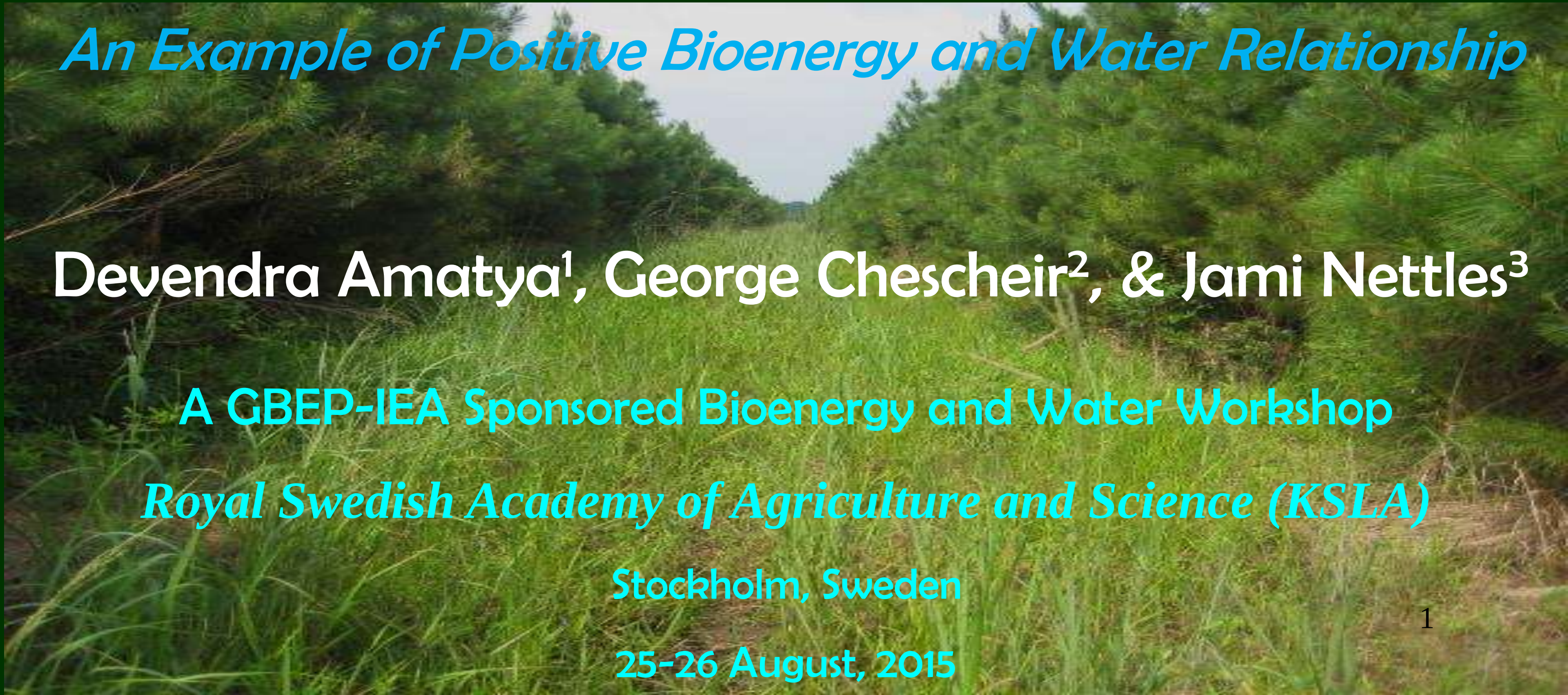
USDA 1/ NC STATE UNIVERSITY 2/ Weyerhaeuser Growing Ideas 3/

Impacts of Switchgrass Intercropping in Traditional Pine Forests on Hydrology and Water Quality



An Example of Positive Bioenergy and Water Relationship

Devendra Amatya[1], George Chescheir[2], & Jami Nettles[3]

A GBEP-IEA Sponsored Bioenergy and Water Workshop

Royal Swedish Academy of Agriculture and Science (KSLA)

Stockholm, Sweden

25-26 August, 2015

ACKNOWLEDGEMENT

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- GBEP Activity Group (AG)-6
- Royal Swedish Academy of Agriculture and Science
- USDA Forest Service Southern Research Station
- USDA Forest Service International Program Office

OTHER COLLABORATORS

- North Carolina State University *(Dr. Timothy Appelboom)*
- U.S. Department of Energy
- Weyerhaeuser Company
- CatchLight Energy- a Chevron|Weyerhaeuser Company Joint Venture
- Virginia-Tech *(Dr. Stephen Schonholtz)*
- University of North Georgia *(Dr. Sudhanshu Panda)*
- University of Georgia *(Dr. Bill Tollner, Dr. Rhett Jackson, and Dr. Augustine Muwamba)*
- Argonne National Laboratory *(Dr. Herbert Ssegane)*
- NCASI, Inc.

Background

Energy Independence and Security Act of 2007 created the mandate for renewable fuels that led to this project:

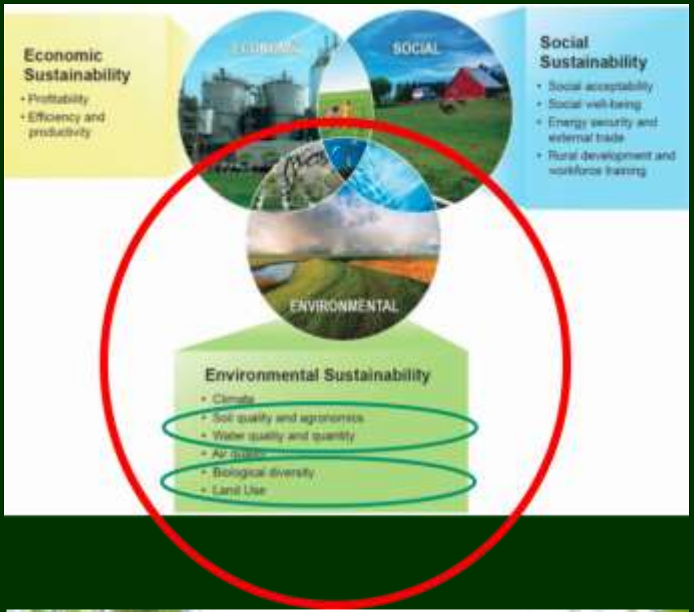
- **Increase the levels of production of biofuels to 15.2 bil gal by 2012 and 36 bil gal by 2022**

There is enough biomass potential in the US to replace 1/3 of petroleum, and dedicated non-food energy crops may be the major source of that supply

United States Congress. 2007. Energy Independence and Security Act of 2007. H.R. 6; 110th
Perlack, Robert D., et al. "US billion-ton update: biomass supply for a bioenergy and bioproducts industry." (2011).

RATIONALE

- ~ 15 mil ha of pine plantations in SE U.S.A.
- *Combining Switch Grass (Panicum Virgatum L.) intercropped in between pine (Pinus Taeda L.) trees has potential for production of a cellulosic energy crop without competition for land for food production*
- Potential for long-term sustainability
- Potential for reducing environmental impacts compared to corn/row crop
- Reduced dependency on fossil biofuel sources
- Benefits to U.S. Agricultural economy



KEY ENABLING FACTORS

- Project initiation from Catchlight Energy LLC, a Chevron| Weyerhaeuser Company joint venture , looking at ways of making renewable liquid transportation fuel.
- Weyerhaeuser's support of sustainability research into the patented system of intercropping switchgrass in sawtimber plantations.
- Support by the US Department of Energy.
- A strong, committed and highly qualified multi-disciplinary research partnership among academia, government, industries, and others.
- Existing long-term research/data on the NC site: Soils, water quantity and quality, productivity, high technical support, validated models, and collaborative relationships.
- In-kind contributions from all cooperating agencies.

Reasons/Main Drivers for Project Implementation

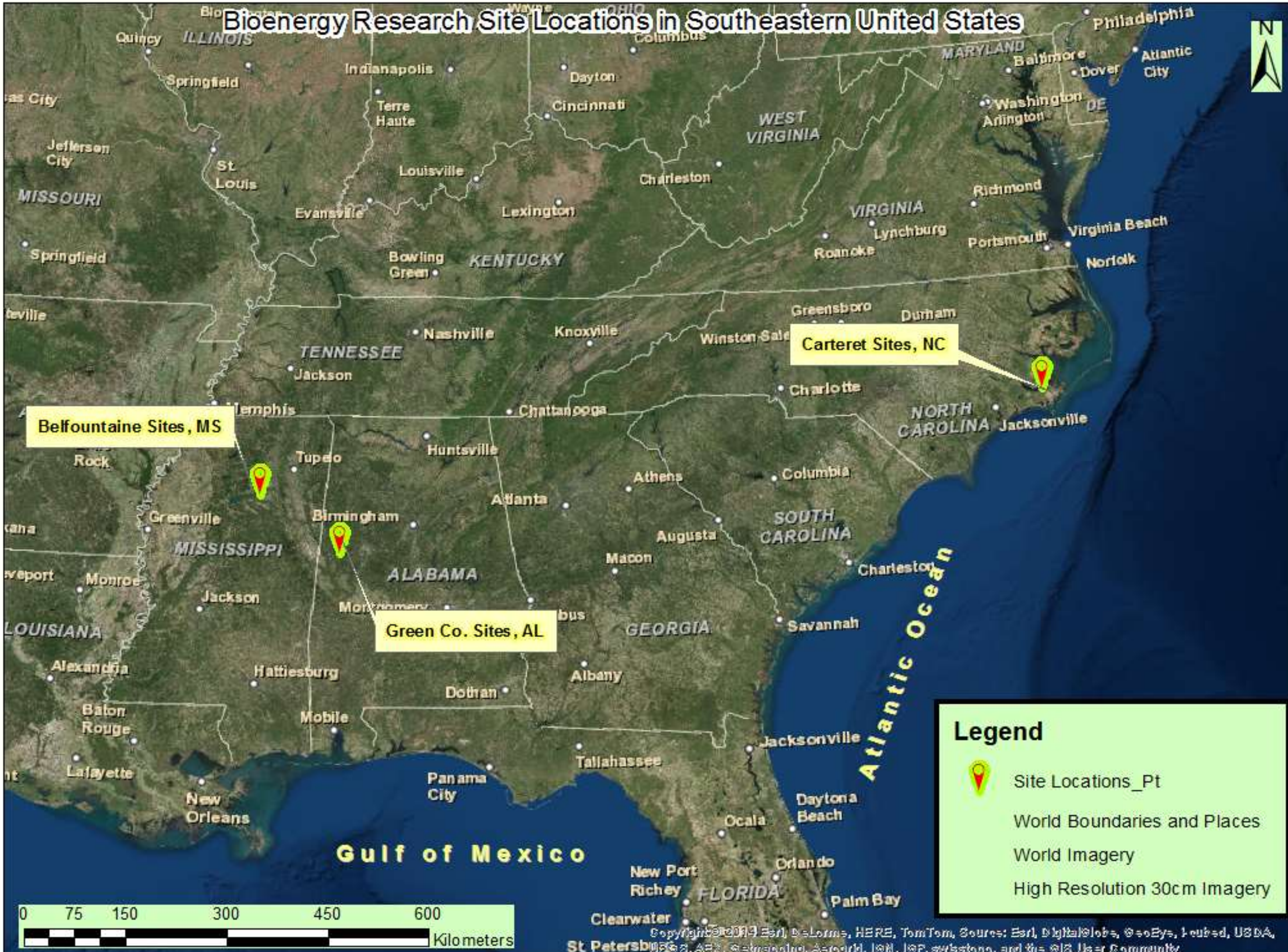
- An urgent need for information about the environmental effects of the production of cellulosic biofuel.

