4.1 Impacts of switchgrass intercropping in traditional pine forests on hydrology and water quality in the southeastern United States

Key lessons Learnt:

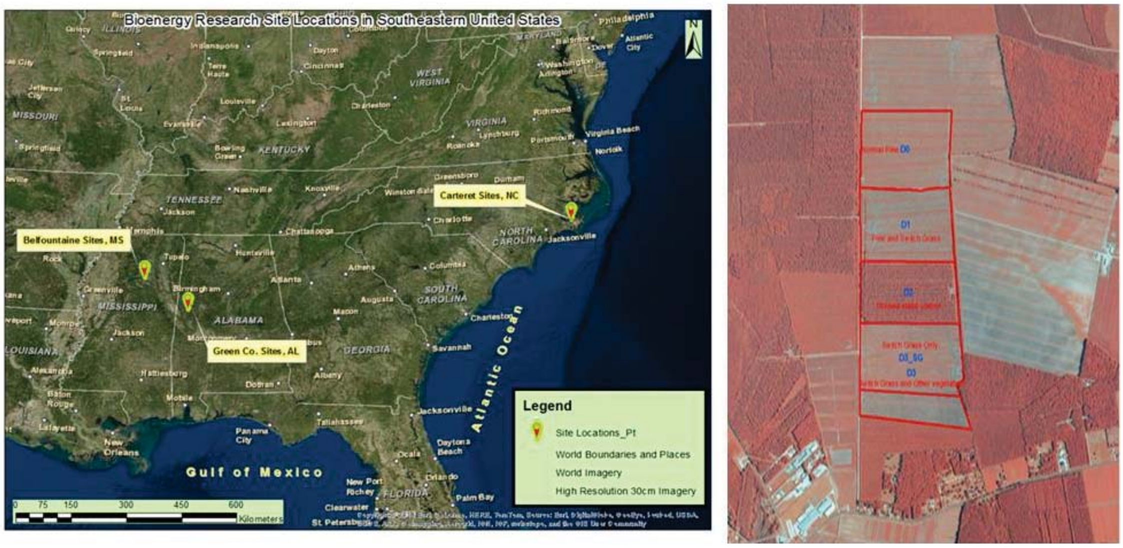
Preliminary results indicate that switchgrass (*Panicum virgatum* L.), grown as a cellulosic biofuel between managed loblolly pine (*Pinus taeda* L.) beds on the Atlantic Coastal Plain forests has no significant effect on shallow ground water table and stream outflows. Although management operations (e.g. harvesting, shearing between pine rows, raking, and bedding) implemented for pine and switchgrass establishment can lead to increases of nitrogen export, the magnitude of increases was lower than those usually observed on agricultural drainage waters in the region. Final results of study will soon be available. An adequate length of study period should be allocated for accurately quantifying effects of switchgrass intercropping on water quantity and quality from pine forests.

Introduction

There are approximately 15 million ha of pine (*Pinus* spp.) plantations in southeastern USA. Switchgrass (*Panicum virgatum* L.), as a cellulosic biofuel crop, intercropped in between pine (*P. taeda* L.) tree rows has potential for producing a cellulosic energy crop without using land currently in food production. Recent studies have shown that switchgrass has potential for long-term sustainability and for reducing environmental effects of bioenergy production compared to corn/row crops (George et al., 2008; Sanderson et al., 1996). This novel intercropping technology may not only reduce dependency on fossil fuels, but also benefit the American agricultural economy (Sanderson et al., 1996). Space, nutrients, and water between pine beds can be used by switchgrass to increase overall bioenergy production potential of pine forest land, possibly making it economically viable. The pine/switchgrass intercropping practice is also hypothesized to increase site nutrient uptake, thereby improving water quality compared to traditionally managed pine forests.

