Bulletin 1210 December 2014

Switchgrass Production as a Bioenergy Crop in Mississippi

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This research was sponsored by the Sustainable Energy Research Center at Mississippi State University with funding from the United States Department of Energy and the Mississippi Agricultural and Forestry Experiment Station.The report was approved for publication as MAFES Bulletin 1210 of the Mississippi Agricultural and Forestry Experiment Station. It was published by the Office of Agricultural Communications, a unit of the Division of Agriculture, Forestry, and Veterinary Medicine at Mississippi State University.

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INTRODUCTION

The Energy Independence and Security Act (EISA) of 2007 was signed into law to address energy policy in the United States (H.R. 6 — 110th Congress, 2007). The Renewable Fuel Standard (RFS) in the EISA mandated that the total amount of biofuel added to gasoline be increased from 4.7 billion gallons in 2007 to 36 billion gallons in 2022. It also required 21 of the 36 billion gallons be derived from non-cornstarch feedstock (i.e., sugar or cellulose). Therefore, a key activity of the Biomass Program within the Office of Energy Efficiency and Renewable Energy (EERE) at the United States Department of Energy (DOE) is to identify and develop a sustainable, high-quality feedstock supply for a biomass-to-bioenergy supply chain.

Currently, corn-based ethanol is an important source of biofuel and contributes roughly 10% to our domestic fuel needs. However, in 2010–11 it took roughly 40% of the U.S. corn crop to produce biofuels and other products, which sparked a food-versus-fuel debate among concerned citizens, researchers, and leaders worldwide. Therefore, a number of annual and perennial herbaceous crops and short-rotational trees have been considered for dedicated energy crops. Results from multi-institutional research studies indicate that perennial, warm-season grasses—specifically switchgrass (*Panicum virgatum* L.)—have a high potential to serve as lignocellulosic feedstock materials for the production of second-generation biofuels (Blanco-Canqui 2010, Wright and Turhollow 2010, Wullschleger et al. 2010).

Switchgrass has been identified as a promising feedstock due to its extensive deep-root system, rapid growth, broad range of adaptability, high drought tolerance, and high biomass yield (Sanderson et al. 1996). A review by Blanco-Canqui (2010) suggested that switchgrass and other warm-season, perennial grasses can improve soil quality, sequester soil organic carbon, reduce soil erosion, and improve wildlife habitat, which will have a greater positive impact on the environment when compared with row crops such as corn. This impact is important since marginal lands with limited resources are being considered as the primary source of land for cellulosic crop production (Adler et al. 2009, Bhardwaj et al. 2011, Blanco-Canqui 2010, Lal 2009).

There is no single descriptive measure that identifies land to be classified as marginal, but it will typically feature poor land quality characterized by a low nutrient status, undesirable soil pH, and a high erodibility factor resulting in an unsuitable environment for row-crop production. A review prepared by the Food and Agriculture Organization of the United Nations (FAO) suggests that biophysical and socio-economic data should be considered when evaluating land-use options (FAO 2007). Biophysical data includes factors of climate, topography, hydrology, soil characteristics, land degradation, and land cover. Socio-economic data includes land-use and management. Bhardwaj et al. (2011) suggests that even though there are several factors that distinguish the concept of marginality, biophysical limitations will be the ultimately causal factor of unacceptable socio-economic conditions.

In addition, the influence of law, regulations, and public policy will have an effect on the decisions landowners make concerning land-use and the resulting environmental consequences (Robertson and Swinton 2005). For example, a special permit and surety bond must be obtained from the Department of Agriculture and Commerce before a nonnative plant species can be established in the state of Mississippi. This law was passed to require a permit in order to identify areas where nonnative plants are cultivated as feedstock for the bioenergy industry. The surety bond is required to pay for removing the nonnative plants if the site is abandoned.

House Bill 634

Mississippi Legislature 2012
Amendments authored by
Preston Sullivan (22nd District)

To prohibit the cultivation of certain nonnative plant species for the purpose of fuel production without first obtaining a special permit from the Department of Agriculture and Commerce for such cultivation; to establish a remedy available to the department for the removal and destruction of nonnative plant species determined to be a nuisance; and for related purposes.

The Conservation Reserve Program (CRP) is a contract payment program in the farm bill written by the U.S. government, directed by the U.S. Department of Agriculture (USDA), administered by USDA Farm Service Agency (FSA), and with technical assistance provided by the USDA Forest Service and USDA Natural Resources Conservation Service (NRCS). CRP is a voluntary program that offers annual rental payments and cost-share assistance for landowners to retire marginal land from crop production if the FSA determines that the tract of land is eligible based on a ranking system derived through the use of an Environmental Benefits Index (EBI) (Hellerstein and Malsolm 2011).

Establishment of native, warm-season, perennial grasses, especially switchgrass, plays a dominate role in the CRP because of the well-documented improvements to soil quality and wildlife habitat (Hamrick et al. 2007; Wright and Turhollow 2010). Bhardwaj (2010) and colleagues compared water and energy footprints of no-till soybean grown for biofuel on marginal land used for conventional row-crop production, land converted from CRP, and land in the CRP with grass cover (as a standard reference). Results from this research indicated that soil quality was improved for physical structure, carbon storage, and nutrient availability in marginal land with a CRP history, compared with marginal land utilized for conventional row-crop production.

Others report similar benefits of growing perennial grasses on marginal land, such as less intensive cultivation once established, reduced wind and water erosion, higher microbial activity, and lower bulk density (Blanco-Canqui 2010, McLaughlin and Kszos 2005, Hamrick et al. 2007). These results demonstrated that a nutrient-efficient, warm-season, perennial native grass such as switchgrass grown on marginal land will provide economic and ecological benefits while minimizing competition for land resources dedicated to production of food and fiber crops.

VARIETY SELECTION

Overview

Many variables are associated with switchgrass establishment. One of the first considerations is variety selection. There are two ecotypes available: lowland and upland. Lowland switchgrass varieties are tall, coarse plants that have 30–50% higher yield potential over upland varieties in the South (Hancock 2009). Upland varieties are shorter and have lower yield potential compared with lowland varieties, but they are more adapted to drier, colder regions of North America and are very winter hardy once established (Gibson and Barnhart 2007).

Figure 1. Varieties of switchgrass were evaluated at the Mississippi State University Pontotoc Ridge-Flatwoods Branch Experiment Station in Pontotoc County, Mississippi.

A trial was conducted from 2007 to 2009 at the Pontotoc Ridge-Flatwoods Experiment Station in Pontotoc County, Mississippi (34.138° N and 89.004° W), to evaluate commercially available switchgrass varieties and several experimental breeding lines (Figure 1). The varieties included in this study are described in Table 1. The experimental synthetic breeding lines were a collaborative effort between the Samuel Roberts Noble Foundation Inc., Ceres Inc., and the University of Georgia to develop high-biomass-yielding varieties for the South with better drought tolerance, less percent lignin deposition, and improved establishment characteristics compared with original native varieties (Bhandari et al. 2010; Bouton 2006).