- Growing and harvesting such crops on forest land appears to be a very attractive option, but the effect on water resources must be quantified/compared to those of existing pine forests.

- Short and long-term assessment of hydrologic and water quality impacts represent a range of intensive biofuel production scenarios that could affect millions of hectares of forest land in the SE U.S.

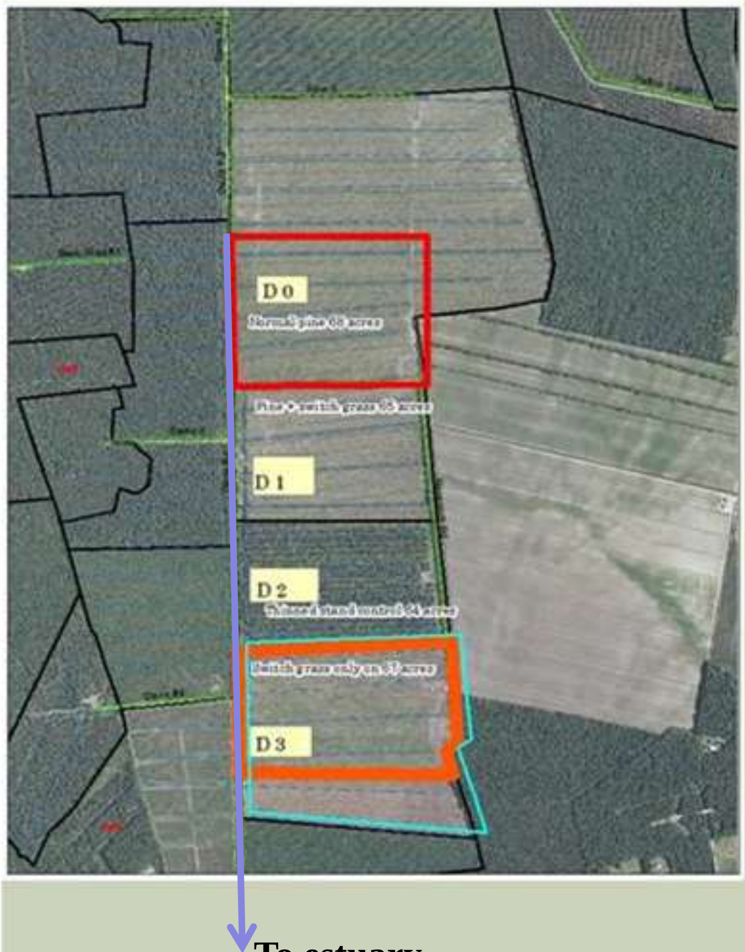
PROJECT STATUS

- Project is ongoing with multidisciplinary studies on hydrology, water quality, carbon, soil productivity, wildlife habitat, biomass production, life cycle analysis, and other ecosystem services
- Data Collection and studies continuing
- Start Date: April 2009
- Tentative End Date: September 2016


Bioenergy Research Site Locations in Southeastern United States
N
Belfountaine Sites, MS
Green Co. Sites, AL
Carteret Sites, NC
ILLINOIS
MISSOURI
WEST VIRGINIA
MARYLAND
DE
VIRGINIA
KENTUCKY
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
MISSISSIPPI
ALABAMA
GEORGIA
LOUISIANA
FLORIDA
Quincy
Springfield
Indianapolis
Dayton
Columbus
Terre Haute
Cincinnati
Jefferson City
St. Louis
Louisville
Charleston
Evansville
Lexington
Philadelphia
Atlantic City
Baltimore
Dover
Washington
Arlington
Richmond
Lynchburg
Roanoke
Portsmouth
Virginia Beach
Norfolk
Springfield
Bowling Green
Nashville
Knoxville
Greensboro
Durham
Winston-Salem
Jackson
Charlotte
Memphis
Chattanooga
Jacksonville
Huntsville
Tupelo
Rock
Athens
Columbia
Atlanta
Greenville
Birmingham
Augusta
Macon
Monroe
Jackson
Charleston
Savannah
Alexandria
Hattiesburg
Albany
Dothan
Baton Rouge
Mobile
Tallahassee
Jacksonville
Lafayette
New Orleans
Panama City
Daytona Beach
Ocala
Orlando
New Port Richey
Clearwater
Palm Bay
St Petersburg
Atlantic Ocean
Gulf of Mexico
Legend
Site Locations_Pt
World Boundaries and Places
World Imagery
High Resolution 30cm Imagery
0 75 150 300 450 600
Kilometers

COASTAL LOWLAND

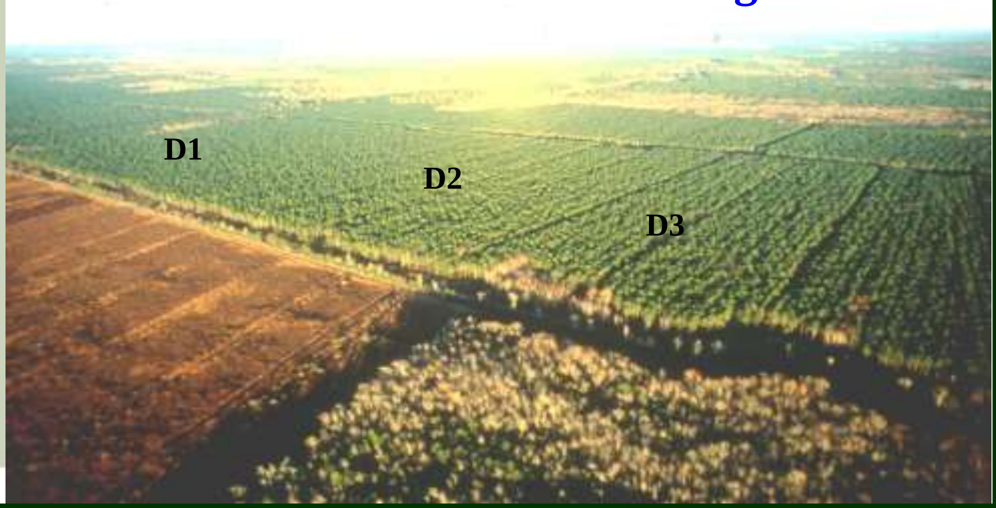
SITE AT CARTERET COUNTY, NC



<u>Switchgrass-Pine Intercropping Study in 2009</u>

D0 = Young pine with understory (Site 1)
D1 = Young pine with switch grass intercropped (Site 2)
D2 = Matured pine (thinned) (Site 3)
D3 = Switch grass only (Site 4)

Long-term (1988-2008) Research History on Traditional Pine Forest Management



USDA | NCASI, Inc. | NC STATE UNIVERSITY | Weyerhaeuser Growing Ideas

Major Findings on Pine Forest Research: 1988-2008

Reported in Several Publications

- Mean Rainfall : 1540 mm (Range: 950 – 2388)
- ET ~ 70%: Interception ~ 15% and Transpiration ~ 55%
- Drainage (Flow) ~ 30%; Deep Seepage ~ 0, Runoff ~ 0
- Harvesting >> Increase Flow by 260 mm, WTE 65 cm
- Increase in nutrients/sediment were short lived; base line levels after 3-4 years after harvest
- Hydrology to base line levels by ~ 8 years after planting
- Thinning >> Short term effects on hydrology/WQ
- Fertilization increased the nutrient levels only for ~ 3 - 4 months after its application.

KEY OBJECTIVES

- To quantify the water balance and effects of switchgrass intercropping on hydrology (water table, SM, and flow) and water quality (nutrients) compared to a control (managed pine forest) using a paired watershed approach.
- *To develop process-based model to assess the long-term hydrology and water quality effects of more intensive practices*

Site Preparation & Establishment

>> Thinning (D2) – 2008

>> In 2009-early 2010

>> Harvesting, Shearing, Bedding, and Raking (D0, D1, D3)

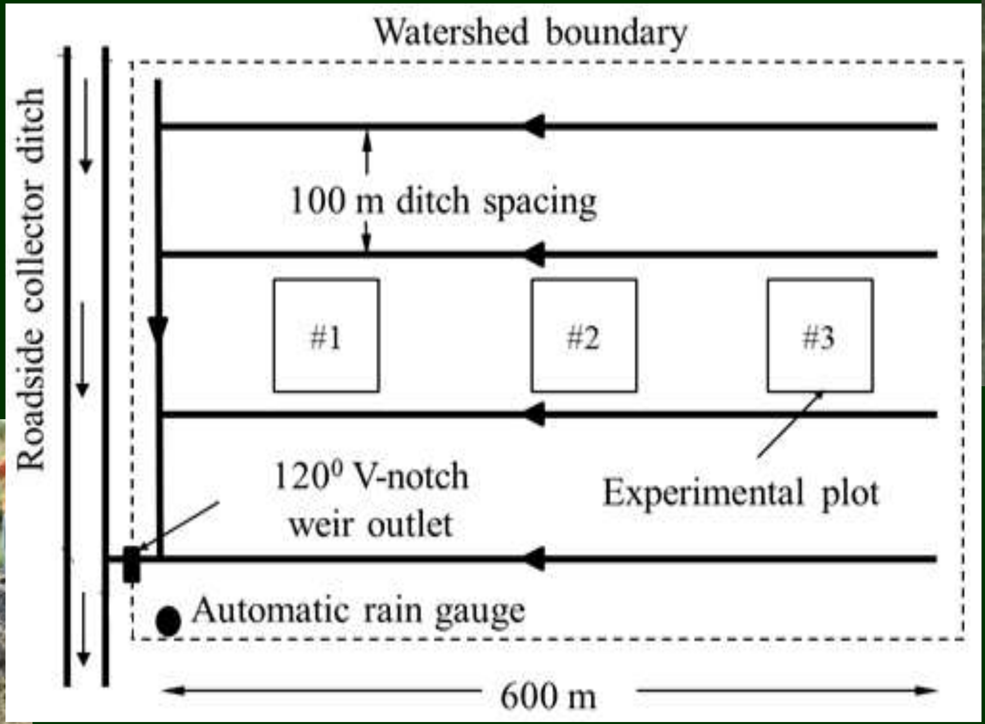
>> 1087 pine trees/ha; 6 m apart (D0 and D1)

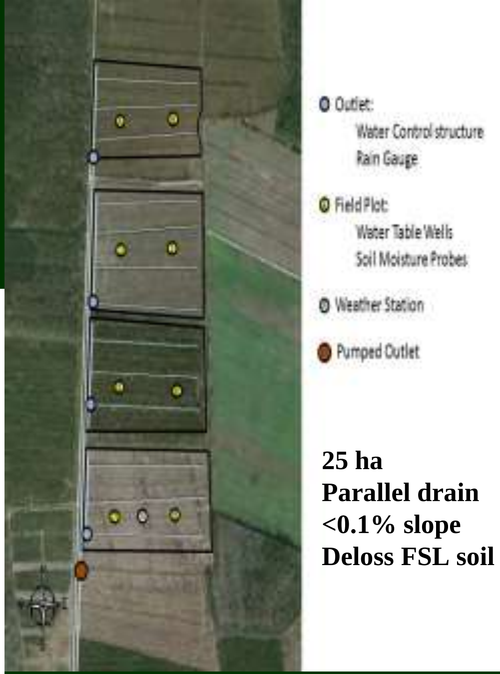
>> SG Intercropped width ~ 3 m

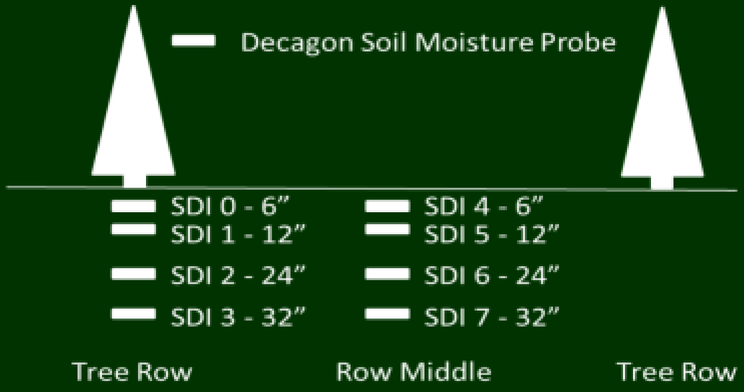
-Switchgrass only (treatment D3)
-Switchgrass broadcasted in April 2012

