The Potential for Using Agroforests for Bioenergy Production in the Lower Mississippi Alluvial Valley

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Introduction

Increased national and international demand for renewable energy has increased the use of biomass for energy production. Currently energy from biomass represents approximately 4% of the energy generated in the US (US Energy Informaiton Administation 2011). New export markets resulting from renewable energy and greenhouse gas reduction standards in the European Union have also increased the demand for energy products such as wood pellets (Sikkema et al. 2011). Wood pellets are commonly used for residential heating or co-firing with coal for electricity generation. Wood pellet production capacity in North America increased from 1.1 million tonnes in 2003 to 6.9 million tonnes in 2009, with the Southern US accounting for 33% of this capacity in 2009 (Spelter and Toth 2009). Exports of pellets from North America to the European Union was estimated to be 0.5 million tonnes in 2009 (Sikkema et al. 2011). The use of dedicated energy grass, such as switchgrass, is also being used for pellet production in the southern US. Development of second-generation conversion technologies that transform cellulosic feedstocks to transportation fuels (de Wit et al. 2010, Londo et al. 2010) will likely increase the demand for biomass in the US and Europe which would increase the value of these crops for farmers and producers.

The Lower Mississippi Alluvial Valley (LMAV) region of the Southern US has a high potential for cellulosic biomass production due to its long growing season and well-developed agricultural industry (Trip et al. 2009). In addition the transportation and pipeline systems within this region provide a suitable logistical infrastructure for the delivery of the feedstocks to processing facilities as well as the distribution to consumers (Strata G. LLC et al. 2009). Thus, the LMAV appears to be well positioned for capitalizing on the potential market values of biomass bioenergy crops.

In order to reduce the impact of bioenergy crop production on the yield of the current agricultural crops grown in this region, bioenergy crops will likely be established on marginal soils which typically have nutrient and/or moisture constraints and are less suitable for traditional agricultural crops. Often these soils support crops and vegetation that provide conservation benefits and important ecosystems services. Given these considerations we are determining the levels of biomass production of two native species, cottonwood trees and switchgrass, grown on marginal soils in the LMAV. In addition, we are assessing how these crops might be grown in either monocultures or alley cropped agroforests to provide suitable biomass yields as well as important ecosystem services such as wildlife habitat and nutrient retention. Growing cottonwood trees and switchgrass in agroforests may not only enhance the ecosystems services of these two crops but also economically benefit small landowners by diversifying their bioenergy crops. Cottonwood-switchgrass agroforests would provide an annually harvested crop (switchgrass) and a perennial (cottonwood) crop which could be managed on a flexible harvesting schedule to take advantage of variations in bioenergy or other product markets. This manuscript provides initial results in regard to cottonwood and switchgrass yields, impacts of these species on nutrient retention or loss, and the potential effects of agroforest systems on small mammal populations in the LMAV.

Methods

This study was established in 2009 at three locations; the (1) UA Pine Tree Branch Station (PTBS) near Colt, AR, (2) the UA Southeast Research and Extension Center (SREC) in Rohwer, AR, and (3) the Stephenson Farm (SF) near Archibald, LA (Figure 1). Five different cropping treatments were established in replicate plots on marginal soils at each location. The five cropping treatments were 1) 100% cottonwood (CW), 2) 100% switchgrass (SG), 3) an alley cropped agroforest dominated by switchgrass (SGCW), 4) an alley cropped agroforest dominated by cottonwood (CWSG), and 5) a soybean-grain sorghum rotation (SGSR), a conventional row cropping system typically grown on marginal soils in the LMAV. The agroforests were planted in parallel 15 and 30 m allies to establish the two different agroforests dominated by either cottonwood (67% of the plot area planted to cottonwood) or switchgrass (67% of plot area planted to switchgrass).

Treatment Establishment and Yield Measurements

Cuttings from three cottonwood clones (ST66, S7C20, and a mixture of clones from a Louisiana Department of Agriculture and Forestry nursery) were planted on a 1.2 x 1.8-m spacing. Sites were subsoiled to a 60 cm depth two to three months prior to hand planting at the two Arkansas sites, while the SF site was planted with a machine planter that created a trench approximately 44 cm in depth at the time of planting. Competition was controlled using a variety of pre- and post-planting herbicides. Trees were fertilized by banding 35.8 kg/ha of ammonium nitrate during the spring of the year following establishment. Basal diameter, diameter at breast height, and tree heights were measured annually. Biomass yields were calculated using individual tree dimensions and the equations by Jenkins et al. (2004).