Materials and Methods

A trial was established on an Atwood silt loam (fine-silty, mixed, thermic Typic Paleududalfs) with a history of no-tillage cotton production and what was considered good-quality soil. The design was a randomized com-

Table 1. Information on switchgrass varieties tested at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2010–2012.

Variety	Type	Origin	Origin date	Release organization	Release date
‘Alamo’	Lowland	Live Oak Co., TX	1972	USDA-NRCS-PMC[1]	1978
‘Kanlow’	Lowland	Wetumka, OK	1957	USDA-NRCS-PMC[1]	1958
‘Cave-in-Rock’	Upland	Cave-in-Rock, IL	1958	USDA-NRCS-PMC[1] & Univ. of Missouri	1973
‘Shawnee’	Upland	Selection from Cave-in-Rock	—	USDA-ARS[2] & Univ. of Nebraska	1995
NF/GA-001	Experimental	Breeding Program	—	SRNF-Ceres-UGA[3]	—
NF/GA-991	Experimental	Breeding Program	—	SRNF-Ceres-UGA[3]	—
NF/GA-992	Experimental	Breeding Program	—	SRNF-Ceres-UGA[3]	—
NF/GA-993	Experimental	Breeding Program	—	SRNF-Ceres-UGA[3]	—
NFSG05-1	Experimental	Breeding Program	—	SRNF-Ceres-UGA[3]	—

[1] United States Department of Agriculture-Natural Resource Conservation Service-Plant Materials Center.
[2] United States Department of Agriculture-Agricultural Research Service.
[3] Samuel Roberts Noble Foundation-Ceres-University of Georgia.

Table 2. Mean biomass yield for lowland, upland, and experimental breeding lines of switchgrass over a 3-year period at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2006–2008.[1]

Varieties	Mean biomass yield[2]		
	2006	2007	2008
	tons/A	*tons/A*	*tons/A*
Alamo	2.25	4.86	7.80
Kanlow	1.04	2.35	5.00
NF/GA-001	2.38	4.20	6.44
NF/GA-991	1.92	4.58	8.29
NF/GA-992	1.75	4.27	7.32
NF/GA-993	2.20	4.66	9.40
NFSG05-1	1.83	5.41	7.08
Shawnee	0.99	2.19	3.59
Cave-in-Rock	1.30	1.86	3.70
LSD (0.05)[3]	0.60	1.22	1.64
Trial Mean	1.74	3.82	6.51

[1] Grown on a productive Atwood silt loam (Fine-silty, mixed, thermic Typic Paleudalf).
[2] Tons of dry matter per acre.
[3] Statistical inferences based on the GLM procedure and mean separations performed by Fisher's Protected LSD test at P=0.05.

plete block with four replications. Plot size was 10 feet by 16 feet. The trial area was prepared by conventional-tillage methods on March 8, 2006. Switchgrass varieties were planted into a firm stale seedbed on May 15, 2006, at 6 pounds of pure live seed (PLS) per acre using an Almaco® grain drill equipped with a cone spinner seed divider and gravity-fed delivery tubes.

Soil test results from the Mississippi State University Extension Service Soil Testing Laboratory indicated a pH of 6.2 with a medium value for phosphate (P_2O_5) and high value for potassium (K_2O). No lime or fertilizer was applied in 2006 during the establishment year to minimize weed competition and interference. After the establishment year, fertilizer at 60-30-30 pounds per acre of $N\text{-}P_2O_5\text{-}K_2O$, respectively, was applied on May 4, 2007, followed by 60-50-0 pounds per acre of $N\text{-}P_2O_5\text{-}K_2O$, respectively, on April 23, 2008.

Ratings for plant height, percentage cover, and percentage canopy coverage were made throughout each growing season. Biomass was harvested annually after a killing frost in December or January each year (Table 2). Plots were mowed on February 23, 2007, and burned on February 29, 2008, to remove remaining switchgrass following harvest.

Results and Discussion

During the establishment year in 2006, percentage cover was lower for lowland ecotypes and higher for experimental lines, ranging from 5–38% and 27–71%, respectively (data not shown). Before harvest in the establishment year (2006), plant height ranged from 18–22, 20–28, and 28–31 inches for upland, lowland, and experimental lines, respectively (data not shown). Biomass yield for 'Alamo' and all experimental lines, except NF/GA992 and NF/GA05-1 was greater than the two upland ecotypes and 'Kanlow' (Table 2).

In the second year (2007), percentage canopy coverage during August was at least 98% for 'Alamo' and the experimental lines, while coverage for all other varieties ranged from 85–91% (data not shown). Second-year biomass yield with all experimental lines and 'Alamo' was at least 4.2 tons per acre, which was greater than the two upland ecotypes and 'Kanlow' (Table 2).

In the third production year (2008), percentage canopy coverage was 100% for 'Alamo' and all experimental lines. Also, lodging before harvest was 23% for the lowland ecotype 'Kanlow', which was greater than all other varieties except the upland ecotype 'Cave-in-Rock,' which lodged 15% (data not shown). Other research reports lodging for 'Kanlow' was highest among 20 varieties compared over a 4-year period (Lemus et al. 2002). 'Cave-in-Rock' has been documented to be resistant to lodging; however, this trial agrees with other literature that observed considerable lodging with this variety (Parrish et al. 2003; Tober et al. 2007).

Third-year biomass yield was at least 7 tons per acre for all varieties except the two upland ecotypes, NF/GA-001, and lowland ecotype 'Kanlow' (Table 2). The highest-yielding varieties were 'Alamo,' NF/GA991, and NF/GA993 at 7.8, 8.29, and 9.40 tons per acre, respectively. Biomass yield for experimental line NF/GA-993 was 20% higher than 'Alamo.' This finding supports other research that suggests new synthetic breeding lines have the potential to improve biomass yield by 20–30% when compared with 'Alamo' (McLaughlin and Kszos 2005).

Switchgrass yield increased each year for all varieties, with trial average biomass yields of 1.74, 3.82, and 6.51 tons per acre for 2006, 2007, and 2008, respectively. These numbers show an increase of 119% from the establishment year in 2006 to the first production year in 2007, followed by a 70% yield increase from 2007 to 2008. It is typical for dry matter yield to increase the first 2 years, with maximum production in the third year followed by stable yields for at least 10 years when managed properly (Mooney et al. 2009; McLaughlin and Kszos 2005).

Results from this variety trial were consistent with other variety trials across the South, which indicate that the lowland ecotype 'Alamo' is the best variety commercially available for use as a feedstock in north Mississippi. In addition, there are several promising experimental varieties that have the potential to produce even higher yields with traits that promote efficient crop production, improve feedstock quality, and enhance establishment characteristics when compared with traditional varieties (check with your local MSU Extension Service Office regarding commercial release of new switchgrass varieties).