-Young pine and switchgrass (treatment D1)
-Switchgrass broadcasted in April 2012

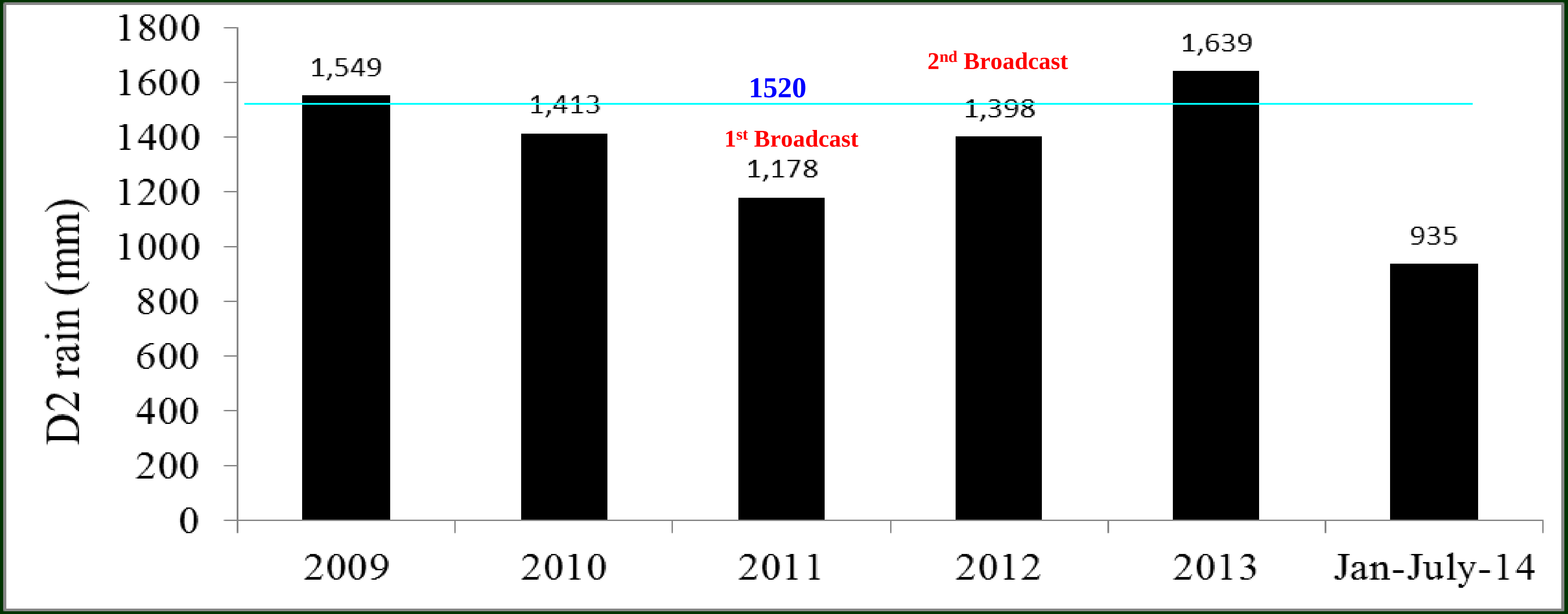
Experimental Layout and Monitoring

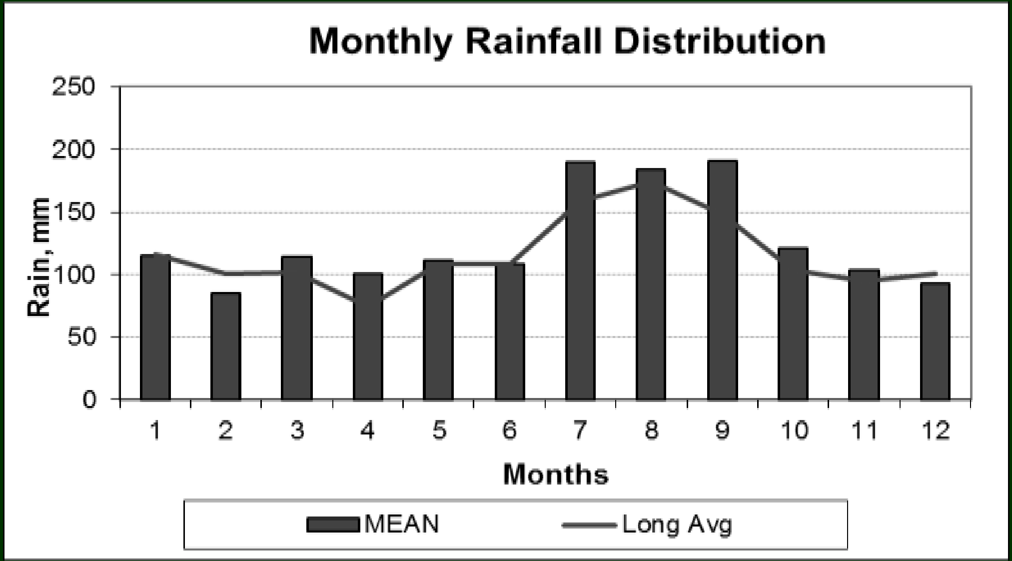






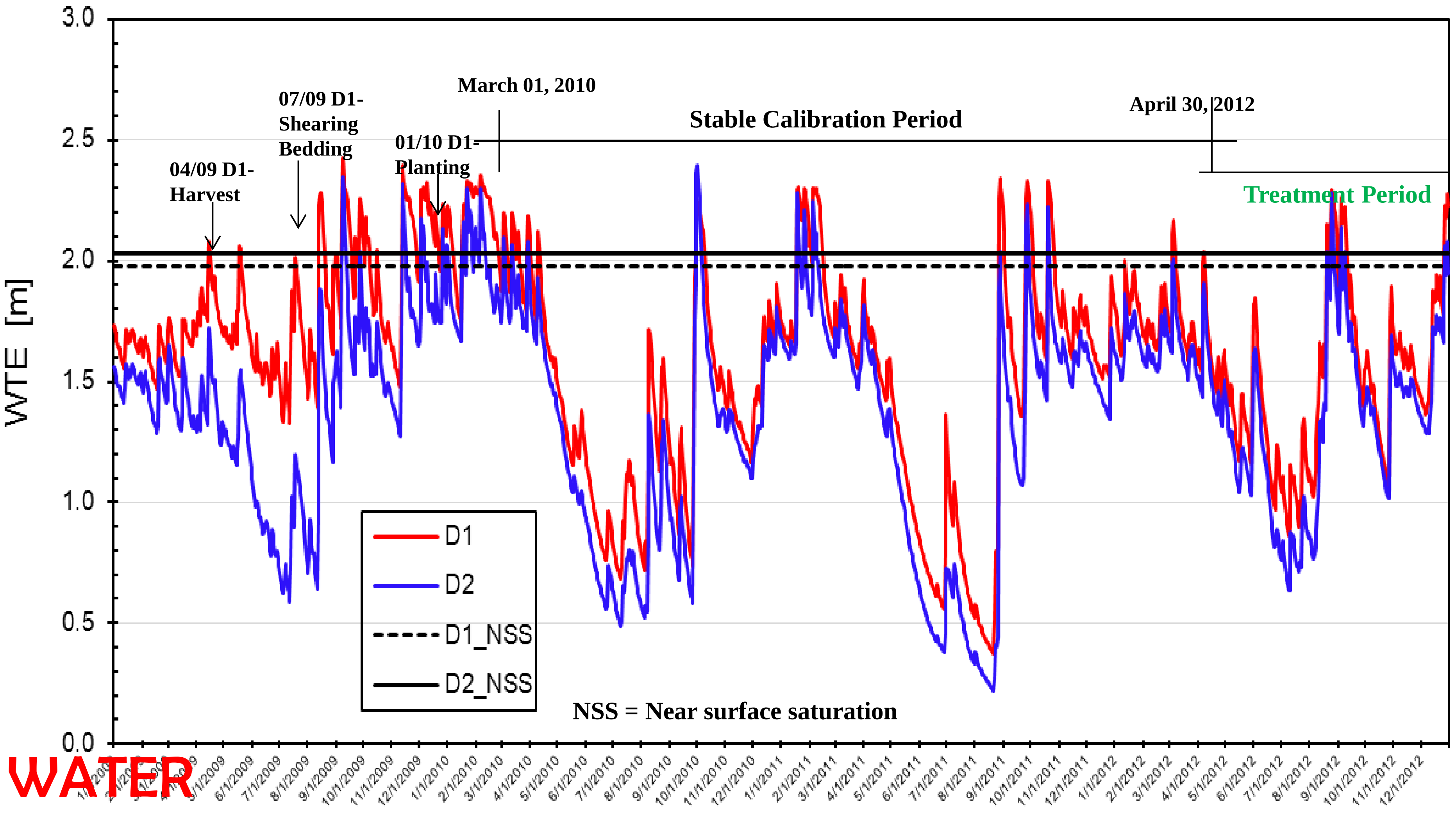
ANNUAL and MONTHLY PRECIPITATION, NC





WATER QUANTITY

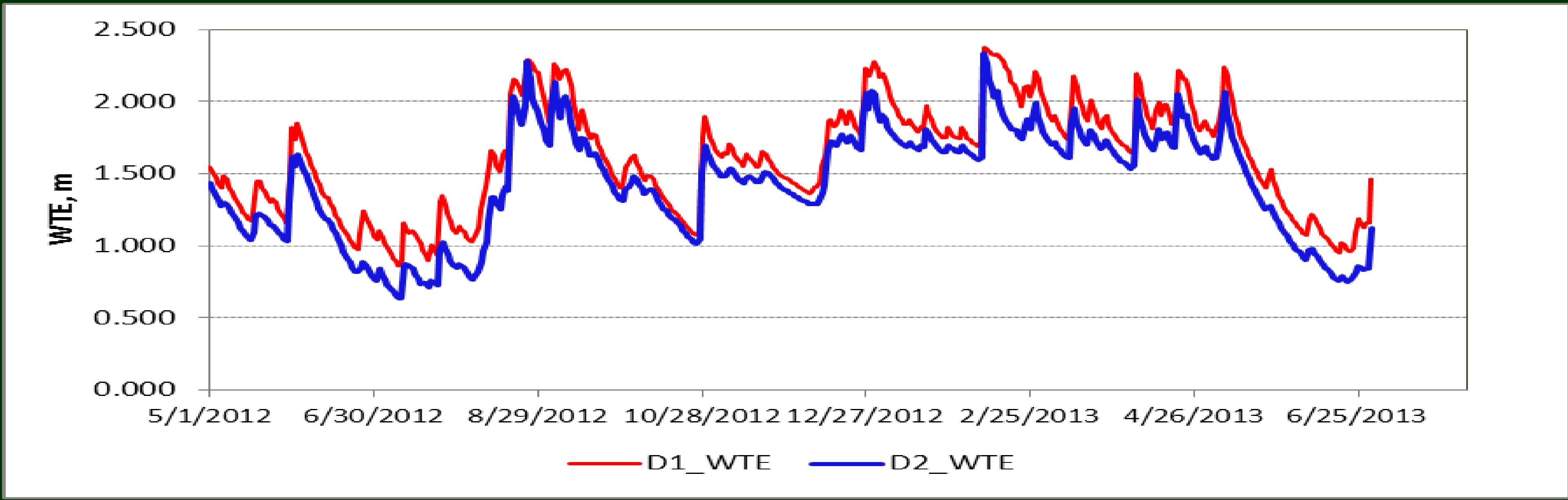
DAILY WATER TABLE ELEVATION
D1 and D2, 2009-2012