In 2009, Catchlight Energy LLC, a Chevron|Weyerhaeuser Company joint venture, established a regional research project to evaluate environmental effects of biomass cultivation in managed forests in the southeastern USA. The water related research was conducted in three states – North Carolina (NC), Alabama (AL), and Mississippi (MS) (Figure 1A). The example presented here is from NC, a coastal site with a long history of silvicultural and water management research (Figure 1B) (Amatya and Skaggs, 2011). Operations necessary for successful switchgrass establishment and growth include site preparation, planting, fertilizing, mowing and bailing and may affect hydrology and nutrient runoff. The main objectives of this study were to characterize temporal effects of management and use pre-treatment (pine forest) data to predict those treatment effects on downstream water quantity and quality. Treatment watersheds (~25 ha each) were: a pine/switchgrass intercropped site (D1), a mid-rotation thinned pine with natural understory (D2), and a switchgrass-only, a mid-rotation thinned pine with natural understory (D2), and a switchgrass-only site (D3) (Figure 1B).

Figure 1A: Location map of watershed study sites in NC, AL and MS in the southeastern US; and Figure 1B: Layout of the experimental watersheds (D0, D1, D2 and D3) for switchgrass-pine research in coastal NC



Source: 1A) Dr. Sudhanshu Panda & 1B) Cliff Tyson, Weyerhaeuser Company

Bioenergy and water relationships

Positive impacts on water quality:

Figure 2 below shows various silvicultural operations (harvesting, site preparation, shearing, bedding, raking and planting) necessary for a successful switchgrass establishment and growth in a pine forest, which may affect site hydrology and nutrient runoff.

Figure 2: Various silvicultural operations for switchgrass establishment in a pine forest in coastal NC

Source: Cliff Tyson, Weyerhaeuser Company

Figure 3: Thinned pine forest, switchgrass intercropped between pine rows and switchgrass only stands in NC

Source: Cliff Tyson, Weyerhaeuser Company

Muwamba et al. (2015) found that although management operations implemented for pine and switchgrass establishments can lead to increases of N export, values were lower than those usually observed on agricultural drainage waters in the region. The authors also showed the importance of considering water quality effects associated with intensive management operations required for switchgrass establishment or other novel forest-based biofuel systems. Preliminary results indicated no significant effects of switchgrass growth on nutrient parameters for intercropped D1 site (Table 1).

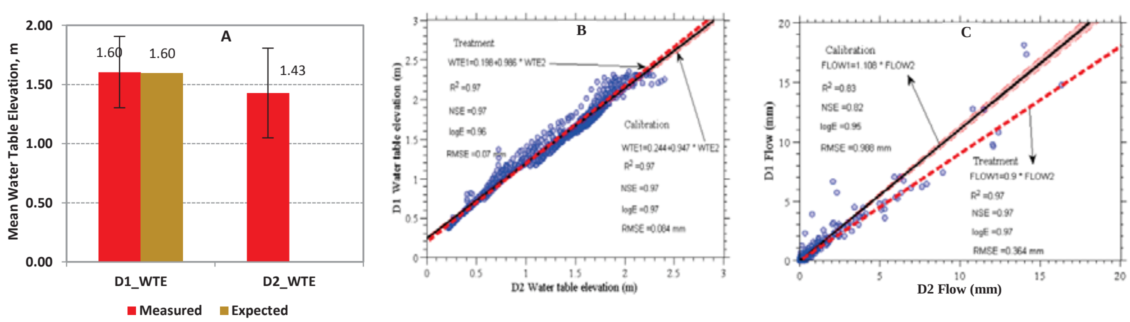
Table 1: Effects of switchgrass establishment (2010 – 2012) and growth (2012 – 2014) treatments compared to traditional pine forest on drainage water nutrient loads.