Variety Selection

Overall, this research indicates that the lowland ecotype 'Alamo' is the best variety commercially available for use as a feedstock in north Mississippi. In addition, there are several promising experimental varieties that have the potential to produce even higher yields with traits that promote efficient crop production and improve feedstock quality compared to native varieties.

Check with your local Extension Service agent regarding commercial release of new switchgrass varieties.

SWITCHGRASS ESTABLISHMENT

Overview

Once established, switchgrass can have a productive life cycle of 10 to 20 years as a bioenergy crop (Garland et al. 2007; de Koff and Tyler 2011). However, the establishment year requires extensive planning and proper implementation of good management practices (Figure 2). Several factors that can contribute to an unsuccessful stand during the establishment year are poor seed quality or excessive seed dormancy, improper planting procedures (planting depth, seedbed condition, etc.), weed competition, and lack of adequate rainfall (Mitchell and Vogel 2012, Hancock 2009). In addition, a producer may incorrectly decide that a stand is unsuccessful due to delayed establishment (slow germination, variable emergence, and low seedling vigor) when compared with establishment of other grass forages. Patience is required. Results from an on-farm study conducted in the northern Great

Figure 2. Seedling stage of switchgrass on an Atwood silt loam at the Pontotoc Ridge-Flatwoods Branch Experiment Station.

Plains on 10 fields that qualified for CRP enrollment indicated that a stand of at least 40% during the first year was considered a successful establishment when switchgrass was grown as feedstock for bioenergy production (Schmer et al. 2006).

Therefore, seed quality does not need to be a limiting factor since it will play an important role in achieving a strong stand of switchgrass. A calculation of seed quality is the percentage of pure live seed (PLS), which is the percentage of viable seed that has the potential to germinate. For the Southeast, 'Alamo' switchgrass should be planted at 6–8 pounds per acre of PLS (USDA-NRCS-PMP 2009). PLS can be calculated by using the percentage of viable seed and percent purity of a given seed lot. This information is "required by law" for any certified seed lot and should be included on the seed tag.

Pure Live Seed

Calculation Example

PLS = (% purity x % viability) ÷ 100

Purity: 92%

Germination: 70%

Dormant seed: 20%

Total Viability: 70% + 20% = 90%

PLS = 92% x 90% ÷ 100 = 82.8%

Thus, PLS is 82.8% and the PLS seeding rate (SR) will be divided by %PLS and multiplied by 100.

SR = 6 lb/A PLS ÷ 82.8 x 100 = 7.25

Hence, 7.25 lb of seed from this lot would need to be planted to achieve a seeding rate of 6 lb PLS.

Adjusted Seed Cost

Calculation Example

In order to compare seed prices, divide cost per pound by percent PLS to account for seed quality.

$5.00/lb ÷ 82.8% x 100 = $6.03/lb PLS

Switchgrass is well adapted to a variety of growing conditions, but it is most productive on moderate to well-drained soils with a pH of at least 5.5 (Hancock 2009). Switchgrass may be planted into a tilled seedbed, stale seedbed, or no-till seedbed. Planting with a properly calibrated no-till drill into nonbedded fields from past row crops is a suggested way to plant (Garland et al. 2007, Mitchell et al. 2012). Seed should be planted to a 0.25-inch depth in fine-textured soil and a 0.5-inch depth in coarse-textured soil for the purpose of maintaining soil moisture for germination (USDA-NRCS-PMP 2009).

The seedbed should be firm to allow good seed-to-soil contact. Mitchell et al. (2012) suggest that a seedbed is firmly packed when only a faint footprint can be seen after walking across the field. This can be achieved with the use of a cultipacker before and/or after planting.

Due to the high dormancy of switchgrass seed, planting seed that is 1 year or older, or seed that has gone through a stratification process may help break dormancy and improve establishment (Teel and Barnhart 2003). Switchgrass will germinate at soil temperatures of 50°F, but seedling growth is more active with a consistent soil temperature of 60–65°F and air temperatures of 75–85°F (Guretzky 2007, Hancock 2009).

Therefore, the best planting date for the Southeast is typically between late April through early June. Later planting dates can be successful, but lack of rainfall could be the limiting factor that would increase the risk of an unsuccessful stand.

If soil tests are medium or higher for P_2O_5 and K_2O, no fertilizer is needed at planting. Nitrogen should not be applied in the establishment year in order to minimize weed interference and competition (West 2009).

It often takes months for switchgrass to become established, and a tall-dense stand should not be expected the first year, unless ideal conditions occur (Hamrick et al. 2007). In fact, it will typically take up to 2 to 3 years for full establishment (Hancock 2009, Mooney et al. 2009, de Koff and Tyler 2011).

Weed control is very important for switchgrass establishment. This control can be achieved with nonselective herbicide applications applied before planting, followed by a weed-control program that utilizes chemical and mechanical methods to minimize weed competition and promote growth of the switchgrass.

These guidelines support establishing a stand of switchgrass on a land resource area that has a successful history of crop production. However, marginal land has been targeted as a primary land resource for production of switchgrass as a bioenergy crop (Blanco-Canqui 2010, Lee et al. 2007, Wright and Turhollow 2010). Therefore, switchgrass planting systems were evaluated on a marginal land at the Pontotoc Ridge-Flatwoods Branch Experiment Station near Pontotoc, Mississippi.

Materials and Methods

This research was established on land that had not been cultivated for more than 10 years, thus simulating CRP. The study was initiated in 2010 and 2011 on an eroded Atwood silt loam (fine-silty, mixed, thermic Typic Paleududalfs). Soil test results for both sites included a 6.0 to 6.5 pH, very low phosphorous levels (13 to 16 pounds per acre), and high to very high potassium levels (260 to 442 pounds per acre). Even though phosphorous was considered very low, no fertilizer was applied in order to determine if switchgrass could be established on a true marginal land resource with minimal input costs.

The trial design was a randomized complete block with three replications in 2010 and a randomized complete block with four replications in 2011. Plot size was 12 feet by 50 feet each year.

On the 2010 site, a burndown treatment of glyphosate at 0.75 pound per acre (acid equivalent) was applied to the trial area on June 11, tillage practices (disc and do-all) were conducted to conventional tilled treatment areas on June 14, a second treatment of glyphosate at 0.75 pound per acre was applied to the trial area on June 29, and all planting systems were implemented on July 1 at rate of 6 pounds of PLS per acre.

On the 2011 site, glyphosate at 0.75 pound per acre (acid equivalent) was applied in early spring on April 14. Conventional tillage treatment areas were then prepared by the same methods used on the 2010 site and left undisturbed until an application of paraquat at 0.6 pound of active ingredient per acre on May 26. All planting systems were implemented on June 9 at a rate of 6 pounds of PLS per acre.

