

Building a Better Biomass Ecosystem: Cottonwood-switchgrass Agroforests on Marginal Land

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Bioenergy markets may provide revenue to landowners on marginal lands in the Lower Mississippi Alluvial Valley (LMAV) where crop returns are low due to low fertility or risk. Cottonwood and switchgrass are native to this region, grow on a wide range of soils, and produce substantial amounts of biomass. Combining these two species in agroforests will provide both annual and periodic harvests of biomass along with valuable ecosystem services such as nutrient retention and wildlife habitat. Four levels of cottonwood and switchgrass cover were established in agroforests on marginal soils at three sites in the LMAV in Arkansas and Louisiana in the spring of 2009. In 2011 switchgrass and cottonwood growth at the most productive sites were respectively 16.2 and 4.6 oven-dry Mg/ha. Cottonwood production has doubled each growing season and could accumulate as much as 18 Mg/ha in the fourth growing season and 34 Mg/ha on a 5-year rotation. Small mammal abundance and diversity were significantly greater in switchgrass and cottonwood agroforests than in control treatments planted to a soybean-grain sorghum rotation. Nitrate concentrations in soil water in the agroforest treatments were generally lower than those in control plots. Initial results suggest that substantial biomass production from cottonwood and switchgrass can occur on marginal soils but production differs significantly among soils. Cottonwood is very sensitive to common herbicide treatments applied to rice fields. Where establishment and growth is adequate, ecosystem services are enhanced by cottonwood and switchgrass agroforests.

Keywords: carbon sequestration, ecosystem services, short rotation woody crops

Introduction

The growing demand for renewable energy is driving the development of dedicated agricultural and forestry systems producing biomass for energy. In the US, renewable energy represented 8% of all production, and biomass was 53% of all renewable energy production in 2010. (US Energy Information Administration 2011). The development of second-generation conversion technologies transforming cellulosic feedstocks to transportation fuels and other blendable energy commodities (de Wit et al. 2010, Londo et al. 2010) will further the demand for biomass in the US which will 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). The transportation and energy distribution systems within this region provide a suitable logistical infrastructure for the delivery of the raw and processed feedstocks, further enhancing the fitness of the region for dedicated biomass for energy production.

To avoid a “food vs. fuels” conflict, we propose to establish bioenergy crops on marginal soils where nutrient and/or moisture constraints make them poorly suited for food crops. We also propose to develop a biomass production system that will provide conservation benefits and valuable ecosystem services. To this end, we are establishing two native species, cottonwood (*Populus deltoides*) and switchgrass (*Panicum virgatum*) on marginal soils in the LMAV. We will assess how these crops might be grown in

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monocultures or in alley cropped agroforests to provide biomass for energy, wildlife habitat, and soil nutrient retention. Agroforests may not only enhance the ecosystems services of these two crops but also economically benefit landowners by diversifying the rotation length and markets for their bioenergy crops.

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). Plots were subsoiled to a 60 cm depth two months prior to 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. Pre-planting herbicides included pendimethalin (2 qt./ac) and imazaquin (4 oz./ac) at PTBS and SREC, and sulfometuron methyl (1 oz./ac) at SF.

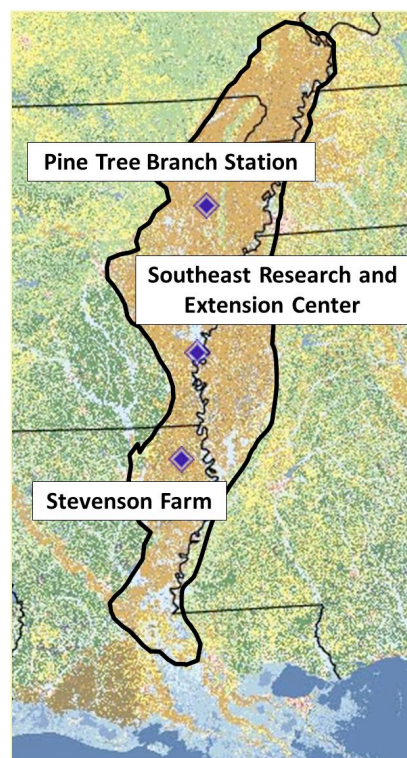


Figure 1. Location of three bioenergy agroforest study sites, UA Pine Tree Branch Station (PTBS), UA Southeast Research and Extension Center (SREC), and the Stephenson Farm (SF) within the Lower Mississippi Alluvial Valley of the Southern US.