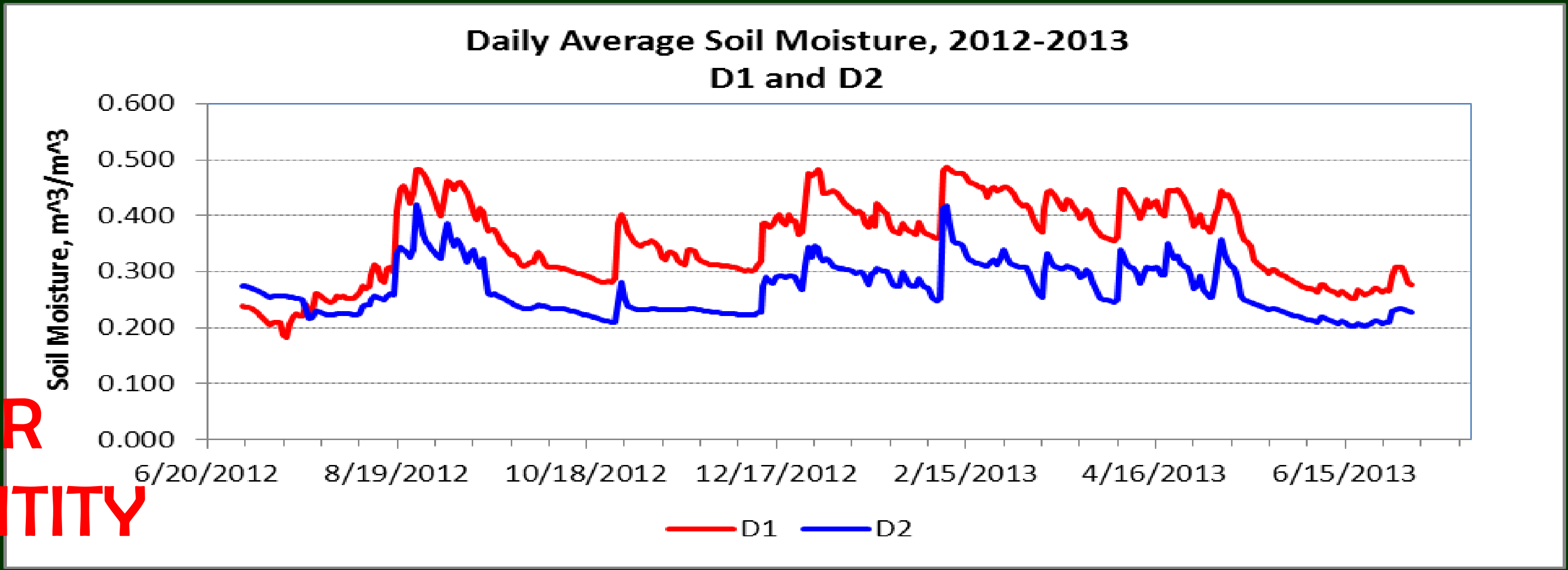


WATER QUANTITY

DAILY WATER TABLE ELEVATION & SOIL MOISTURE

D1 and D2, 2012-13 Treatment

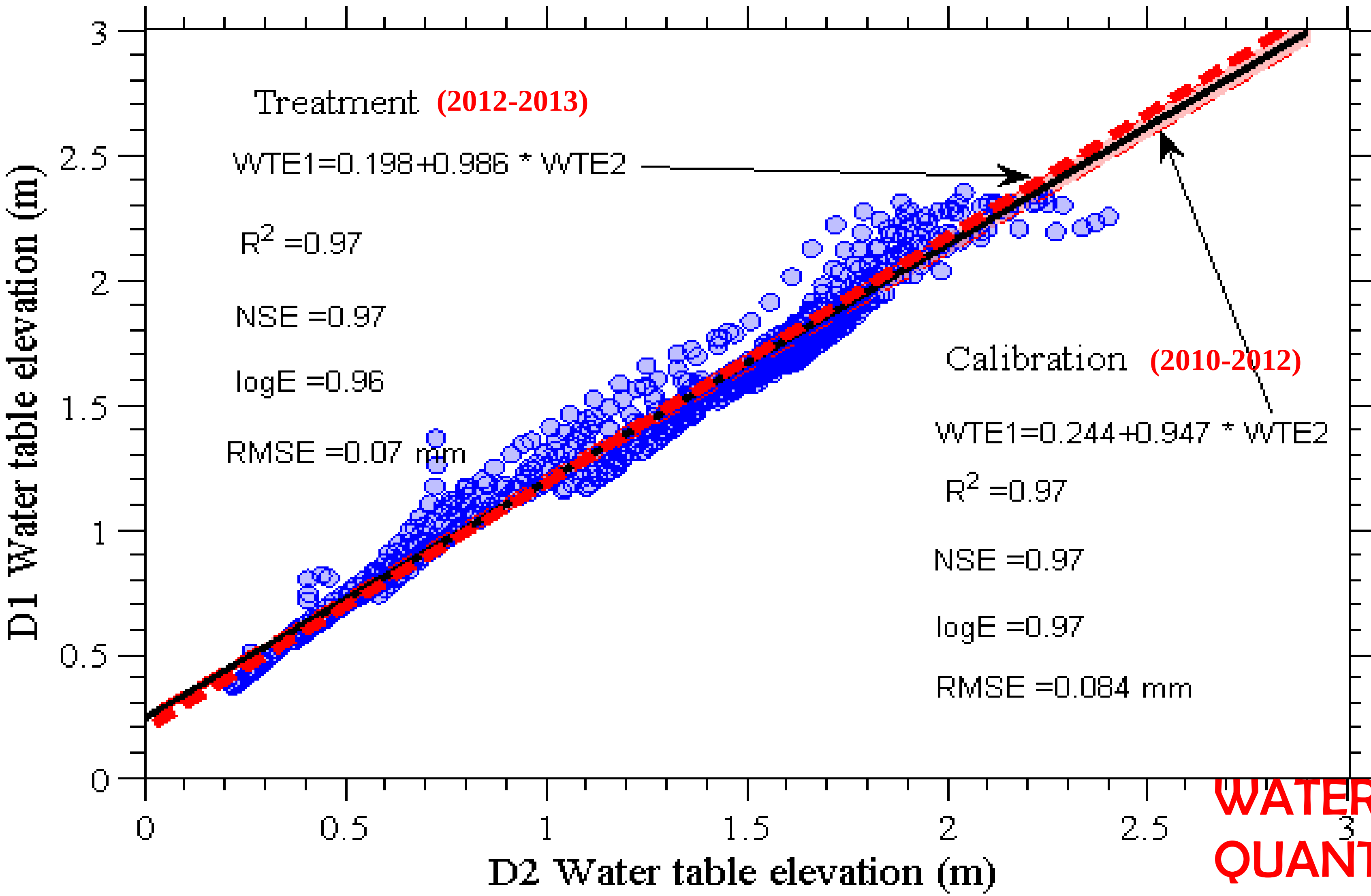




WATER QUANTITY

CALIBRATION & TREATMENT RELATIONSHIPS

(DAILY WATER TABLE ELEVATIONS)

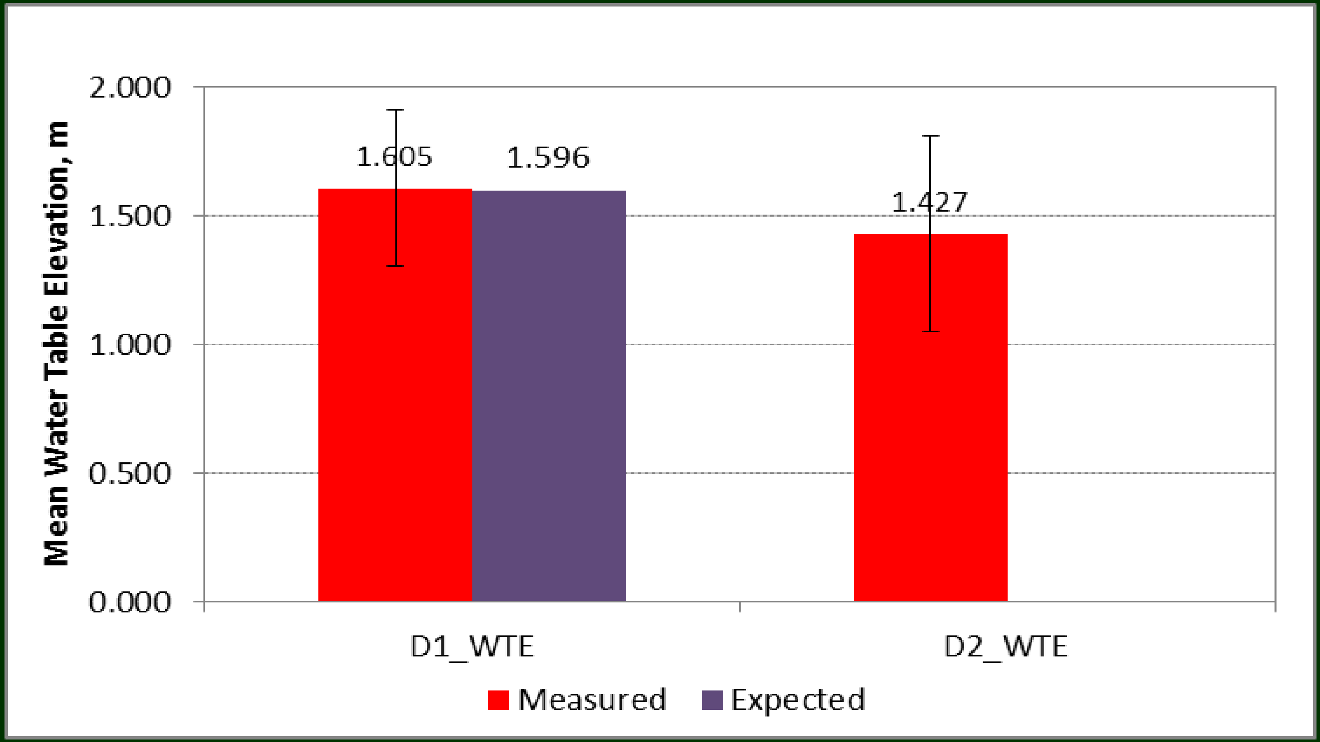


WATER QUANTITY

MEAN DAILY WATER TABLE ELEVATION,

Treatment Period (2012-2013)

D1 (Intercropped) & D2 (Pine)