On both sites, switchgrass was planted in 9 rows spaced 7 inches apart with a Great Plains® no-till grain drill equipped with a small seed attachment or sown broadcast with a mechanical seed sower. There were four no-tillage planting treatments: (1) No-till + Drill (NT-D); (2) No-till + Drill + Cultipack (NT-D-CP); (3) No-till + Broadcast (NT-B); and (4) No-till + Broadcast + Cultipack (NT-B-CP). There were also five conventional-tillage planting treatments: (1) Tillage + Cultipack + Drilled + Cultipack (T-CP-D-CP); (2) Tillage + Cultipack + Drilled (T-CP-D); (3) Tillage + Cultipack + Broadcast + Cultipack (T-CP-B-CP); (4) Tillage + Broadcast + Cultipack (T-B-CP); and (5) Tillage + Cultipack + Broadcast (T-CP-B).

Switchgrass emergence was determined by visual assessment of percentage ground cover on a scale of 0 (no coverage) to 100 (complete coverage). Weed management practices were employed to minimize competition and interference. The 2010 study site was not harvested following the establishment year due to insufficient production of biomass. However, both study sites were harvested on February 9, 2012, with second-year biomass yield for the 2010 trial and first-year biomass yield for the 2011 trial. The studies were rated for percentage stand and vigor in spring 2012.

Establishment Method

Even though it appears planting with a no-till drill into unbedded fields from past row crops is the ideal way to plant (Mitchell et al. 2012), all no-till planting system treatments failed to achieve more than a 10% switchgrass stand in both years on a marginal soil left fallow for more than 10 years regardless of seeding method.

However, results from both years indicate that utilizing a drill-seeded-cultipack planting system in a conventional-tilled environment was the best method for establishing switchgrass on marginal land.

Results and Discussion

Even though switchgrass can be successfully established with no-tillage in undisturbed soil with a crop production history, all no-till planting system treatments failed to achieve more than a 10% switchgrass stand in both years on marginal soil left fallow for more

Table 3. Emergence, vigor, and yield of 'Alamo' switchgrass during establishment at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2010–2012.[1]

Planting system[2]	Emergence[3]			Plant vigor[4]	Biomass year 2[5]
	Year 1	Year 2	Year 3		
	%	%	%		*lb/A*
T-CP-D-CP	50 a	50 a	72 a	2.6	694
T-CP-D	50 a	53 a	72 a	2.6	575
T-CP-B-CP	10 b	13 b	30 b	3.3	265
T-B-CP	7 b	10 b	40 ab	3.6	300
T-CP-B	0 b	7 b	27 b	4.0	207
P [6]	<0.0001	<0.0001	0.0322	0.0676	0.0639

[1] Grown on marginal land with eroded Atwood soil (Fine-silty, mixed, thermic Typic Paleudalf) with a 2–5% slope.
[2] Planting systems include tillage-cultipack-drill-cultipack (T-CP-D-CP), tillage-cultipack-drill (T-CP-D), tillage-cultipack, broadcast-cultipack (T-CP-B-CP), tillage-broadcast-cultipack (T-B-CP), and tillage-cultipack-broadcast (T-CP-B).
[3] Percent ground cover.
[4] Scale of 1–10 where 1 is active growth and 10 is inactive growth.
[5] Pounds of dry matter per acre.
[6] Statistical inferences based on the GLIMMIX procedure; means followed by the same letter in a column are not significantly different at p=0.05 level of significance.

than 10 years, regardless of seeding method (data not shown). This limitation was probably due to the thick layer of existing vegetation that remained on the soil surface after the nonselective herbicide treatment, which created a less-than-desirable seedbed. Wolf and Fiske (2009), report that at least 50% bare ground is desirable to ensure good seed-soil contact; otherwise, there is a risk of the residue becoming pinned down in front of the coulters, creating a fold where the seed would be caught and entrapped (hair pinning).

Heavy grazing by livestock can reduce existing vegetation and provide some surface seedbed preparation from "hoof action" before planting (Ball et al. 2002). Other suggestions include a controlled burn with an approved plan from the NRCS and local fire department. Also, no-till production of a glyphosate-resistant row crop (soybean, corn, etc.) with 1 or more years of production before establishment can help prepare the field. These options provide the opportunity to develop site-specific land preparation strategies for a true no-till planting of switchgrass based on certain characteristics (vegetative species, density of cover, topography, etc.) of the land resource area.

In the 2010 study site, switchgrass emergence with all drilled-seeded treatments in a conventional-tilled environment was greater than broadcast-sown treatments for all 3 years, except for the T-B-CP treatment in year 3 (Table 3). Ground coverage during the first year of establishment was 50% for drilled seed and 10% or less for broadcast-sown seed. Emergence improved each year, and by year 3, ground coverage was 72% for drilled and 40% or less for broadcast-sown seed. Plant vigor was higher with drilled seed, but it was only greater than the T-CP-B planting system (Table 3). Biomass yield after year 2 was lower than expected for all treatments, ranging from 207 to 694 pounds per acre.

The 2011 study site exhibited similar results, with greater emergence for all drilled treatments compared

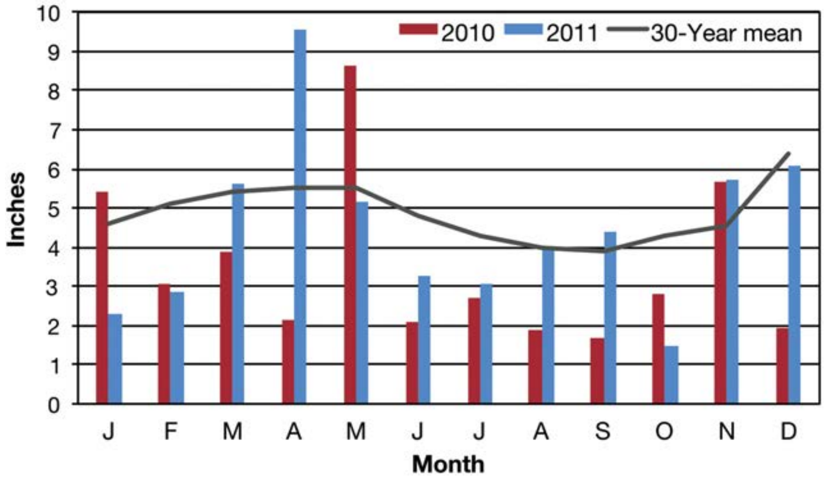

Figure 3. Monthly rainfall at the Pontotoc Ridge-Flatwoods Branch Experiment Station in Pontotoc County, Mississippi, during 2010–2011.

with broadcast-sown seed in a conventional-tilled soil (Table 4). Biomass yield was lower than expected for both studies, which is probably due to lack of sufficient rainfall and high temperature that caused less-than-desirable soil moisture during germination and the early growth stages of development (Figures 3 and 4). However, results from both years indicate that utilizing a drill-seeded-cultipack planting system in a conventional-tilled environment was the best method for establishing switchgrass on marginal land.