Following initial herbicide application and tillage operations, 11.2 kg/ha of the “Alamo” switchgrass variety was planted in the late spring using a seed drill. Emergence and establishment were monitored the first year and supplemental planting of switchgrass was performed if warranted. Following the first growing season after establishment, the switchgrass was mowed but not removed from the plot. Yields were determined in the fall of the second and third growing season following establishment. Remaining switchgrass was harvested and baled and removed from each plot following yield determinations.

The soybean-grain sorghum rotation consisted of two consecutive years of soybean crops followed by one year of grain sorghum. Since two of the fields had been planted to soybeans prior to study initiation, soybeans were planted the first and third year of the study, and grain sorghum the second year. The soybean and grain-sorghum were planted with varieties and methods commonly recommended for the soil and climate of each specific location. Herbicide, pesticides, and fertilizer were utilized as dictated by each location and climate. Grain yields as well as harvesting residue measurements were made at plant maturity using plot harvesters and manual collection methods. Grains were then harvested using harvesting equipment available at each location.

Small Mammals

Small mammals were trapped within a 75 x 75-m trapping grid located in the interior of one 90 x 90-m plot from each treatment at each study site during four collection seasons (February, April, June-July, October-November) in 2011. A total of 36 traps were positioned on each 15 m intersection of the grid. Traps were baited with oatmeal. During the winter traps were supplied with a small piece of cotton to aid the captured animal in heat retention. Trapping occurred during five consecutive nights during each season for a total of 720 trapping nights for each treatment.

Each individual collected was identified to species, with the exception of *Peromyscus* spp. and *Reithrodontomys* spp. which were identified to genus, using defining body characteristics (i.e., pelage). After identification the animals were then weighed to the nearest gram using a Pesola spring scale. Sex was determined based on urogenital distance and the presence/absence of gonads. Finally, age class (adult or juvenile) was determined based on weight and other physical characteristics. Monel, self-piercing, metal ear tags were used to uniquely identify (mark) each captured individual. All individuals were released at the site of capture.

Population composition and species diversity were determined independently for each site, treatment, and season. Shannon's diversity index (Shannon 1948), total number of individual's captured per 100 trap nights, sex/age distributions, and proportion of captures by habitat type were calculated for each treatment during each season at each site. Because sprung traps and incidental captures were minimal throughout the course of trapping, captures per 100 trap nights were simply calculated as total number of captures divided by the appropriate number of 100 trap nights.

Soil Water Chemistry

Soil water chemistry was monitored using four tension lysimeter. Lysimeters were installed to a depth of 30 cm in each plot assigned to the SG, CW, or SGSR cropping treatments. A tension of 45 kPa was established in each lysimeter at the initiation of each soil water collection period. Soil water was collected once every two weeks starting in January 3, 2012 and ending June 20, 2012. Water was composited from the four lysimeters at a plot and analyzed for dissolved NO_3-N, NH_4-N, organic N, total N, and total P.

Results

Crop Establishment and Production

Switchgrass was successfully established at the PTBS and SF sites but not the SREC site during the first growing season. Soils at the SREC site have a high clay content which forms a crust that is difficult for newly emerged switchgrass plants to penetrate. Following multiple attempts, successful establishment occurred at this site following a wet and warm winter in 2011, indicating that unique sowing strategies are needed for effective switchgrass establishment on clay soils. Following the second growing season, switchgrass density at the SF and PTBS sites were respectively 17 and 28 crowns/m^2. Yields from these two sites following the third growing season in 2011 were respectively 8.5 and 16.1 dry Mg/ha.

Aboveground cottonwood biomass and production was determined for the 3rd growing season (2011). Cottonwood survival was between 30% and 82% with the greatest biomass accumulation (7.2 oven dry Mg/ha) occurring at the SREC site and the lowest (0.56 oven dry Mg/ha) occurring at the SF site. Low productivity at the SF site was related to poor survival due to a shallow hardpan, heavy grass competition, and two years of drought. Survival of cottonwood at the PTBS site was adequate but low biomass accumulation resulted from damage associated with aerial drift of quinclorac (Facet®) herbicide from adjacent fields. Biomass production at the SREC site during the third growing season was 4.7 oven dry

Mg/ha which represented approximately 65% of the total accumulated aboveground biomass of cottonwood at this site. We expect that annual production at this site will double during 2012.

Average aboveground biomass yield of grain sorghum during the second year of the study was 5.4 oven dry Mg/ha. Approximately 29.2% of the biomass was grain while the remainder was in stem, foliage, and seed head remains. Average soybean aboveground production was 2.25 oven dry Mg/ha. Soybean grain represented approximately 30% of the total aboveground biomass.