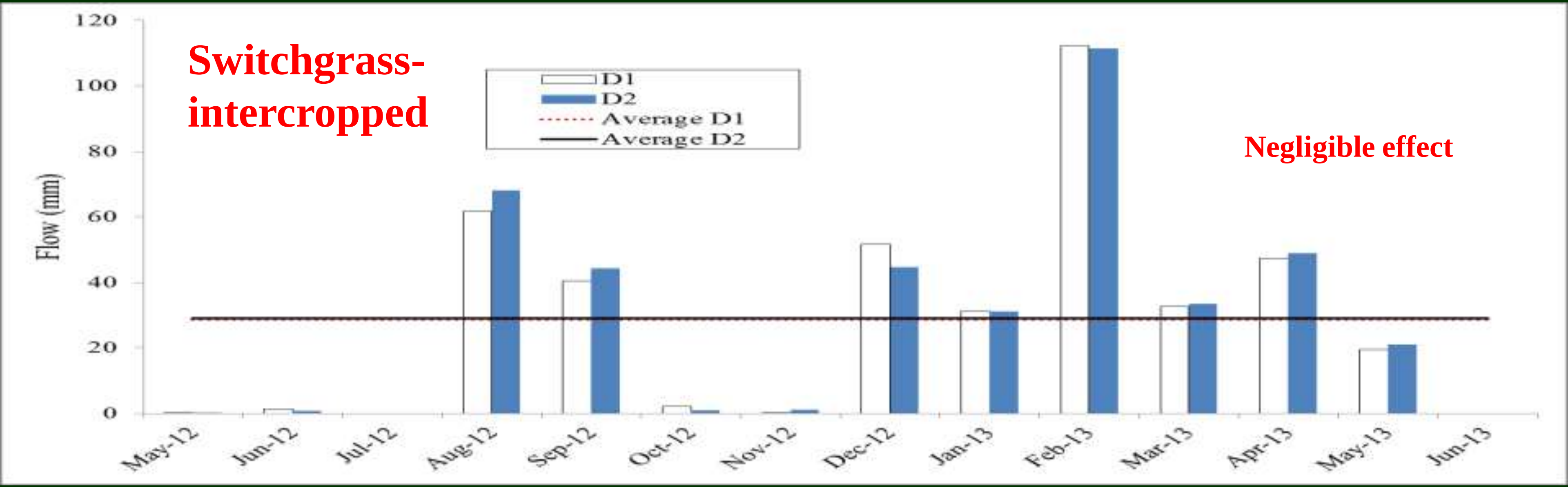


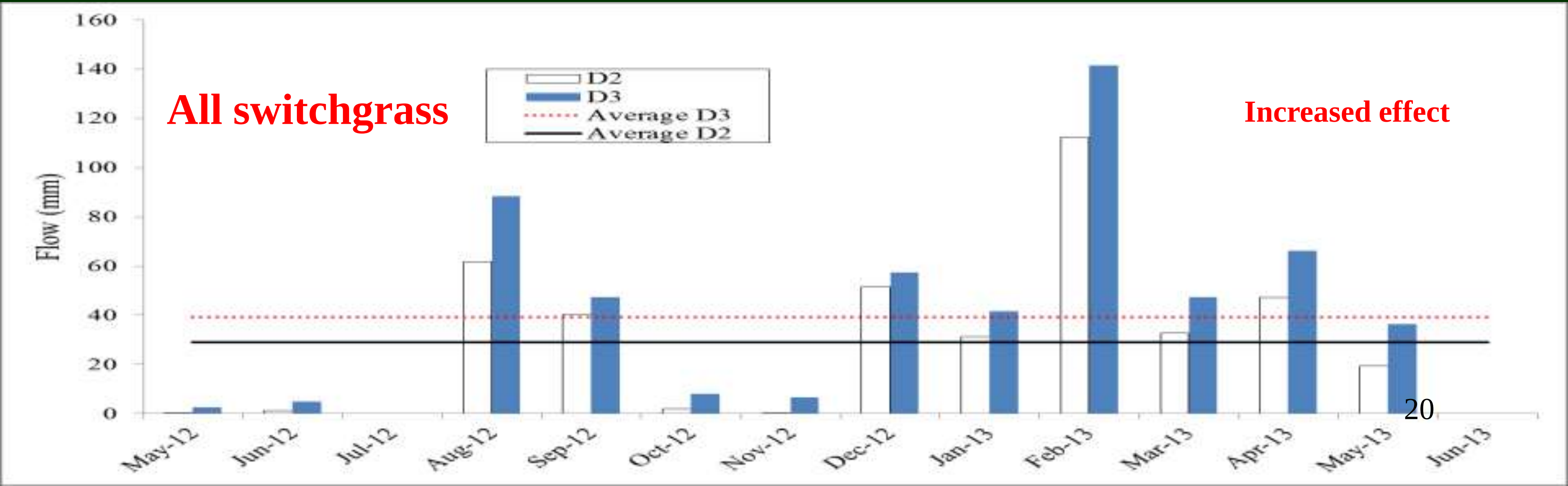
No effects of treatment on mean daily WTE

WATER QUANTITY

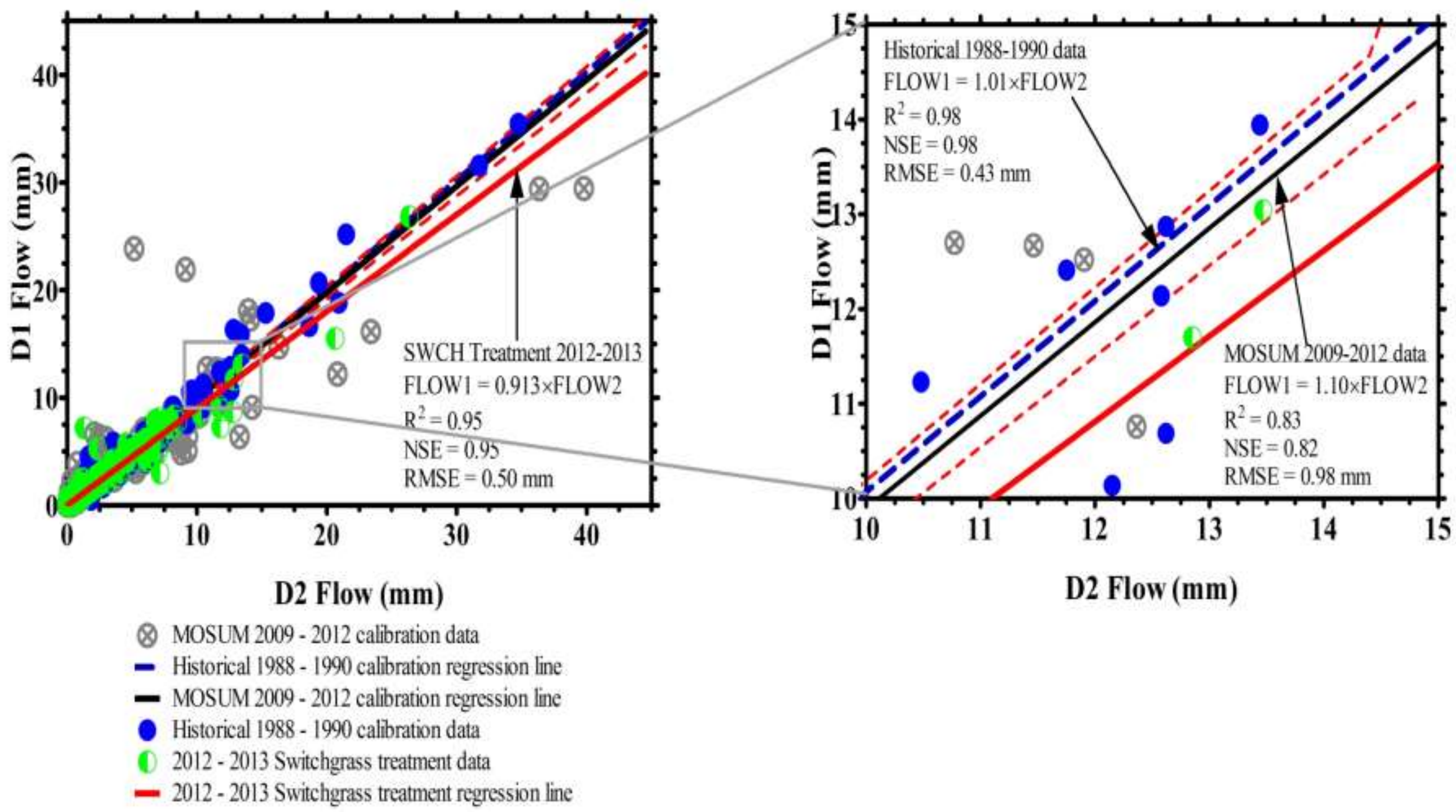
MONTHLY FLOW (D1-D2 & D3-D2)

WATER QUANTITY



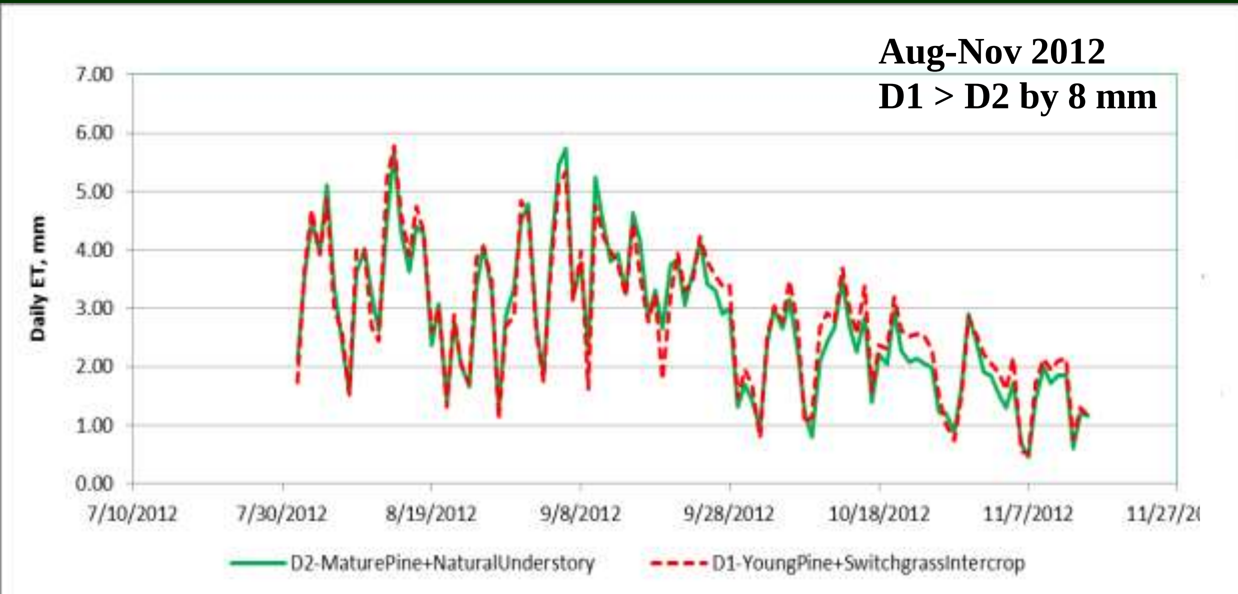


CALIBRATION & TREATMENT RELATIONSHIPS
(DAILY DRAINAGE FLOWS)