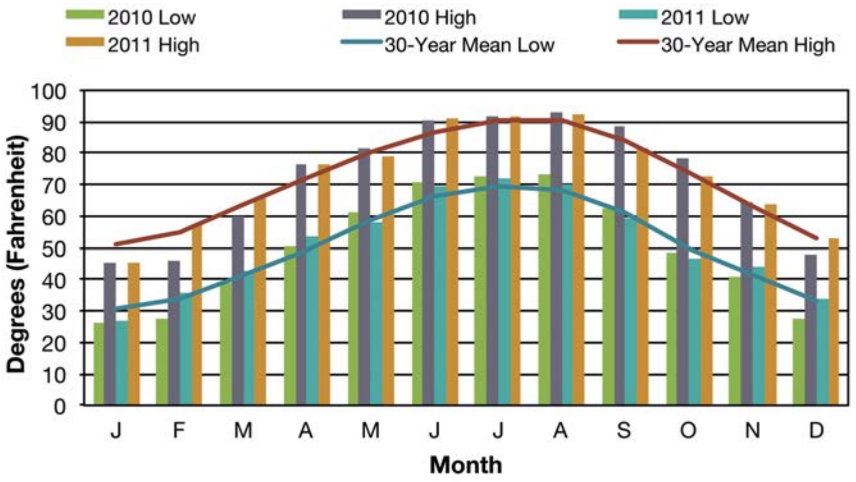

Figure 4. Monthly temperature and 30-year mean at the Pontotoc Ridge-Flatwoods Branch Experiment Station during 2010–2011.

Table 4. Emergence, vigor, and yield of 'Alamo' switchgrass during establishment at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2011-2012.[1]

Planting system[2]	Emergence[3] Year 1	Emergence[3] Year 2	Plant vigor[4]	Biomass year 1[5]
	%	%	%	*lb/A*
T-CP-D-CP	73 a	91 a	2.3 c	430 a
T-CP-D	77 a	89 a	2.6 bc	424 a
T-CP-B-CP	40 b	74 b	3.3 ab	323 b
T-B-CP	20 b	58 c	3.3 ab	266 bc
T-CP-B	40 b	61 c	3.5 a	225 c
P [6]	0.0013	0.0002	0.0191	0.0013

[1] Grown on marginal land with non-eroded Atwood soil (Fine-silty, mixed, thermic Typic Paleudalf) with a 0–2% slope.

[2] Planting systems include tillage-cultipack-drill-cultipack (T-CP-D-CP), tillage-cultipack-drill (T-CP-D), tillage-cultipack, broadcast-cultipack (T-CP-B-CP), tillage-broadcast-cultipack (T-B-CP), and tillage-cultipack-broadcast (T-CP-B).

[3] Percent ground cover.

[4] Scale of 1–10 where 1 is active growth and 10 is inactive growth.

[5] Pounds of dry matter per acre.

[6] Statistical inferences based on the GLIMMIX procedure; means followed by the same letter in a column are not significantly different at p=0.05 level of significance.

FERTILIZER MANAGEMENT STRATEGY

Overview

Since switchgrass is a perennial with an extensive deep-rooting system that can reproduce by rhizomes and seed (Ball et al. 2002), it has the potential to grow and thrive on marginal land with a low soil nutrient status (McLaughlin and Kszos 2005, Bouton 2006, Kering et al. 2012). Switchgrass is considered nutrient-efficient because it recycles (translocates) minerals and carbohydrates downward to the roots before a killing frost (Lemus et al. 2009). These nutrients that overwinter in the crown and rhizome will be available for regrowth in the spring, which reduces fertilizer requirements compared with annual row-crop plants (Propheter and Staggenborg 2010, de Keoff and Tyler 2011).

The amount of nutrients available the next spring after the overwintering process could be affected by the time and frequency of harvest procedures. Research indicates that total N required by switchgrass was reduced by 66% with a single-harvest system compared with a double-harvest system (McLaughlin et al. 1998).

Figure 5. No fertilizer (left side) and fertilizer N at 50 pounds per acre (right side of plot) was applied to second-year 'Alamo' switchgrass on marginal land at Pontotoc Ridge-Flatwoods Branch Experiment Station.

The double-harvest system can reduce biomass yield in the following years due to nutrient removal in aboveground biomass, since at least one of the harvest procedures would occur before translocation of nutrients to the root system (de Keoff and Tyler 2011). Therefore, a single-harvest system after the first killing frost has been shown to maximize yield and minimize removal of soil nutrients.

Soil testing is recommended on marginal land to make sure pH level is at least 5.5 and values of phosphorous and potassium are at least in the medium range. Research suggests that switchgrass growth and development will be enhanced with the addition of P_2O_5 and K_2O if these nutrients test below 10 ppm (20 pounds per acre) and 90 ppm (180 pounds per acre), respectively (Hancock 2009, Garland et al. 2007, Mitchell et al. 2012). In Oklahoma, the addition of P_2O_5 at 40 pounds per acre increased biomass yield by 17% in soil with low available phosphorous (Kering et al. 2012). Recommendations from Tennessee also suggest the addition of 40 pounds per acre of P_2O_5 in soils that test low in phosphorous and 80 pounds per acre of K_2O in soil that tests low in potassium (Garland et al. 2007).

Numerous publications indicate that fertilizer N should not be applied during the establishment year to minimize weed competition and mitigate "cost risk" associated with an unsuccessful stand (Guretzky 2007, Garland et al. 2007, Hamrick 2007, Mitchell et al. 2008). The yield response of established switchgrass to fertilizer N rate varies widely from 37 pounds per acre in Alabama (McLaughlin and Kszos 2005), 50 pounds per acre in South Dakota (Mulkey et al. 2006), 60 pounds per acre in Tennessee (de Koff and Tyler 2011), 50–75 pounds per acre in Georgia (Hancock 2009), and 90–120 pounds per acre in Iowa (Teel 1998).

In order to clarify an appropriate fertilizer N rate for north Mississippi, a trial was conducted on established stands of switchgrass at the Pontotoc Ridge-Flatwoods Branch Experiment Station in Pontotoc County (Figure 5).

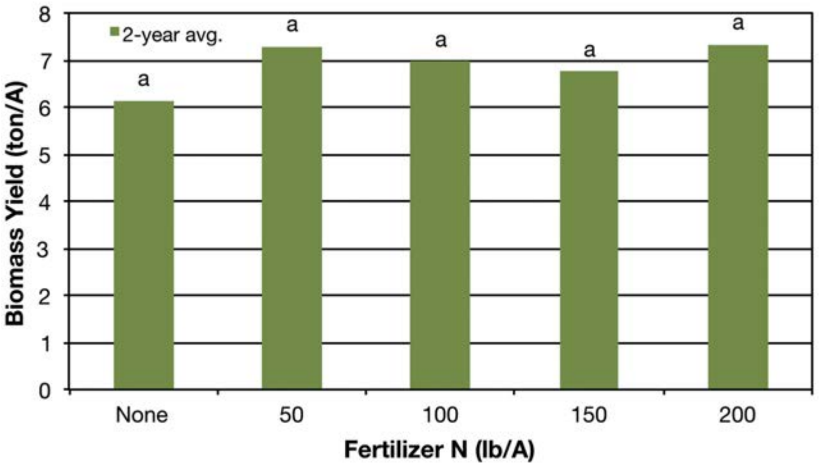

Figure 6. 'Alamo' switchgrass biomass yield on a productive Atwood silt loam (Fine-silty, mixed, thermic Typic Paleudalf) at the Pontotoc Ridge-Flatwoods Branch Experiment Station during 2007–2008. Data was pooled across years, and means followed by the same letter were not significantly different according to Fisher's Protected LSD test at P=0.05.