These results indicate that given the variability of marginal soils in the LMAV, the specific bioenergy crop planted to a given site will need to be carefully considered. Within the three sites studied, cottonwood and switchgrass establishment success and production varied considerably. Even at the best sites, an extended establishment time (three or more years) could be needed before substantial biomass production levels are attained. Such establishment difficulties may make landowners reluctant to alter current management practices on these marginal soils.

Small Mammals

A total of 560 captures of 289 individuals occurred at the three sites during the four seasons. Approximately 63.3% of the individuals were captured at SREC. A total of 7 species or genus groups were captured: the hispid cotton rat (*Sigmodon hispidus*), *Peromyscus* spp., house mouse (*Mus musculus*), *Reithrodontomys* spp., marsh rice rat (*Oryzomys palustris*), woodland vole (*Microtus pinetorum*), and least shrew (*Cryptotis parva*). The house mouse, hispid cotton rat, marsh rice rat, and *Peromyscus* spp. represented the vast majority of the individuals captured. These four groups accounted for 50.5, 18.6, 14.5, and 12.1%, respectively, of the individuals captured. The three remaining species or genus groups (*Reithrodontomys* spp., woodland vole, and least shrew) individually accounted for less than 2.0% of the captured individuals.

Where switchgrass was successfully established (PTBS and SF), the greatest amount of individuals captured occurred in the SG treatment (1.94-2.92 individuals/100 trap nights). At these sites the number of captures in the SGCW and CWSG treatments was also higher than those in the CW or SGSR treatments (for example Table 1). At these two sites, 60-84% if the captures in the CW, SGCW, CWSG, and SG cropping treatments occurred in switchgrass, indicating a preference for switchgrass compared to the cottonwood trees. The number of captures (0.69-1.11 individuals/100 trapping nights) in the soybean-grain sorghum rotation was consistently lower than those in the SG, SGCW, or CWSG cropping treatments. At the SREC site where switchgrass had not been successfully established by 2011, the highest number of captures occurred in the CW cropping treatment (7.92 individuals/100 trapping nights) and the lowest in the SGSR cropping treatment (3.75 individuals/100 trapping nights).

Small mammal diversity was consistently highest in the SGCW and CWSG cropping treatments, which contained both cottonwood and switchgrass (Table 2). Shannon's diversity index was consistently greater with the SG cropping treatment than with the CW or SGSR cropping treatments.

These initial findings indicate that replacing conventional row crops with bioenergy crops such as switchgrass on marginal soils in the LMAV can increase small mammal populations. Planting alley cropped cottonwood and switchgrass would likely increase the diversity of the small mammal populations in comparison establishing any of the single-cropping systems tested.

Soil Water Chemistry/Nutrient Retentions

Concentrations of N in soil water were generally greater in the soybean-grain sorghum rotation (SGRS) treatment then either the switchgrass (SG) or cottonwood (CW) cropping treatments. Although NO_3-N soil water concentrations varied among sites and sampling periods, NO_3-N concentrations were consistently greater in the SGRS treatment than the other two treatments during each sampling period (Figure 2). Average NO_3-N concentrations in the SGRS cropping treatment were approximately 5 to 6 times greater than in the SG and CW cropping treatments (Table 3). Nitrate-N was the dominant N ion in these soil solutions and total N concentrations like NO_3-N were significantly greater in the SGRS treatment than in the SG or CW crops. Concentrations of NH_4-N, organic N, and total P were numerically but not significantly ($p \leq 0.10$) greater in the SGRS than the other two cropping treatments (Table 3).

The higher levels of soil water N in the SGRS treatment likely reflected the nitrogen fixing ability of the soybeans and the fertilizer applied to this cropping treatment. In addition soybeans and grain sorghum are annual crops which have rapid decomposition of harvest residues and below-ground tissues. Comparisons in root biomass among these three cropping treatments at the three study sites (unpublished data) indicated significantly higher levels of living roots in the SG and CW treatments than the SGRS. By maintaining living roots during the entire year, cottonwood and switchgrass were able to absorb available N, reduce N inputs from decomposing roots, and increase N retention better than the crops growing in the soybean-grain sorghum rotation. The similar concentrations of N in the soil water of the switchgrass and cottonwood suggest that these two crops have similar N retention abilities.

Summary

Biomass yields from switchgrass and cottonwood during the initial establishment phase significantly varied among different marginal soils and locations in the LMAV. It may take an extended period of time for these crops to reach their maximum yield and provide suitable amounts of biomass for energy production. The amount of N retention in these biomass crops appear to be greater than those from typical row crop agriculture practiced on marginal soils in the LMAV. In addition small mammal populations and diversity can be increased with conversion of row crop agriculture to cottonwood and switchgrass agroforests.