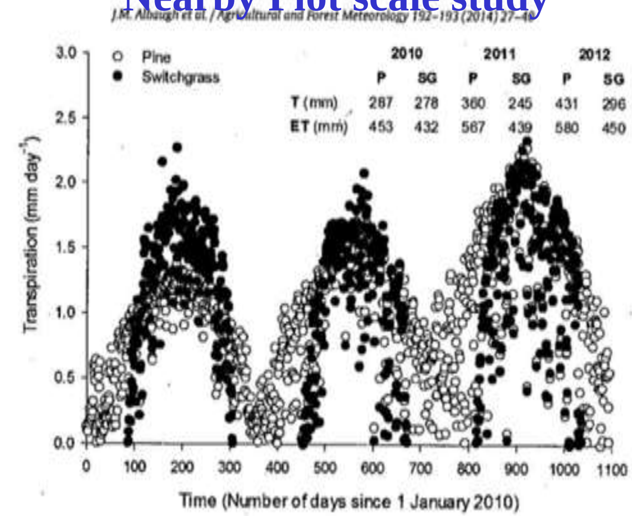
WATER QUANTITY

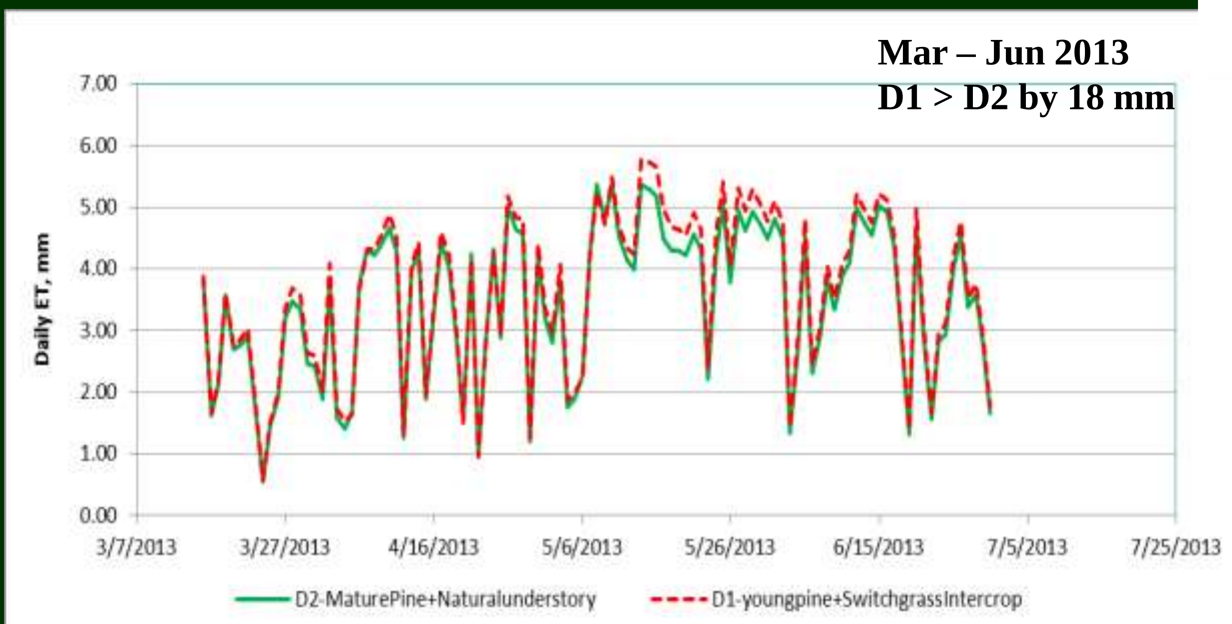
DAILY ET, D1 & D2, Treatment Period



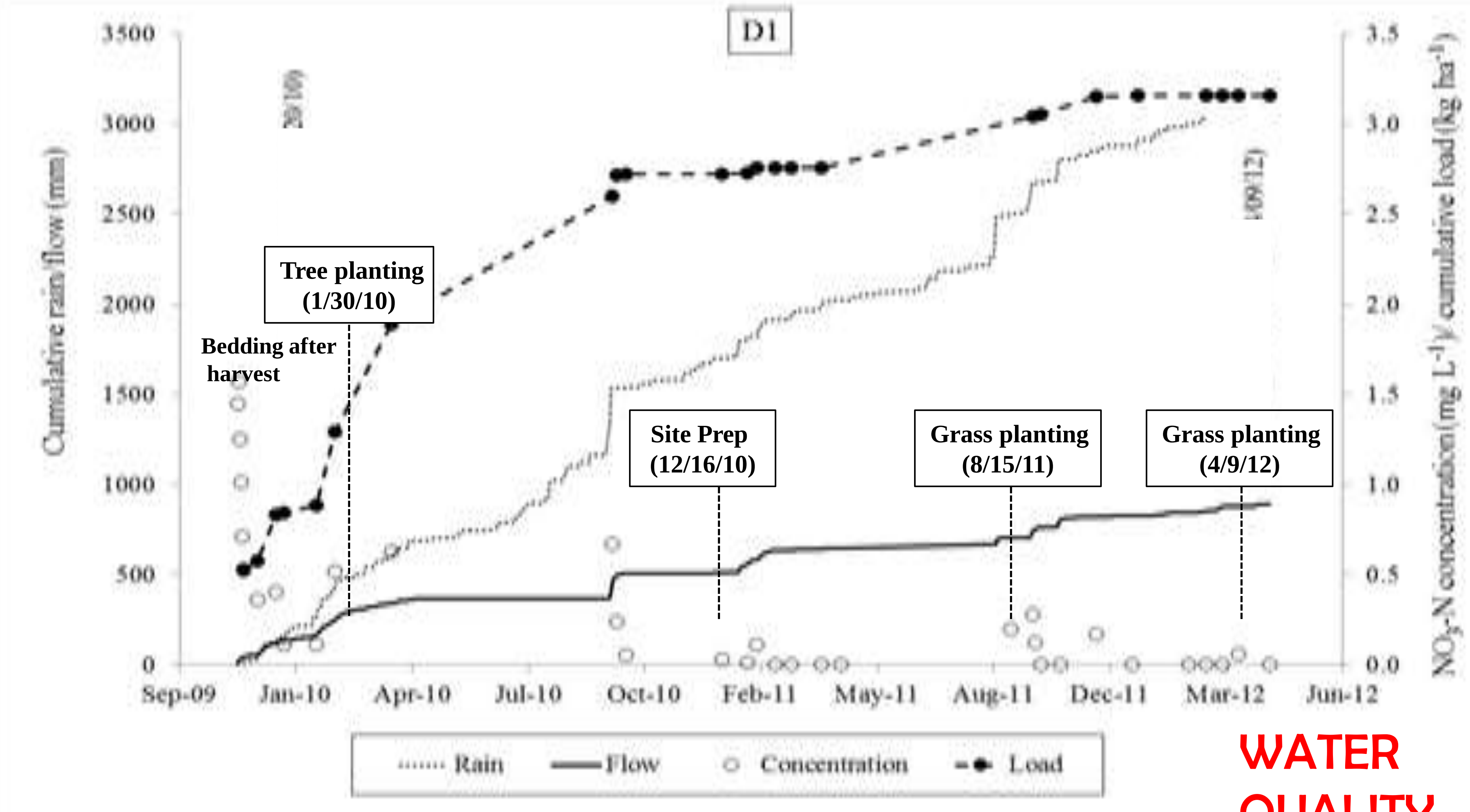
WATER QUANTITY

Nearby Plot scale study





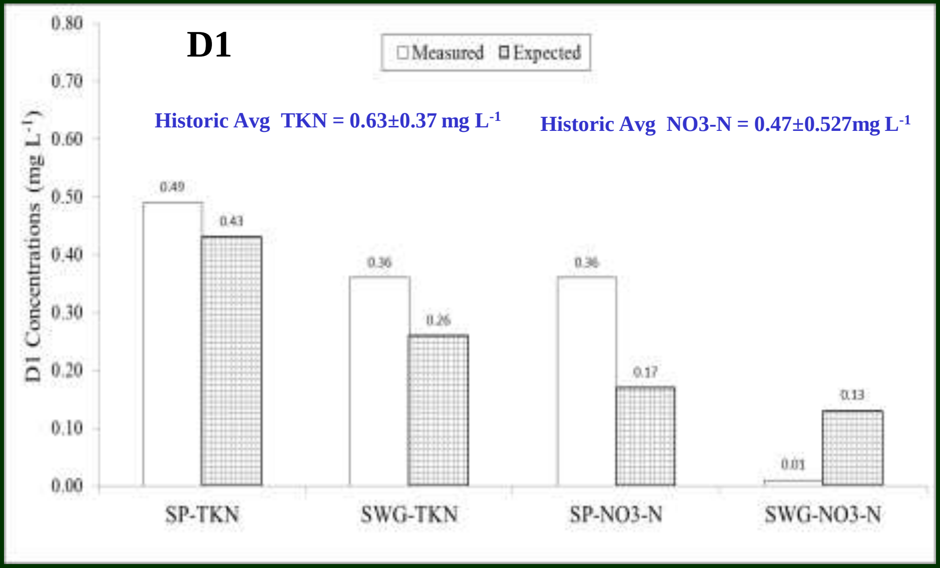
NO3-N Concentrations and Loads at NC Intercropped Site during Establishment