Materials and Methods

The trial was established on an Atwood silt loam (fine-silty, mixed, thermic Typic Paleududalfs) with a productive no-tillage row-crop history. The trial design was a randomized complete block with four replications. Plot size was 6 feet by 30 feet. Alamo switchgrass at 6 pounds of PLS per acre was planted on May 15, 2006, without the addition of any fertilizer. Nitrogen treatments in the form of 34% ammonium nitrate (NH_4NO_3-N) were applied on May 4, 2007, and April 23, 2008. Fertilizer N (NH_4NO_3) treatments were 0, 50, 100, 150, and 200 pounds per acre. In addition, 30 pounds per acre of P_2O_5 and K_2O were applied in 2007, and 50 pounds per acre of P_2O_5 were applied in 2008. A 3x6-foot section was harvested out of each plot on December 11, 2007, and February 8, 2009.

Results and Discussion

The 2-year average biomass yield for all N treatments was slightly higher but not different when compared to the untreated check (Figure 6). Therefore, the addition of nitrogen fertilizer is not recommended for switchgrass on this type of productive soil with a successful no-tillage row-crop history.

Some suggest that N fertilizer is only beneficial on poor-quality, marginal soil at rates no higher than 62 pounds per acre (McLaughlin 1992). However, Lee et al. (2007) reported that even though total mix species biomass (switchgrass, annual grasses, and broadleaf weeds) with NH_4NO_3-N at 100 pounds per acre was greater than the untreated check, yield of switchgrass alone was not different when compared to the untreated check of a stand established for 26 years on a silty clay loam in South Dakota on marginal land enrolled in the CRP.

This finding illustrates that switchgrass can be productive without the addition of nonorganic nitrogen, but research indicates that future biomass yield will not be sustainable and tends to decline as the stand matures (Muir et al. 2001). Therefore, our research and information provided in reports from across the U.S. suggest fertilizer N rates should range from 0 to 50 pounds per acre of NH_4NO_3-N, depending on factors such as soil nutrient status, land quality, and the time and frequency of switchgrass harvesting procedures.

Fertilizer Management

The 2-year average biomass yield for all N treatments was slightly higher but not different when compared to the untreated check. Therefore, the addition of fertilizer N would not be practical when switchgrass is grown for 2–3 years on this type of productive soil with a successful no-tillage row crop history.

Some suggest that N fertilizer is only beneficial on poor quality, marginal soil at rates no higher than 62 pounds per acre (McLaughlin 1992).

Therefore, based on research results from the Pontotoc Branch of Mississippi State University and information in reports from across the nation, the rate of fertilizer N would certainly range from 0–50 pounds per acre of NH_4NO_3-N, depending on factors such as soil nutrient status, land quality, biomass yield, and the time and frequency of switchgrass harvesting procedures.

WEED MANAGEMENT

Overview

Because very few herbicides are labeled for use in switchgrass, weed control before planting is critical for successful establishment. To ensure a weed-free seedbed in a conventional-tilled environment, a nonselective herbicide such as glyphosate can be applied to kill existing vegetation at least 2 weeks before cultivation followed by cultipacking. The seedbed should remain undisturbed for at least a month to allow a flush of weed seed to germinate and emerge, and then a second nonselective herbicide treatment should be applied followed by planting operations at 4 days after treatment (Garland 2008, Hancock 2009, USDA-NRCS 2009, Renz et al. 2009, Rasnake and Lacefield 2004).

Figure 7. Injury (front plot) to 'Alamo' switchgrass with nicosulfuron (Accent) at the Pontotoc Ridge-Flatwoods Branch Experiment Station.

After switchgrass seedlings emerge, some suggest using a mechanical rotary mower at 6–10 inches to clip weeds growing above the switchgrass for stand improvement and development during the establishment year (Hancock 2009, USDA-NRCS 2009, Renz et al. 2009, Rasnake and Lacefield 2004). However, this practice should not be used after the end August to allow accumulation of nutrient reserves in the root system before overwintering.

Broadleaf weeds in switchgrass can be controlled with POST applications of 2,4-D amine or metsulfuron-methyl (Cimarron or Ally) after switchgrass reaches the 4-leaf stage (Mitchell et al. 2012, Hancock 2009, Renz 2009). However, grass weed competition in switchgrass during the establishment year is more problematic, and the suppression of grass weeds is considered a more important factor of biomass production than broadleaf-weed suppression (Miesel et al. 2012).

Early evaluations of several grass herbicides, including nicosulfuron (Accent) and primisulfuron (Beacon), suggest that there is no proven postemergence herbicide that will consistently control grasses without injury to switchgrass seedlings (Figure 7), with the exception of atrazine (AAtrex and other trade names), which offers residual control of broadleaf weeds and some grasses (Curran et al. 1998). Others indicate that low rates of Accent will control grass weeds satisfactory and only injure switchgrass temporarily (Minelli et al. 2004). More recently, Curran et al. (2011) evaluated quinclorac (Paramount) and sulfosulfuron (Outrider) and reported that effective annual grass control without injury to seedling switchgrass was still elusive. Further review of research reports indicates that weed control can be managed more effectively with a tank-mix partner system (Mitchell et al. 2010).

In recent years, the state of Tennessee received Section 24(c) Special Local Need Labels for Accent and AAtrex in switchgrass grown for biofuel for the control or suppression of certain weeds. In 2010, the EPA approved registration of a nicosulfuron + metsulfuron-methyl (Pastora) formulation blend for use in Tennessee on switchgrass pastures for control of most grass weeds, with the exception of bermudagrass [*Cynodon dactylon* (L.) Pers.], crabgrass (*Digitaria* spp.), and dallisgrass (*Paspalum dilatatum* Poir.).

In order to determine weed management practices for north Mississippi, studies were conducted in 2010 and 2011 at the Pontotoc Ridge-Flatwoods Branch Experiment Station in Pontotoc County to evaluate weed control and switchgrass tolerance to mechanical (rotary mowing) and chemical (selected herbicides) practices.

Materials and Methods

The 2010 study site was a Bude silt loam (fine-silty, mixed, thermic Glossaquic Fragiudalfs) with a soil pH of 6.7, medium phosphorous level (65 pounds per acre), and low potassium level (93 pounds per acre). Previous land use history was sweetpotato followed by glyphosate-resistant soybean planted no-till to a stale seedbed. Therefore, this site will be referred to as "productive land." Weed species present were redroot pigweed (*Amaranthus retroflexus* L.) and broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash].