Five different cropping treatments were established in replicate plots on marginal soils at each location in March of 2009. The five cropping treatments were 1) 100% cottonwood (CW), 2) 100% switchgrass (SG), 3) an alley cropped agroforest with 30m switchgrass alleys and 15m cottonwood alleys, (SGCW), 4) an alley cropped agroforest with 30m cottonwood alleys and 15m switchgrass alleys (CWSG), and 5) a conventional soybean-grain sorghum rotation for marginal soils in the LMAV (SGSR), which acted as a control treatment for the study. The switchgrass variety used was Alamo, seeded at a rate of 11.2 kg ha⁻¹. Two known cottonwood genomes (ST-66 and S7C20) and nursery-run mixture (Mixed) from the Louisiana Department of Agriculture and Forestry nursery in Monroe, LA were planted on 1.2 x 1.8m spacing, 4485 trees/ha. Post planting competition control was controlled using a variety of herbicides as necessary at each site. Each site also required one aerial application of imidacloprid (Provado 8 oz. /ac)

to control cottonwood leaf beetle (*Chrysomela scripta* Fabricius). Trees were fertilized by banding 35.8 kg/ha of ammonium nitrate during the spring of the year following establishment. Establishment and maintenance costs for trees averaged \$2200/ha and \$250/ha for switchgrass. 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 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 seasons. 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 followed by one year of grain sorghum. Since two of the sites (SREC and PTBS) 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. After sampling, grains were then harvested according to common practice in the region.

Small mammals were trapped using 36 traps baited with oatmeal 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 through four collection seasons (February, April, June-July, October-November) in 2011. 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 was monitored using four tension lysimeters 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 NO₃-N, NH₄-N, organic N, total N, and total P.

Results and Discussion

Biomass production

Cottonwood biomass accumulation was substantially higher at the SREC site than other sites (Table 1), but for different reasons. Survival of cottonwood clones at the SF site in Louisiana averaged 28-31% for the three varieties because of severe grass competition and drought in the first two growing seasons. Tree survival was much better at the PTBS site, averaging 63-64% by variety, but there, seasonal damage from rice herbicides in nearby fields killed terminal growth each year in May-June and in response to the herbicide damage the trees developed a very branchy, shrub-like form. At the SREC, tree survival averaged 78 to 86%, and tree height and diameter growth were also greatest, resulting in significantly better biomass accumulation.

Table 1. Third year cottonwood, switchgrass, and soybean biomass production at three agroforestry sites within the Lower Mississippi Alluvial Valley.

Cottonwood Clonal Variety (oven-dry kg/ha)			
	S7C20	ST-66	Mixed
PTBC ¹	1114 ^a	776 ^a	798 ^a
SREC ²	6974 ^b	6779 ^b	8087 ^b
SF ³	634 ^a	387 ^a	679 ^a
Switchgrass (oven-dry kg/ha)			
PTBC	16,200 ^c		
SREC	0.0		
SF	6,941 ^b		
Soybean (green kg/ha)			
	Grain	Trash	
PTBC	2186 ^b	2407 ^b	
SREC	1886 ^b	3233 ^b	
SF	1010 ^a	1349 ^a	
Values with different alphabetical superscripts are different at the 5% level of significance.			
1 – Pine Tree Branch Station, near Colt, Arkansas			
2 – Southeast Research and Extension Center, near Rohwer, Arkansas			
3 – Stevenson Farm, near Archibald, Louisiana			

Switchgrass production (Table 1) was best at the PTBS and annual production in year three of the switchgrass stand was more than double the best 3-year accumulation of cottonwood treatments. Switchgrass establishment failed repeatedly at the SREC site due to the high clay content of the soils. During the mild winter of 2011-2012 an adequate stand of switchgrass was established, indicating that unique planting strategies are necessary on heavy-clay sites.

Biomass production from the control plots in 2011 (Table 1) clearly indicated the marginal nature of the three sites. Grain yields ranged from 6.8 bu./ac to 14.7 bu./ac; typical soybean yields for Arkansas are greater than 30 bu./ac (Coats and Ashlock, 2011).