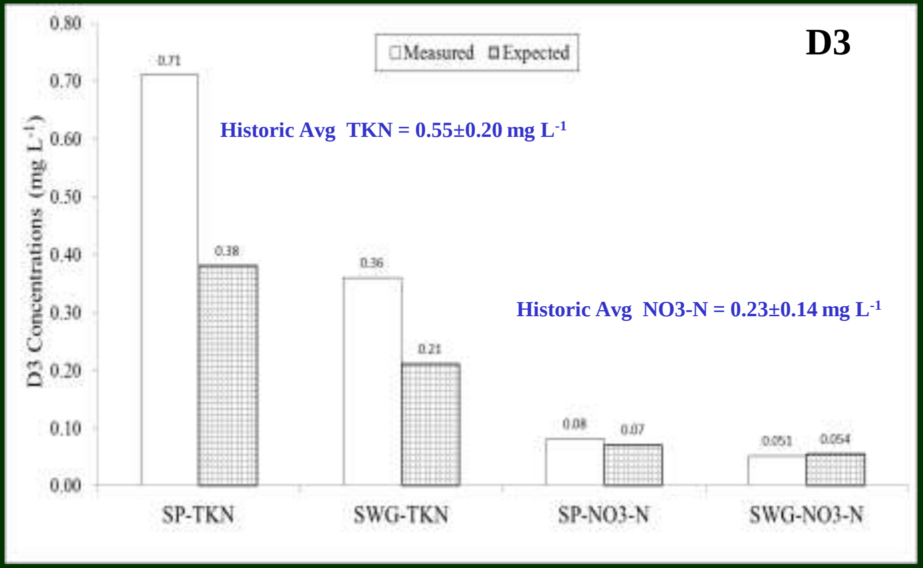


WATER QUALITY

WATER QUALITY EFFECTS

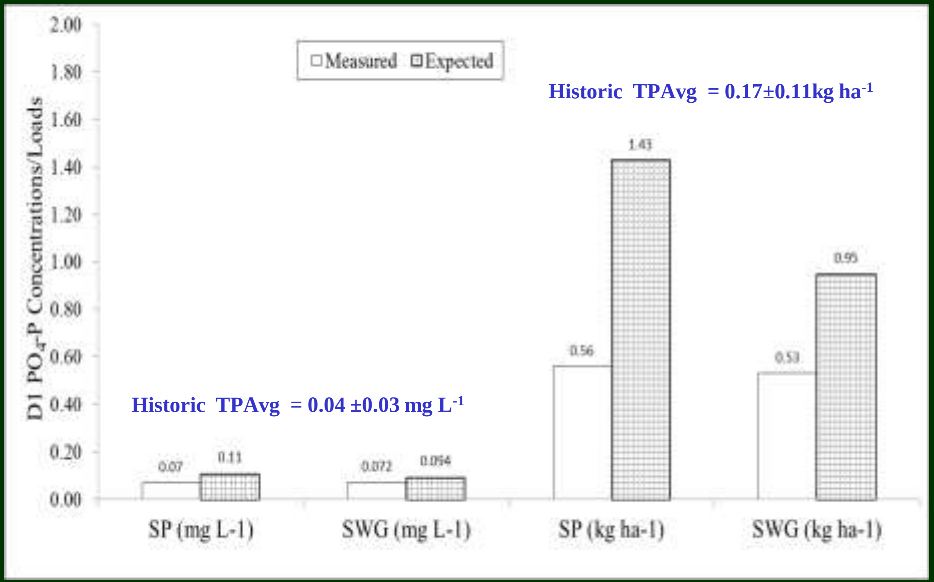
WATER QUALITY

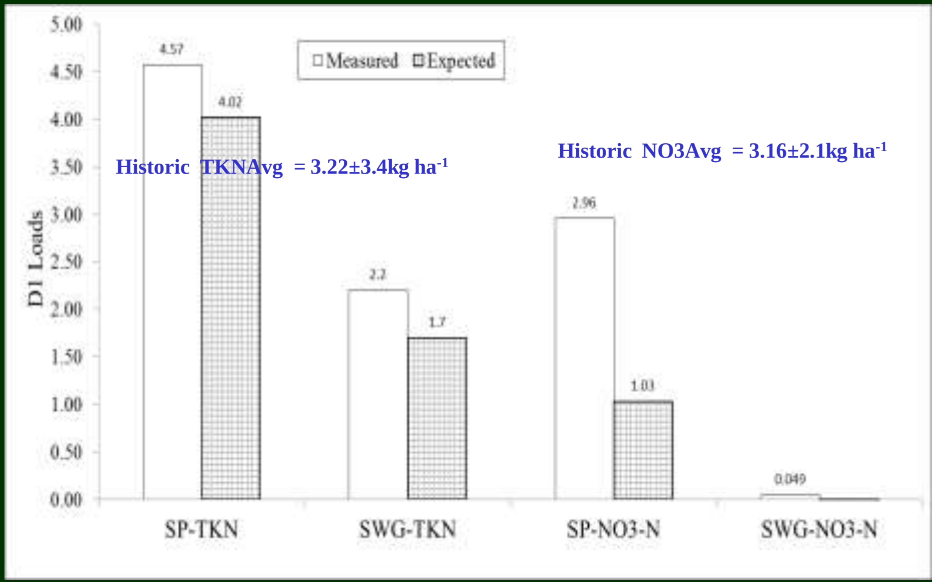




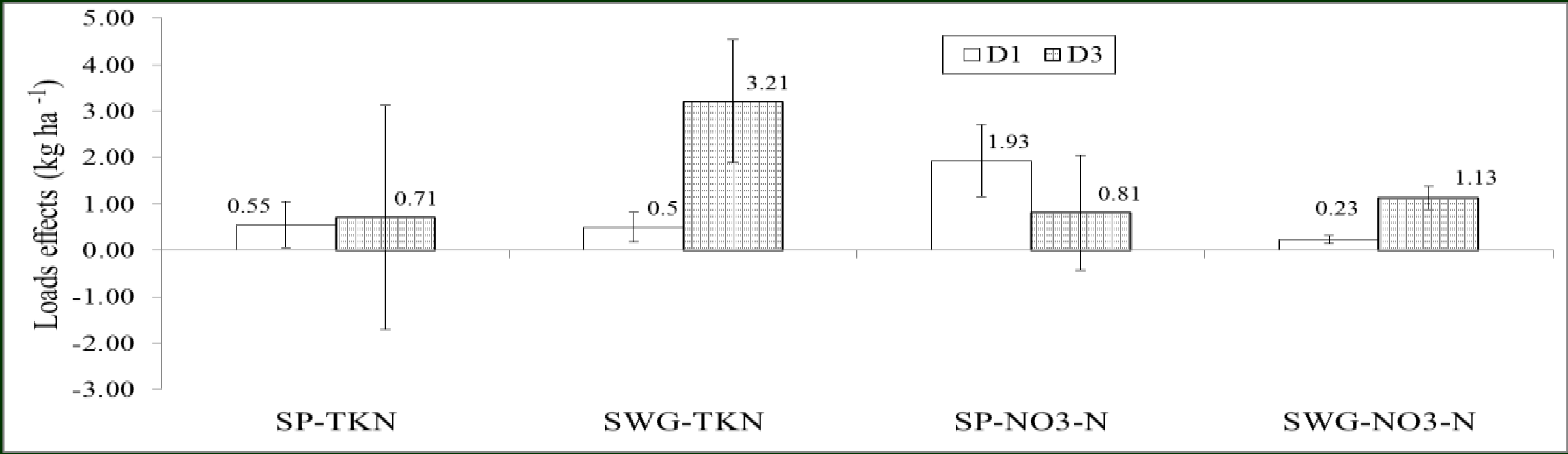
SP – Site Preparation (2009-12)
SWG – Switchgrass Growth (2012-13)

D1 - Switchgrass Intercropped Pine
D3 – Switchgrass only

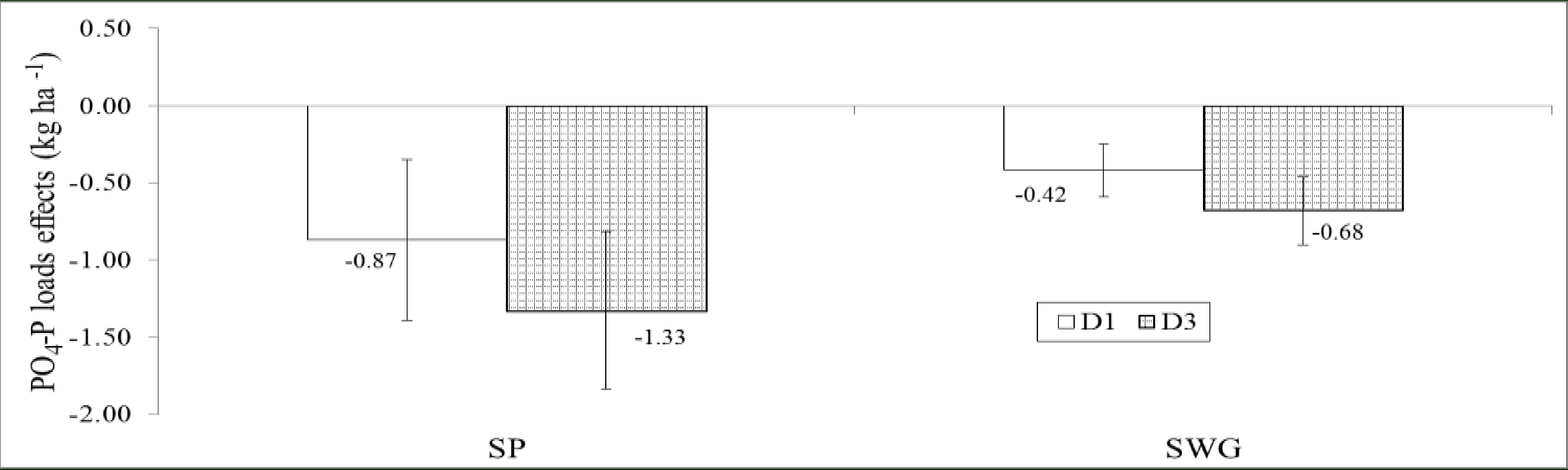




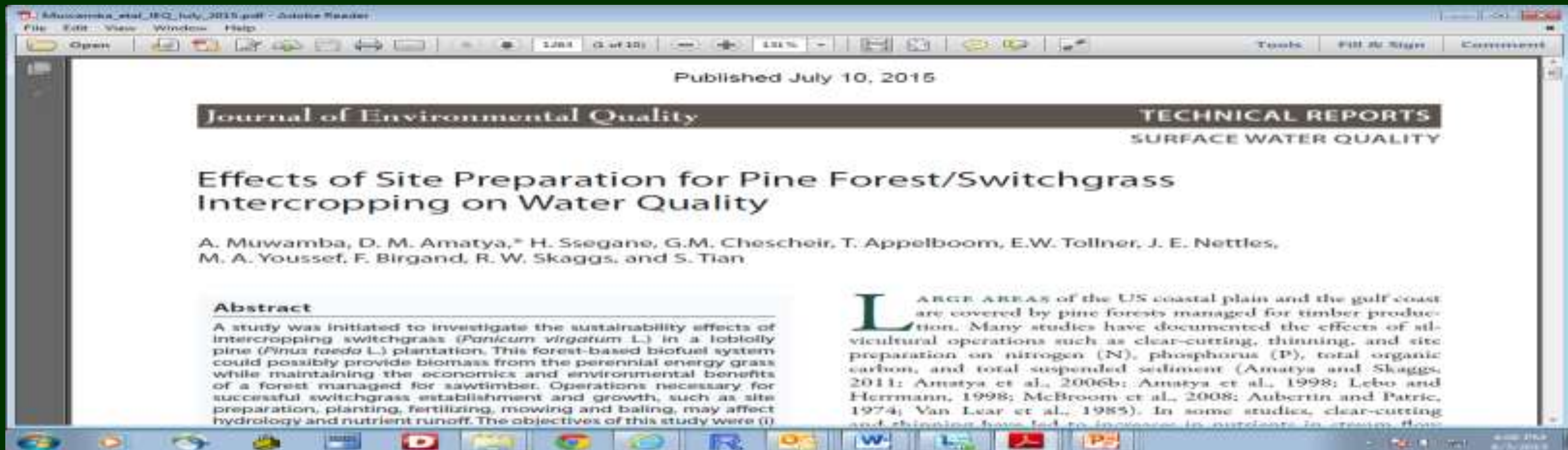
WATER QUALITY EFFECTS Contd..