The 2011 study site was an Atwood silt loam (fine-silty, mixed, thermic Typic Paleudalfs) with soil pH of 6.0, very low phosphorous level (13 pounds per acre), and high potassium level (260 pounds per acre). This land had been fallow for more than 10 years with vegetative cover and topographical features typical to "marginal land" in north Mississippi that is enrolled in the CRP. Weed species present were morningglory species (*Ipomoea* spp.), rhizome johnsongrass [*Sorghum halepense* (L.) Pers], prickly sida (*Sida spinosa* L.), and broadleaf signalgrass.

On both study sites, the experimental design was a randomized complete block with four replications, and plot size was 6 feet by 30 feet with a 6-foot alley between plots to ensure no overlapping of herbicide treatments. Fertilizer was not applied to the productive or marginal land areas in either year. Switchgrass was planted in nine rows spaced 7.5 inches apart with a Great Plains® no-till grain drill equipped with a small seed attachment.

On the 2010 productive land site, a burndown treatment of glyphosate at 0.75 pounds per acre (acid equivalent) was applied in early spring on April 6, followed by paraquat at 1 pound per acre on May 28 and no-till planted at a rate of 6 pounds of PLS per acre on June 2.

On the 2011 marginal land site, glyphosate was applied at 0.75 pound per acre (acid equivalent) in early spring on April 14. The site was then conventional tilled in the spring and left undisturbed until a paraquat application of 0.6 pound of active ingredient per acre on May 26. Switchgrass was planted into a stale seedbed on June 9 at a rate of 6 pounds of PLS per acre. In addition, broadleaf signalgrass was planted to ensure a uniform population of this grass species in the study area.

Herbicide treatments for 2010 and 2011 study sites are included in Table 5. All treatments were applied

Table 5. Postemergence herbicides for weed control systems research in 'Alamo' switchgrass grown as a bioenergy crop at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2010–2012.

Trade name[1]	Rate	Common name	Rate[2]
	product/A		*ai/A*
Pastora DF	1.5 oz	nicosulfuron + metsulfuron-methyl	0.84 oz 0.23 oz
Pastora DF	1.0 oz	nicosulfuron + metsulfuron-methyl	0.56 oz 0.15 oz
Pastora DF	0.88 oz	nicosulfuron + metsulfuron-methyl	0.50 oz 0.13 oz
Pastora DF	1.0 oz	nicosulfuron + metsulfuron-methyl	0.56 oz 0.15 oz
AAtrex 4L	2.0 qt	atrazine	2.00 lb
Pastora DF	0.5 oz	nicosulfuron + metsulfuron-methyl	0.28 oz 0.08 oz
AAtrex 4L	1.0 qt	atrazine	2.00 lb
Accent 75DF	0.75 oz	nicosulfuron	0.56 oz
Accent 75DF	0.75 oz	nicosulfuron	0.56 oz
AAtrex 4L	2.0 qt	atrazine	2.00 lb
AAtrex 4L	2.0 qt	atrazine	2.00 lb
Cimmarron/Ally 60DF	0.25 oz	metsulfuron-methyl	0.15 oz

[1] An untreated check was included for comparison. All treatments included 0.25% v/v nonionic surfactant, except atrazine alone, which included 1% v/v crop oil concentrate.
[2] Amount of active ingredient per acre.

Table 6. Broadleaf signalgrass control and 'Alamo' switchgrass injury with herbicide systems research at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2010–2011.

Postemergence herbicide weed control systems[1]	Broadleaf signalgrass control at 3 WAT	Switchgrass injury at 3 WAT
product/A	%	%
Pastora 1.5 oz	72 a	39 a
Pastora 1.0 oz	72 a	37 a
Pastora 0.88 oz	68 a	37 a
Pastora 1.0 oz + AAtrex 2 qt	59 ab	42 a
Pastora 0.5 oz + AAtrex 1 qt	45 b	25 b
Accent 0.75 oz	59 ab	39 a
Accent 0.75 oz + AAtrex 2 qt	62 ab	36 a
AAtrex 2 qt	13 c	0 c
Cimmarron 0.25 oz	0 d	0 c
Untreated	0 d	0 c
P[2]	< 0.0001	< 0.0001

[1] All treatments included 0.25% v/v nonionic surfactant, except atrazine alone, which included 1% v/v crop oil concentrate.

[2] Statistical inferences based on the GLIMMIX procedure; means followed by the same letter in a column are not significantly different at p=0.05 level of significance.

POST to 4-inch switchgrass at 27 and 32 DAP in 2010 and 2011, respectively. In conjunction with the herbicide treatments, mowing/clipping treatments at a height of 6 inches were made at approximately 3, 4, and 5 weeks after herbicide treatment (WAT) to evaluate their impact on weed control and yield.

Data was collected throughout the growing season for weed control and switchgrass injury in both years. Broadleaf signalgrass was the most dominate weed species present at both sites and will be reported as a 2-year average. Switchgrass was harvested January 11, 2011, and February 9, 2012, for 2010 and 2011 study sites, respectively.

Results and Discussion

At 3 WAT, the 2-year average of broadleaf signalgrass control ranged from 59–72% with all treatments that included Accent and Pastora, except the low rate of Pastora at 0.5 ounce + AAtrex at 1 quart (Table 6). The addition of AAtrex or Cimmarron as a tank-mix partner with Accent or Pastora did not improve broadleaf signalgrass control. Also, AAtrex or Cimmarron alone was not different than the untreated check. Switchgrass injury was at least 36% for all treatments that included Accent or Pastora, except the low rate of Pastora at 0.5 ounce + AAtrex at 1 quart (Table 6). There was no switchgrass injury with AAtrex or Cimmarron alone.

In 2010, biomass yield ranged from 1,073 to 3,770 pounds per acre (Table 7). Yield was less than 1,735 pounds per acre with all treatments that included Pastora and Accent and no different than the untreated check, except the low rate of Pastora at 0.5 ounce + AAtrex at 1 quart. Yield with AAtrex and Cimmarron alone was at least 3,350 pounds per acre, and

