles (2013a), Consistency of Hydrologic Relationships of a Paired Watershed Approach, American Journal of Climate Change, 2, 147–164, doi:10.4236/ajcc.2013.22015.

Ssegane, H., D. M. Amatya, E. W. Tollner, Z. Dai, and J. E. Nettles (2013b), Estimation of Daily Streamflow of Southeastern Coastal Plain Watersheds by Combining Estimated Magnitude and Sequence, Journal of the American Water Resources Association, 49(5), 1150–1166, doi:10.1111/jawr.12077.

Tian, S., M. A. Youssef, D. M. Amatya, and E. D. Vance (2014), Global sensitivity analysis of DRAINMOD-FOREST, an integrated forest ecosystem model, Hydrol. Process., 28(15), 4389–4410, doi:10.1002/hyp.9948.

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Tian, S., M. A. Youssef, G M Chescheir, R. W. Skaggs, J. Cacho, and J. Nettles (2016a), Development and preliminary evaluation of an integrated field scale model for perennial bioenergy grass ecosystems in lowland areas, Environmental Modelling and Software, 84, 226–239, doi:10.1016/j.envsoft.2016.06.029.

Tian, S., J. F. Cacho, M. A. Youssef, G. M. Chescheir, M. Fischer, J. E. Nettles, and J. S. King (2016b), Switchgrass growth and pine-switchgrass interactions in established intercropping systems, GCB Bioenergy, doi:10.1111/gcbb.12381.

Dissertations and Theses

Cacho, J. F. (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, Doctor of Philosophy, North Carolina State University.

Dobbs, N.A. (2016). Hydrology and Water Quality Dynamics in Coastal Plain and Upland Watersheds with Loblolly Pine (Pinus taeda) and Switchgrass (Panicum virgatum) Intercropping in the southeastern United States. Doctor of Philosophy, North Carolina State University.

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, Master of Science, North Carolina State University.

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