References

Berry, L. and K. Mitchell. 2009. Logistics Assessment of the Delta Region. http://agbioworks.org/downloads/home.cfm?CFID=39720412&CFTOKEN=290d0d89942ac09d-146C623C-5056-A338-C8FE15167EFC783B&jsessionid=84303a2ba7643b83c2195c7d7b4357ea3f7b

de Wit, M and Faaijl, APC. 2010. Biomass Bioenergy 34:188-202.

Jenkins, Jennifer C.; Chojnacky, David C.; Heath, Linda S.; Birdsey, Richard A. 2004. Comprehensive database of diameter-based biomass regressions for North American tree species. Gen. Tech. Rep. NE-319. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 45 p.

Londo, M., Lensink, S., Wakker, S., Fischer, G., Prieler, S. 2010. The REFUEL EU road map for biofuels in transport. Biomass Bioenergy 34:244-55.

Shannon, C.E. 1948. A mathematical theory of communication. Bell System Technical Journal 27:379-423, 623-656.

Sikkema, R., Steiner, M., Junginger, M., Wolfgang, H., Morten, T.H, and Faaij, A. 2011. The European wood pellet markets: current status and prospects for 2020. Biofuels, Bioprod., Bioref. 5:250-278.

Spelter, H. and Toth, D. 2009. North America's wood pellet sector. Research Paper FPL-RP-656. Madison, WI. U.S.D.A., Forest Service, Forest Products Laboratory. 21. p.

Tripp, S. , Powell, S.R., Nelson, P. 2009 Regional strategy for biobased products in the Mississippi Delta, Executive Summary. Battelle Technology Partnership Practice, pp 23.

US. Energy Information Administration. 2011. Annual Energy Review 2010. DOE/EIA-0384(2010. pp 384.

Figures

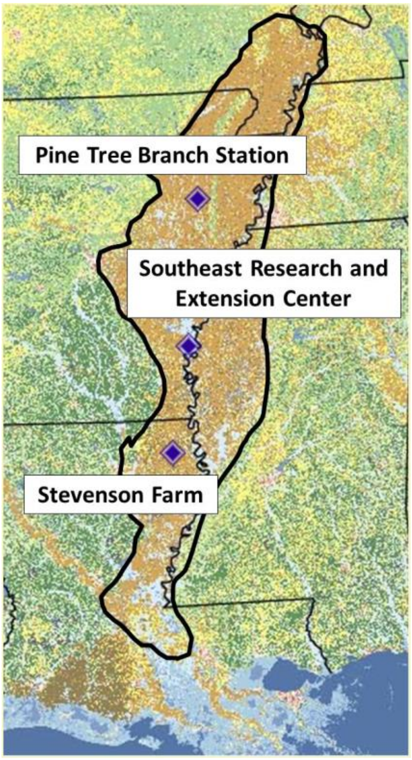

Figure 1. Location of three bioenergy agroforest study sites, UA Pine Tree Branch Station (PTBS), UA Southeast Research and Extension Center (SREC), and the Stephenson Farm (SF) within the Lower Mississippi Alluvial Valley of the Southern US.

