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

An Example of Positive Bioenergy and Water Relationship

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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

RATIONAL

- ~ 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
To estuary

COASTAL LOWLAND
SITE AT CARTERET COUNTY, NC

Switchgrass-Pine Intercropping Study in 2009
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)


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

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

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

- 25 ha
- Parallel drain
- <0.1% slope
- Deloss FSL soil
ANNUAL and MONTHLY PRECIPITATION, NC

WATER QUANTITY

Monthly Rainfall Distribution

<table>
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<th>Months</th>
<th>Rain, mm</th>
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<tr>
<td>12</td>
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</tr>
</tbody>
</table>

Mean: [Graphical representation]

Long Avg: [Graphical representation]
DAILY WATER TABLE ELEVATION
D1 and D2, 2009-2012

NSS = Near surface saturation

04/09 D1-Harvest
07/09 D1-Shearing
01/10 D1-Planting
March 01, 2010
Stable Calibration Period
April 30, 2012
Treatment Period

WATER QUANTITY
DAILY WATER TABLE ELEVATION & SOIL MOISTURE
D1 and D2, 2012-13 Treatment

WTE, m


D1_WTE  D2_WTE

Daily Average Soil Moisture, 2012-2013
D1 and D2

Soil Moisture, m³/m³


D1  D2
CALIBRATION & TREATMENT RELATIONSHIPS
(DAILY WATER TABLE ELEVATIONS)

Treatment (2012-2013)

$WTE1 = 0.198 + 0.986 \times WTE2$

$R^2 = 0.97$
$NSE = 0.97$
$logE = 0.96$
$RMSE = 0.07 \text{ mm}$

Calibration (2010-2012)

$WTE1 = 0.244 + 0.947 \times WTE2$

$R^2 = 0.97$
$NSE = 0.97$
$logE = 0.97$
$RMSE = 0.084 \text{ mm}$
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)

- **Switchgrass-intercropped**
  - Negligible effect

- **All switchgrass**
  - Increased effect
CALIBRATION & TREATMENT RELATIONSHIPS
(DAILY DRAINAGE FLOWS)

Expected D1 Flow: 447 mm
Observed D1 Flow: 400 mm

WATER QUANTITY
DAILY ET, D1 & D2, Treatment Period

Aug-Nov 2012
D1 > D2 by 8 mm

Mar – Jun 2013
D1 > D2 by 18 mm

WATER QUANTITY

Nearby Plot scale study

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.

Janine M. Albaugh, Jean-Christophe Domes, Chris A. Matier, Eric B. Sucre, Zakarya H. Laggari, John S. King

Department of Forest and Environmental Sciences, North Carolina State University, Raleigh, North Carolina, USA

Journal homepage: www.elsevier.com/locate/agrformet

Abstract

Despite growing interest in using meteorological data on the physiology of this species and its effect on stand water use and carbon fluxes, there are few large-scale dataset available for understanding the relative effects of environmental factors on carbon fluxes and productivity. To address this gap, we used a process-based model of the plant–soil–atmosphere system to understand the relative effects of temperature, precipitation, and atmospheric CO2 concentration on the carbon balance of pine and switchgrass intercrops. We examined the relative effects of temperature, precipitation, and atmospheric CO2 concentration on the carbon balance of pine and switchgrass intercrops. We examined the relative effects of temperature, precipitation, and atmospheric CO2 concentration on the carbon balance of pine and switchgrass intercrops.
WATER QUALITY EFFECTS

D1

Historic Avg TKN = 0.63±0.37 mg L⁻¹
Historic Avg NO₃-N = 0.47±0.527 mg L⁻¹

D3

Historic Avg TKN = 0.55±0.20 mg L⁻¹
Historic Avg NO₃-N = 0.23±0.14 mg L⁻¹

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

D1 - Switchgrass Intercropped Pine
D3 – Switchgrass only

Historic TKNavg = 0.17±0.11 kg ha⁻¹
Historic NO₃Avg = 3.16±2.1 kg ha⁻¹

Historic TNAvg = 3.22±3.4 kg ha⁻¹
Historic TPavg = 0.04 ±0.03 mg L⁻¹
A CHIEVED OUTCOMES


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.
- **A DRAINMOD-SWG eco-hydrology model on progress for low-gradient landscapes**
- **Remote Sensing approach**
Framework of the Bio-energy Crop Model

Phenology

Sprouting → Stem growth → Anthesis → Maturity → Harvest

Climatic inputs

GPP → NPP

Nitrogen availability

CO₂

Plant respiration

N availability

DRAINMOD

Hydrology

Soil moisture status, water movement

Root distribution

LAI

Leaf → Stalk → Root → C store

Regrowth, Combat stress

Root distribution

Litter inputs

DRAINMOD-NII

Soil C/N

Framework of the Bio-energy Crop Model
Remote Sensing

Band 1 - Blue (water mapping, soil, vegetation, differentiation)
Band 2 - Green (vegetation index)
Band 3 - Red (Chlorophyll absorption, vegetation, differentiation)
Band 4 - NIR (chlorophyll absorption, biomass amount, water body delineation)
Band 5 - SWIR 1 (Delineation of healthy vegetation)
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
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Questions?