SP – Site Preparation; SWG – Switchgrass Growth



ACHIEVED OUTCOMES

- 

Published July 10, 2015

Journal of Environmental Quality — TECHNICAL REPORTS — SURFACE WATER QUALITY

Effects of Site Preparation for Pine Forest/Switchgrass Intercropping on Water Quality

A. Muwamba, D. M. Amatya,* H. Ssegane, G.M. Chescheir, T. Appelboom, E.W. Tollner, J. E. Nettles, M. A. Youssef, F. Birgand, R. W. Skaggs, and S. Tian

Abstract

A study was initiated to investigate the sustainability effects of intercropping switchgrass (*Panicum virgatum* L.) in a loblolly pine (*Pinus taeda* L.) plantation. This forest-based biofuel system could possibly provide biomass from the perennial energy grass while maintaining the economics and environmental benefits of a forest managed for sawtimber. Operations necessary for successful switchgrass establishment and growth, such as site preparation, planting, fertilizing, mowing and baling, may affect hydrology and nutrient runoff. The objectives of this study were (i)

Large areas of the US coastal plain and the gulf coast are covered by pine forests managed for timber production. Many studies have documented the effects of silvicultural operations such as clear-cutting, thinning, and site preparation on nitrogen (N), phosphorus (P), total organic carbon, and total suspended sediment (Amatya and Skaggs, 2011; Amatya et al., 2006b; Amatya et al., 1998; Lebo and Herrmann, 1998; McBroom et al., 2008; Aubertin and Patric, 1974; Van Lear et al., 1985). In some studies, clear-cutting

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Hydrol. Earth Syst. Sci. Discuss., 12, 1–36, 2015

Hydrology and Earth System Sciences Discussions

Hydrologic calibration of paired watersheds using a MOSUM approach

H. Ssegane[1], D. M. Amatya[2], A. Muwamba[3], G. M. Chescheir[4], T. Appelboom[4], E. W. Tollner[3], J. E. Nettles[5], M. A. Youssef[4], F. Birgand[4], and R. W. Skaggs[4]

[1]Energy Systems Division, Argonne National Laboratory, Lemont, IL, USA
[2]Center for Forested Wetlands Research, USDA-FS, Cordesville, SC, USA
[3]University of Georgia, Athens, GA, USA
[4]North Carolina State University, Raleigh, NC, USA
[5]Weyerhaeuser Company, Columbus, MS, USA

Received: 29 November 2014 – Accepted: 3 December 2014 – Published:

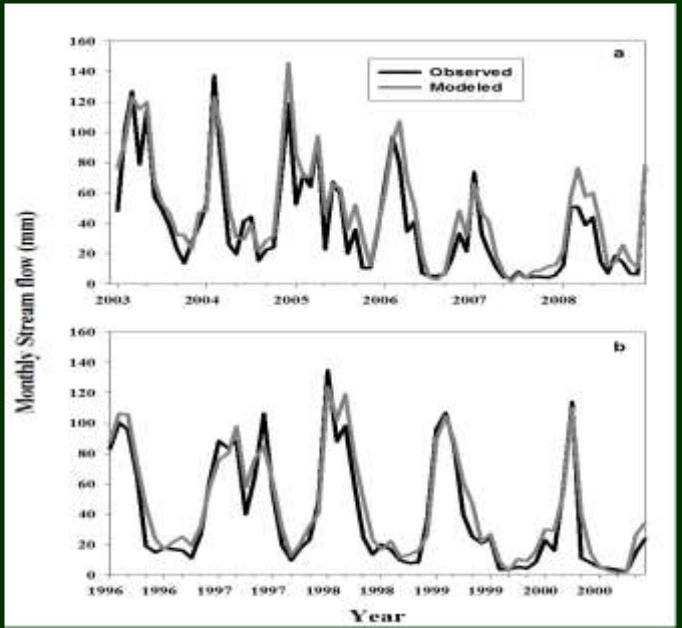
Correspondence to: H. Ssegane (hssegane@anl.gov)

Published by Copernicus Publications on behalf of the European Geosciences Union.

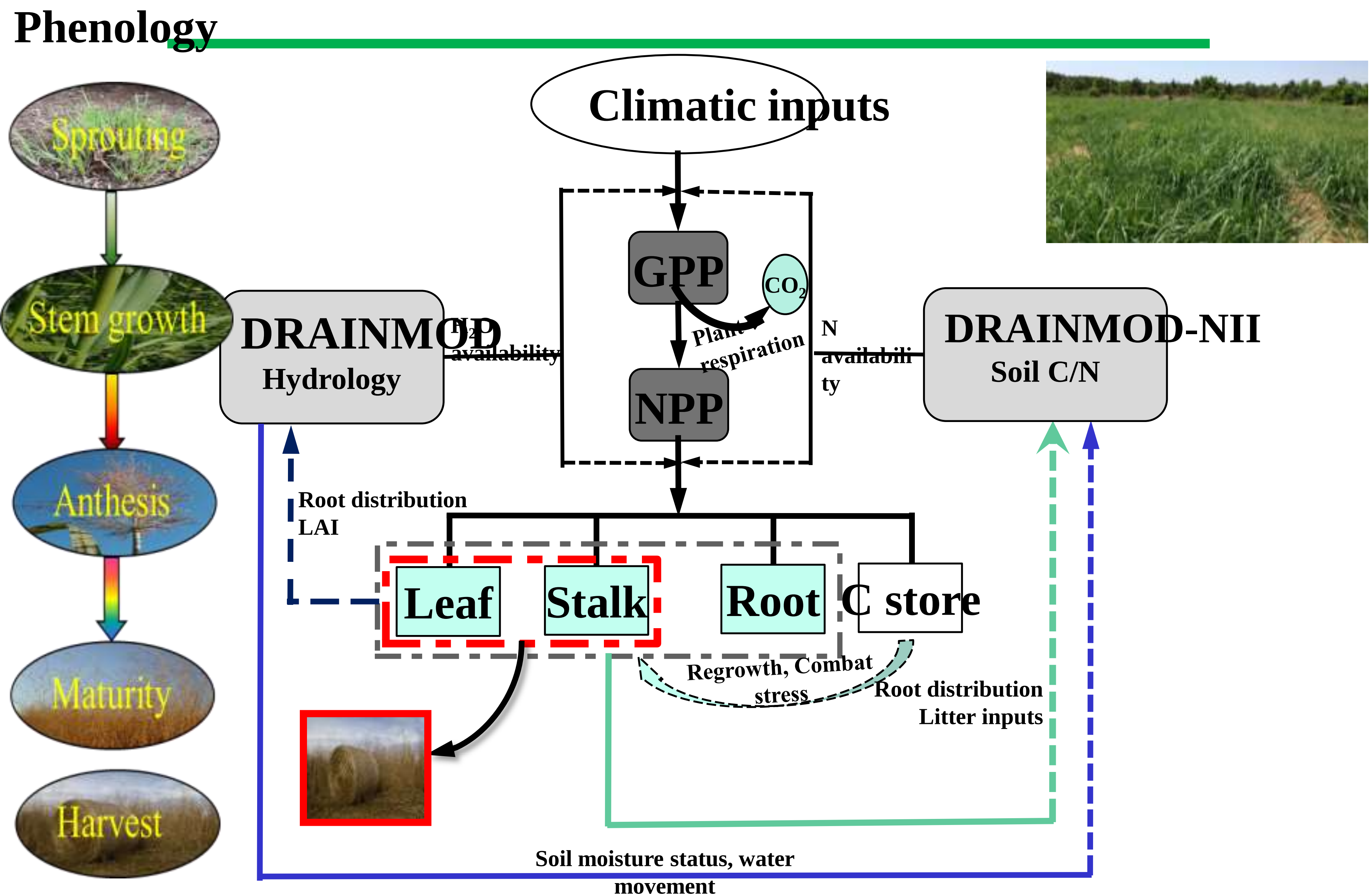
- *Bennett, E.M. 2013. Hydrology and Water Quality Impacts of Site Preparation for Loblolly Pine (Pinus taeda) and Switchgrass (Panicum virgatum) Intercropping in Upland Forested Watersheds in Alabama. M.S Thesis. North Carolina State University. Manuscript in review: Biomass and Bioenergy*

POTENTIAL FOR SCALING UP & REPLICABILITY

- No experimental scaled-up but Modelling study
- **Water Quantity Implications of Regional-Scale Switchgrass Production in the SE U.S**. (using SWAT model) *(Christopher et al., 2015; Biomass & Bioenergy)*
- On ~ 5 million ha Tombigbee Watershed, MS/AL
- Max conversion of pine to switchgrass increased annual stream flow by 7%.
- Conversion of young (≤ 4 yr) and old (≥ 16 yr) pine to switchgrass increased stream flow by 2%.
- Changes in annual flow driven by changes in ET.
- Stream flow changes resulting from biofuel production scenarios should be considered.
- Guidance to public policymakers as they influence a plan for large-scale cellulosic biofuel production, while sustaining water quality and quantity.
- ***<u>A DRAINMOD-SWG eco-hydrology model on progress for low-gradient landscapes</u>***
- ***<u>Remote Sensing approach</u>***



Framework of the Bio-energy Crop Model

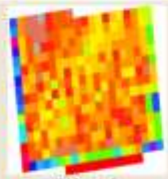
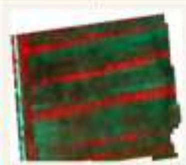


Remote Sensing

BAND WIDTH INFO OF LANDSAT, SPOT & ORTHOIMAGERY RS DATA ALONG WITH THEIR APPLICATION

Color Infrared (CIR) Orthoimagery

Band 1 – Blue (water mapping, soil/vegetation differentiation, deciduous/evergreen forest differentiation)
Band 2 – Green (greenness in vegetation differentiation)
Band 3 – Red (chlorophyll absorption for plant differentiation
Band 4 – NIR (chlorophyll absorption, biomass amount, waterbody delineation study)

Site # & Description	Landsat 8 (30 m resolution)	SPOT MSS (10m/Pansharpened to 5m resolution)	Orthoimagery (0.15 m resolution)	Comments related to ET/ET Parameter estimation
D0 (Young pine with understory)	 320 pixels	 1700 pixels	 21006387 pixels	❑ Low resolution Landsat imagery could not distinguish among Pine + Switchgrass intercropping as one single pixels covered both the vegetation as a MIXEL (average for entire PLOT was considered in Model Development) ❑ Medium resolution SPOT imagery after getting pansharpened to 5 m resolution, could distinguish between rows of Pine and Switchgrass as the row width was around 6 m. ❑ Ultra-high resolution orthoimagery could distinguish individual vegetation and also could easily separated the barren soil from switchgrass. Also helped to provide single pixel digital value for transect point locations.
D1 (Young pine rows with switchgrass intercropped rows)	 306 pixels	 1632 pixels	 19921286 pixels	
D2 (Matured pine)	 277 pixels	 1431 pixels	 17768565 pixels	
D3 (Switchgrass with barren soils rows)	 360 pixels	 1856 pixels	 21802569 pixels	

(2.08 – 2.35)

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

Band	Wavelength	Useful for mapping
Band 1 – coastal aerosol	0.43 - 0.45	coastal and aerosol studies
Band 2 – blue	0.45 - 0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 - green	0.53 - 0.59	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - red	0.64 - 0.67	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.88 - 0.85	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.57 - 1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.11 - 2.29	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 - Panchromatic	0.50 - 0.68	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.36 - 1.38	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 - 11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.5 - 12.51	100 meter resolution, Improved thermal mapping and estimated soil moisture

BAND AND BAND RATIO CORRELATION WITH PLANT HYDROLOGIC PARAMETERS

ET

Leaf Area Index

- Soil Adjusted Vegetation Index
  SAVI = ((NIR-RED)/(NIR+RED+L))*(1+L)
- Crop Vigor Index
  CVI = (MIR-GREEN)/(MIR+GREEN)
- Normalized Difference Vegetation Index
  NDVI = ((NIR-RED)/(NIR+RED)
- MIR/NIR Band → Stomatal Conductance
- TIR Band → Canopy Temperature
- MIR Band → Soil Moisture

MAIN CHALLENGES ENCOUNTERED

- Selection of sites suitable for novel system
- Problems with Switchgrass establishment
- Some Ag-equipment not rugged enough for forest sites
- Extreme coastal climate – Hurricanes/Tropical storms
- Weir Submergence
- Comparison of treatments across geographic regions
- Complex hydrogeology at upland sites

ACKNOWLEDGEMENTS

- Weyerhaeuser Company
- CatchLight Energy
- NC State University
- Drs. M Youssef, F Birgand, S Tian
- Cliff Tyson, Clay Mangum,
  - Weyerhaeuser
- Wilson Huntley, NCSU
- US Forest Service – Southern Research Station

THANKS!!

Questions?