Watershed	Load, kg ha^{-1} (Site Preparation)			Load, kg ha-1 (Switchgrass Growth)		
Nutrients ---→	TKN	NO_3-N	PO_4-P	TKN	NO_3-N	PO_4-P
Switchgrass Intercrop(D1)	0.55±0.50	1.93±0.77	-0.87±0.52	0.50±0.32	0.23±0.09	-1.33±0.51
Switchgrass only (D3)	0.71±2.42	0.81±1.24	-0.42±0.17	3.21±1.33	1.13±0.26	-0.68±0.22

*Growth effects are preliminary only

Positive impacts on water availability:
This is being evaluated using measured water table and flow data from switchgrass treatment watersheds compared to the traditional pine forest using a paired watershed approach (Ssegane et al., 2015). Preliminarily, there is no significant effect of switchgrass intercropping on daily water table elevations and flows for switchgrass intercropped pine (D1; Figure 4). Complete data are being analysed for final results of the hydrologic and water availability study.

Figure 4: (A) Measured and expected mean annual water table and calibration and treatment regressions for (B) daily water table elevation and (C) daily flows for switchgrass intercropped pine (D1)



Source: 4A) Devendra Amatya ; 4B) Dr. Herbert Ssegane, Argonne National Laboratory; & 4C) Dr. Herbert Ssegane, Argonne National Laboratory

Positive impacts on biomass/bioenergy production:
This system could not only provide a reliable source of biomass but could also increase financial returns on forestry, which would, in turn, encourage forest establishment. Switchgrass is a native C4 plant with high water use efficiency, dense root system that resists erosion and as a perennial, does not have the soil impact of an annual crop. An intercropping system would mean no additional land would be needed, boosting dedicated energy crop supply beyond predictions without removing land from food production.

Prospects

Main drivers for implementing the project:
This study is evaluating possible biomass production scenarios that could affect millions of hectares of forest land in the southeastern USA (Figure 1A). While cellulosic biofuel crops are just beginning to be planted on a large scale, there is an immediate need for information on environmental effects of these crops. Growing and harvesting such crops on forestland appears to be a very attractive option, but for these biofuel technologies to be viable, effects on water resources must be quantified and compared to those of existing land uses. This study is expected to provide short and long-term assessments of hydrologic and water quality impacts of practices that represent a range of intensive biofuel practices on forest lands.

Key enabling factors:

- Catchlight Energy's willingness to investigate a novel approach of land use design by intercropping switchgrass between pine used for timber production, substituting the natural understory for a biofuel to displace fossil fuel with a potential of generating an income while waiting for final harvest of crop trees.
- A research need to investigate hydrology and water quality of sites affected by land use and management changes to comply with state and federal water quality regulations on discharges to downstream waterbodies.
- Research funding made available by Catchlight Energy LLC, which was later supplemented by additional funding through US Department of Energy to North Carolina State University.
- A strong, committed multi-collaborative research partnership joined by multidisciplinary cooperators from academia, government, industries, and other agencies.
- A history of long-term research on the Carteret site (Amatya and Skaggs, 2011), which includes many peer reviewed publications, validated models, productivity, weather and water quality data, highly qualified technical support and collaborative relationships. Understanding existing forest and water relations and site monitoring has been very helpful to testing a novel system such as this study.
- In-kind contributions from all cooperating agencies.

Main challenges encountered:

- Selection of suitable sites for experimental studies.
- Initial experimental design due to a novel idea of switchgrass intercropping in a pine forest.
- Land acquisition and establishing paired watershed calibration for assessing treatments.
- Complexities of hydrogeologic features for an accurate watershed water balance.
- Limited resources (funding, manpower, time) for operational management at study sites and measurements of suite of environmental variables during treatments in complex pine-switchgrass ecosystems for comprehensive and accurate assessments.
- Site preparation in a forestland and uncertainty in weather pattern for switchgrass establishment.
- Malfunctioning of instruments/sensors/loggers during research period due to unforeseen causes.