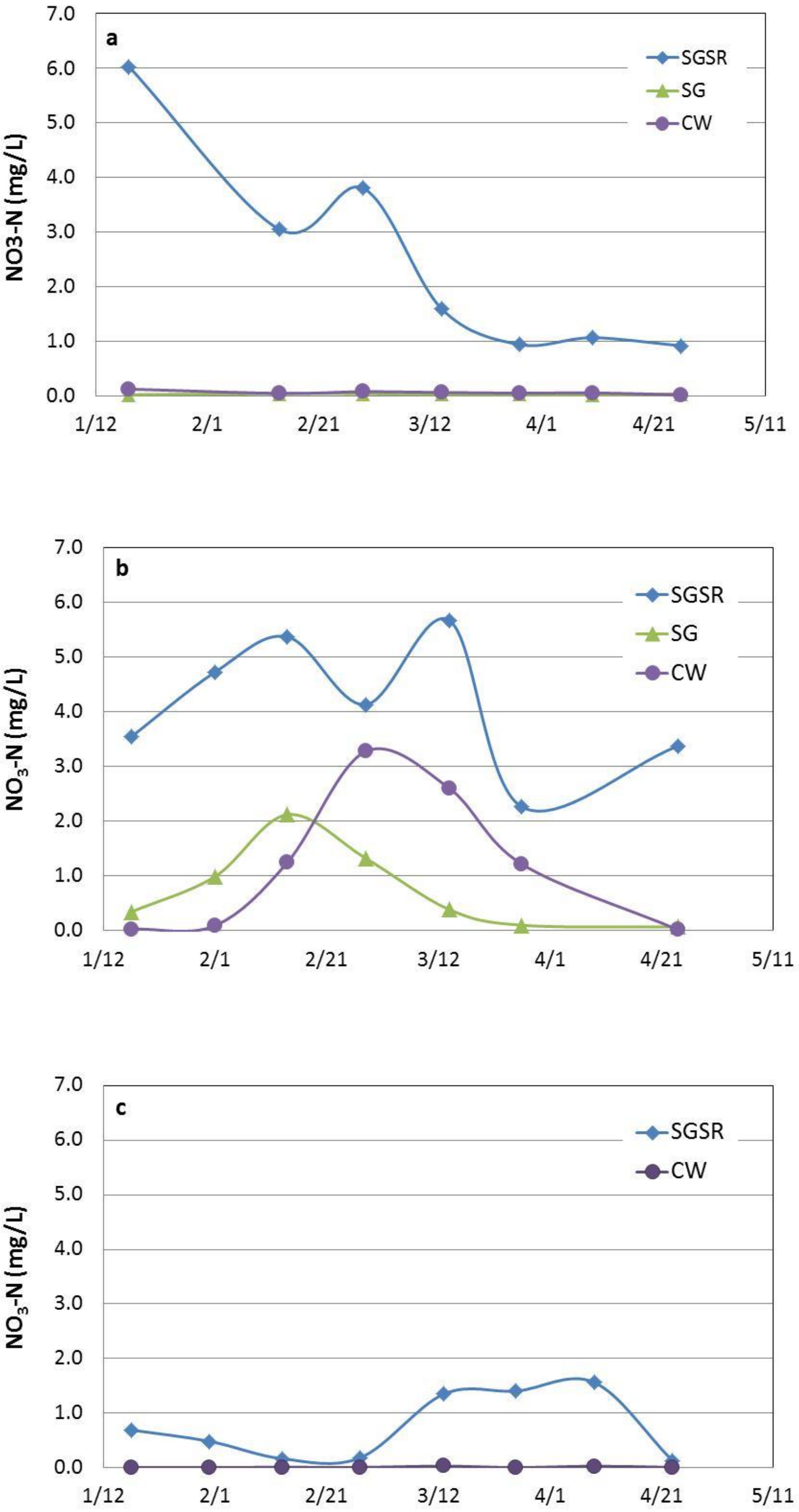

Figure 2. **Soil water NO_3-N concentrations in the soybean grain sorghum rotation (SGSR), 100% switchgrass, (SG) and 100% cottonwood (CW) treatments during 2012 at the a) UA Pine Tree Branch Station, b) UA Southeast Research and Extension Station, and c) Stephenson Farm.**

Tables

Species	Treatment (CW)	(SG)	(CWSG)	(SGCW)	(SGSR)	Total
Sigmodon hispidus	0	11	1	3	0	15
Peromyscus spp.	6	9	6	8	4	33
Mus musculus	0	0	1	0	1	2
Reithrodontomys spp.	0	0	0	1	0	1
Oryzomys palustris	0	0	2	2	0	4
Microtus pinetorum	0	0	0	0	0	0
Cryptotis parva	0	0	0	0	0	0
Total	**6**	**20**	**10**	**14**	**5**	**55**
Number of ind./100 trapping nights	0.83	2.92	1.39	1.81	0.69	1.53

Table 1. Small mammal community characteristics by treatment for all seasons combined at the Pine Tree Branch Station, Colt, Arkansas, 2011.

Site	Treatment (CW)	(SG)	(CWSG)	(SGCW)	(SGSR)
PTBS	0.00	0.69	1.09	1.12	0.50
SREC	1.34				0.16
SF	0.67	0.52	1.27	1.04	0.00

Table 2. Shannon diversity index of the small mammal community in each treatment at each site during 2011.

Site & Treatment	NO_3-N (mg/L)	NH_4-N (mg/L)	Soil Water Organic N (mg/L)	Total N (mg/L)	Total P (mg/L)
PTBS & SF					
SGSR	3.32*	0.88	1.26	5.14*	0.08
SG	0.39	0.09	0.24	0.72	0.03
PTBS, SREC, & SF					
SGSR	2.38*	0.69	1.01	3.84*	0.07
CW	0.41	0.10	0.29	0.78	0.04

Table 3. Mean N and P soil water concentrations in the soybean grain sorghum rotation (SGSR), switchgrass (SG) and cottonwood (CW) cropping treatments. SGSR concentrations noted with * are significantly ($p \leq 0.10$) higher than those for the SG or CW cropping treatments.