While cottonwood biomass accumulation in year three is only half that of switchgrass annual production, the growth and development of cottonwood biomass accumulation at Rohwer over three growing seasons (Table 2) indicates that the optimum rotation for the cottonwood may not yet be reached. Projected cottonwood biomass accumulation at SREC for years 4 and 5 are 18 and 34 Mg/ha, respectively. And growth and development of cottonwood in future rotations from the established root systems (coppice regeneration) may also exceed what has been observed to date.

Table 2. Progression of cottonwood biomass accumulation at Southeast Research and Extension Center, Rohwer, Arkansas, 2009 to 2011.

Growing Season	Annual Growth (OD kg/ha)	Cumulative biomass (OD kg/ha)
2009	873	873
2010	1781	2654
2011	4626	7280

Small Mammals

A total of 560 captures of 289 individuals occurred at the three sites during the four seasons with 63% of the individuals captured at the SREC. Seven 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 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 number captures 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 (Table 3). At PTBS and SF, 60-84% of the captures in the CW, SGCW, CWSG, and SG cropping treatments occurred in switchgrass, indicating a preference for grass cover to tree cover. 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).

Table 3. Small mammal community characteristics by treatment for all seasons combined at the Pine Tree Branch Station, Colt, Arkansas, 2011.

Species	Treatment					Total
	(CW)	(SG)	(CWSG)	(SGCW)	(SGSR)	
<i>Sigmodon hispidus</i>	0	11	1	3	0	15
<i>Peromyscus</i> spp.	6	9	6	8	4	33
<i>Mus musculus</i>	0	0	1	0	1	2
<i>Reithrodontomys</i> spp.	0	0	0	1	0	1
<i>Oryzomys palustris</i>	0	0	2	2	0	4
<i>Microtus pinetorum</i>	0	0	0	0	0	0
<i>Cryptotis parva</i>	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

Where both switchgrass and cottonwood cover was available (PTBC and SF), small mammal diversity was consistently greatest in cropping treatments containing both cottonwood and switchgrass (Table 4).

Shannon's diversity index was consistently greater with the SG cropping treatment than the SGRS cropping treatment.

Table 4. Shannon diversity index of the small mammal community in each treatment at three biomass production sites in the Lower Mississippi Alluvial Valley in 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

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 and Nutrient Retention

Concentrations of N in soil water were generally greater in the soybean-grain sorghum (SGRS) than either the switchgrass (SG) or cottonwood (CW) treatments. Although NO₃-N soil water concentrations varied among sites and sampling periods, NO₃-N concentrations were consistently greater in the SGRS treatment than the other two treatments during each sampling period (Figure 2). Average NO₃-N concentrations in the SGRS cropping treatment were approximately 5 to 6 times greater than in the SG and CW cropping treatments (Table 5). Nitrate-N was the dominant N ion in these soil solutions and total N concentrations like NO₃-N were significantly greater in the SGRS treatment than in the SG or CW crops. Concentrations of NH₄-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 5).