Potential for scaling-up and replicability:

The above study is being replicated as paired watershed (8 to 27 ha) studies on Weyerhaeuser Company lands in Greene County, AL (Bennett, 2013) and Calhoun County, MS in USA (Figure 1A). An additional study is being performed at the plot scale (0.8 ha size) in Lenoir County, NC (Albaugh et al., 2014). Treatments on all of these three studies are similar to those described above for the NC site (Figure 1B) (Muwamba et al., 2015; Ssegane et al., 2015). The system was scaled-up operationally, but ultimately not implemented (Nettles et al., 2015). Regional scale effects of the intercropped system on water quality will be examined at the completion of the paired watershed study, and a simulation study was conducted for water quantity (Christopher et al., 2015). In that study, a widely used hydrologic model (SWAT) calibrated with data from the above experimental studies, was applied on ~ 5 million ha of the Tombigbee Watershed located in MS and AL to examine water quantity effects of various land use change scenarios ranging from switchgrass intercropping a small percentage of pine forest land to conversion of all pine forests to only switchgrass. Results showed that maximum conversion of pine to switchgrass increased annual stream flow by 7 percent. Conversion of young (≤ 4 years) and old (≥ 16 years) pine to switchgrass only increased stream flow by 2 percent. Change in annual flow was driven by change in ET. Projecting stream flow change will provide guidance to public policy makers as they plan for large-scale production of cellulosic biofuels while sustaining water quality and quantity.

References and additional information

References:

Albaugh, J.M., J-C, Domec, C. A. Maier, E.B, Sucre, Z.H, Leggett, J.S. King.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, USA. *Agricultural and Forest Meteorology*. 192–193:27–40.

Amatya, D.M. and R.W. Skaggs. 2011. Long-term hydrology and water quality of a drained pine plantation in North Carolina, USA. *Trans of the ASABE*, 54(6):2087-2098.

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, Raleigh, North Carolina, U.S.A.

Christopher, S., S. Schoenholtz, and J.E. Nettles. 2015. Water Quantity Implications of Regional-Scale Switchgrass Production in the Southeastern U.S. Accepted*, Biomass and Bioenergy.*

Muwamba, A., 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. 2015. Nutrient balance and export from four watersheds during the calibration period at pine switchgrass treatment forests in coastal North Carolina. *J of Environmental Quality,* 44:1263-1272

Nettles, J., P. Birks, E. Sucre, B. Bilby. 2015. Sustainable production of bioenergy feedstock from the industrial forest: Potential challenges of operational scale implementation. Accepted, Current Sustainable/Renewable Energy Reports, Dec. 2015.

Ssegane, H., D.M. Amatya, A. Muwamba, G.M. Chescheir, T. Appelboom, E.W. Tollner, J.E.Nettles, M.A. Youssef, F.Birgand, and R.W. Skaggs. 2015. Hydrologic Calibration of Paired Watersheds on Pine and Switchgrass using a MOSUM Approach, *Hydrol. Earth Syst. Sci.* Discuss., 19, 1–35, 2015.

George, N., Tungate, K., Hobbs, A., Fike, J., Atkinson, A., 2008. A Guide for Growing Switchgrass as a Biofuel Crop in North Carolina, North Carolina Solar Center, North Carolina State University, Raleigh, USA.

Sanderson, M.A., Reed, R.L., McLaughlin, S.B., Wullschleger, S.D., Conger, B.V., Parrish, D.J., Wolf, D.D., Taliaferro, C., Hopkins, A.A., Ocumpaugh, W.R., Hussey,M.A., Read, J.C., Tischler, C.R., 1996. Switchgrass as a sustainable bioenergy crop. *Bioresource Technol*. 56, 83–93.

Contact name: Devendra M Amatya, PhD, PE

Affiliation/Organization: United States Department of Agriculture (USDA), Forest Service, Southern Research Station, Center for Forested Wetlands Research (CFWR), Cordesville, South Carolina (SC).

Additional information:
The CFWR's hydrology/water quality program is designed to address important water and water management issues including the impacts of natural and anthropogenic factors in low-gradient forested landscapes, using both the monitoring and modelling approaches. The CFWR's Research Hydrologist Devendra Amatya is conducting research to quantify and evaluate the effects of cultivating loblolly pine, switchgrass as a biofuel source, and switchgrass-pine intercropping on hydrology and water quality of pine forests in North Carolina in partnership with North Carolina State University, Weyerhaeuser Company, University of Georgia and University of North Georgia.