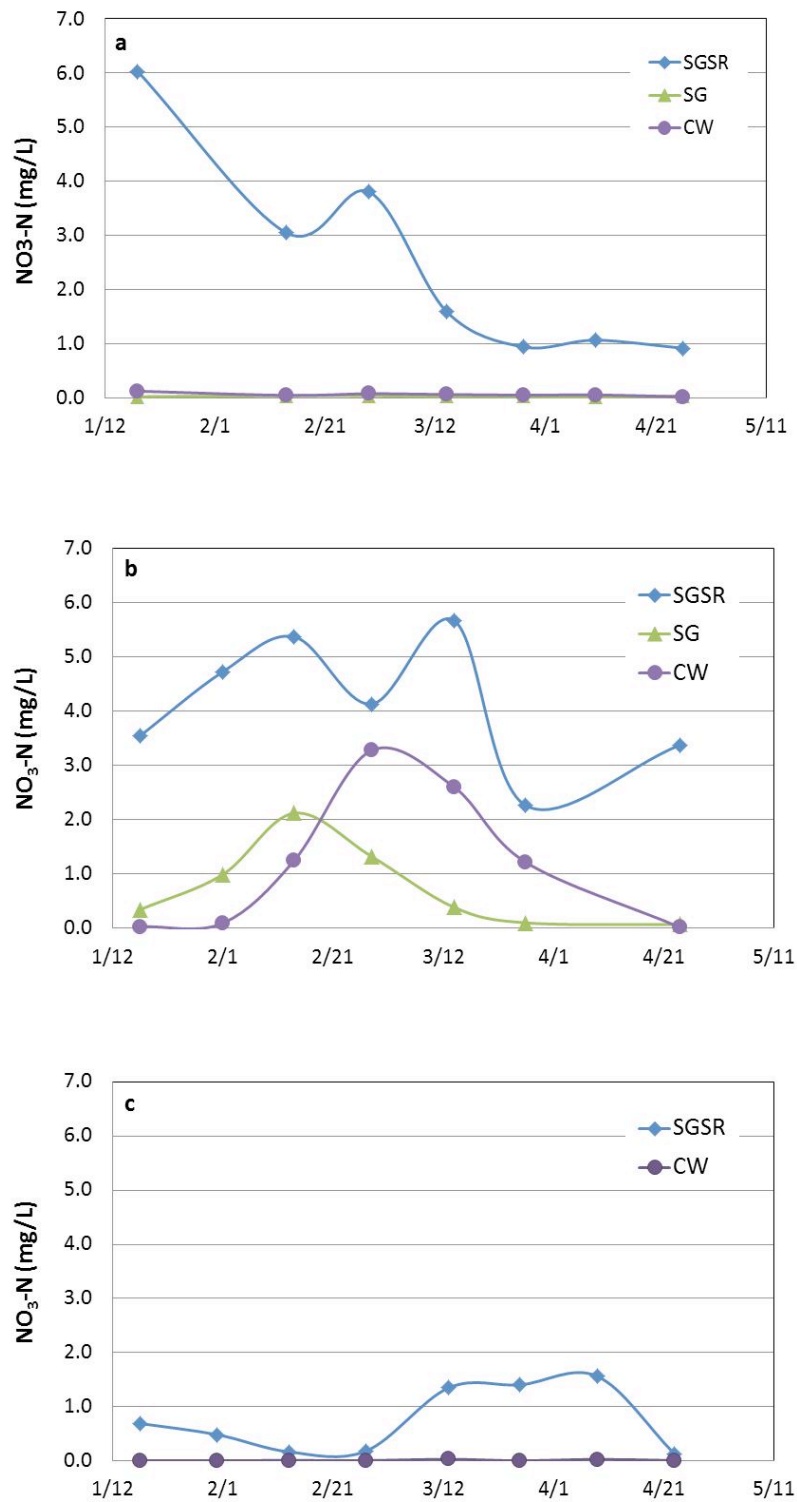


Figure 2. Soil water $\text{NO}_3\text{-N}$ concentrations in the soybean grain sorghum rotation (SGSR), 100% switchgrass, (SG) and 100% cottonwood (CW) treatments during 2012 at the a) UA Pine Tree Branch Station, b) UA Southeast Research and Extension Station, and c) Stephenson Farm.

Table 5. Mean N and P soil water concentrations in the soybean grain sorghum rotation (SGSR), switchgrass (SG) and cottonwood (CW) cropping treatments on three biomass production sites in the Lower Mississippi Alluvial Valley in 2011.

Site & Treatment	Soil Water NO ₃ -N (mg/L)	NH ₄ -N (mg/L)	Organic (mg/L)	N (mg/L)	Total (mg/L)	N (mg/L)	Total (mg/L)	P
<u>PTBS & SF</u>								
SGSR	3.32*	0.88	1.26		5.14*		0.08	
SG	0.39	0.09	0.24		0.72		0.03	
<u>PTBS, SREC, & SF</u>								
SGSR	2.38*	0.69	1.01		3.84*		0.07	
CW	0.41	0.10	0.29		0.78		0.04	
SGSR concentrations noted with * are significantly ($p \leq 0.10$) higher than those for the SG.								

The higher levels of soil water N in the SGSR 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 SGSR. The maintenance of living roots of cottonwood and switchgrass during the entire year would likely help to absorb available N, reduce N inputs from decomposing roots, and thus increase N retention. The similar concentrations of N in the soil water of the switchgrass and cottonwood suggest that these two crops have similar N retention abilities.

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