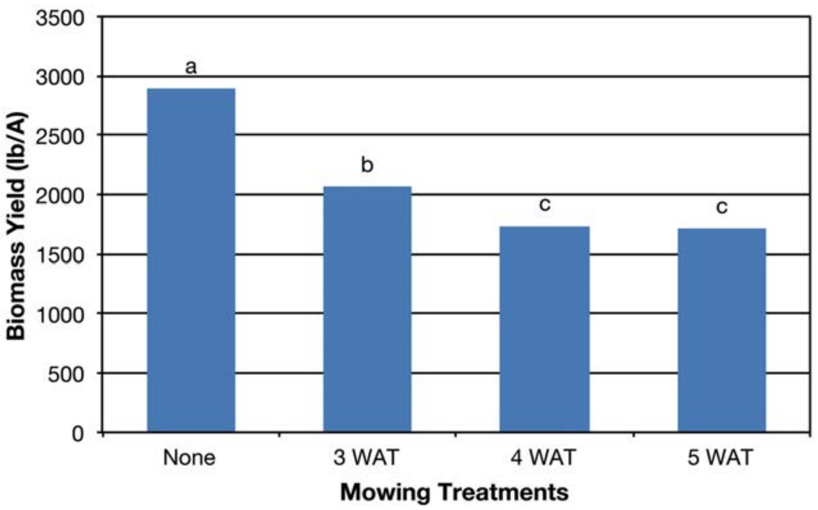

Figure 8. Effect of mowing at 3, 4, and 5 weeks after treatment on yield of 'Alamo' switchgrass grown on productive land with an Atwood silt loam (Fine-silty, mixed, thermic Typic Paleudalf) at the Pontotoc Ridge-Flatwoods Branch Experiment Station during 2010. Means followed by the same letter were not significantly different according to Fisher's Protected LSD test at P=0.05.

greater than all other treatments. Higher yields associated with these broadleaf herbicides could be attributed to less injury to the switchgrass compared with the grass herbicides because there was less grass weed competition at this productive row-crop site due to a history of good weed-management practices.

In 2011, biomass yield with all herbicide systems was greater than the untreated check, except Accent at 0.75 ounce. Yield with Pastora at 1 ounce was greater than all other treatments, except Pastora at 1 ounce + AAtrex at 2 quarts and Pastora at 0.88 ounce. An herbicide rate effect was evident with yields of 130, 213, 265, and 155 pounds per acre for Pastora at 0.5, 0.8, 1, and 1.5, respectively. This rate effect can also be explained with an increase in broadleaf signalgrass control from 45% to 72%, as well as an increase in switchgrass injury from 25% to 39% at 3 WAT with Pastora at 0.5 and 1.5 ounce, respectively. Therefore, this research indicates that the optimum use rate for Pastora is 1 ounce, which corresponds with the labeled rate for Pastora registered on switchgrass grown in the state of Tennessee.

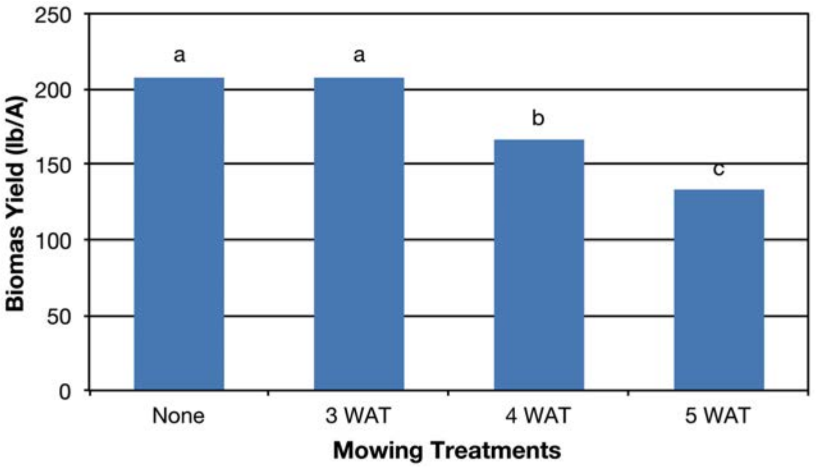

Figure 9. Effect of mowing at 3, 4, and 5 weeks after treatment on yield of 'Alamo' switchgrass produced on marginal land with Atwood silt loam (Fine-silty, mixed, thermic Typic Paleudalf) at the Pontotoc Ridge-Flatwoods Branch Experiment Station during 2011. Means followed by the same letter were not significantly different according to Fisher's Protected LSD test at P=0.05.

The effect of mowing 3, 4, and 5 WAT at three different growth stages across all herbicide systems on switchgrass yield was evaluated on establishment year stands in 2010 and 2011. Biomass yield in 2010 was greater with no mowing when compared with all other treatments (Figure 8). When compared with no mowing, yield decreased by 29%, 40%, and 41% with mowing 3, 4, and 5 WAT, respectively. In 2011,

Table 7. Dry biomass yield of 'Alamo' switchgrass grown as a bioenergy crop with herbicide systems research at the Pontotoc Ridge-Flatwoods Branch Experiment Station, 2010–2011.[1]

Postemergence herbicide weed control systems[2]	Dry biomass yield[3]	
	2010	2011
product/A	*lb/A*	*lb/A*
Pastora 1.5 oz	1593 cd	155 de
Pastora 1.0 oz	1723 c	265 a
Pastora 0.88 oz	1731 c	213 abc
Pastora 1.0 oz + AAtrex 2 qt	1441 cd	223 ab
Pastora 0.5 oz + AAtrex 1 qt	2162 b	130 ef
Accent 0.75 oz	1073 e	112 fg
Accent 0.75 oz + AAtrex 2 qt	1460 cd	165 cde
AAtrex 2 qt	3770 a	128 ef
Cimmarron 0.25 oz	3359 a	177 bcd
Untreated	1317 de	93 g
P [4]	< 0.0001	< 0.0001

[1] Grown on productive land with Bude silt loam (fine-silty, mixed, thermic Glossaquic Fragiudalfs) in 2010 and marginal land with Atwood silt loam (fine-silty, mixed, thermic Typic Paleudalfs) in 2011.

[2] All treatments included 0.25% v/v nonionic surfactant, except atrazine alone, which included 1% v/v crop oil concentrate.

[3] Pounds of dry matter per acre.

[4] Statistical inferences based on the GLIMMIX procedure; means followed by the same letter in a column are not significantly different at p=0.05 level of significance.

biomass yield with no mowing and mowing at 3 WAT were the same and greater than mowing at 4 and 5 WAT (Figure 9). Mowing at 4 and 5 WAT decreased yield by 20% and 36%, respectively, when compared with the other treatments.

These results agree with other research that indicates weed control was temporary and not sufficiently effective with mowing, especially for severe weed populations and rapidly growing weeds such as johnsongrass and pigweed (Minelli et al. 2004). However, mowing could be included as a component of the weed control system in certain situations.

Results from these weed management studies demonstrate the importance of identifying weed species and estimating their population in a field before and during switchgrass establishment. For example, the 2010 trial was conducted on productive soil with a history of good weed management. Therefore, low weed populations were present during the establishment year, and the effect of herbicide injury to switchgrass had more of an impact on yield than weed competition and interference.

This was not the case in 2011 because the trial was conducted on marginal land with high weed populations, especially broadleaf signalgrass. Therefore, if certain grass weed populations are high enough to compete with switchgrass during the establishment year, the benefit of a weed-control system that includes nicosulfuron, such as Accent or Pastora, will outweigh the risk of injury to switchgrass seedlings. A label is not currently approved for the use of these two herbicides in switchgrass for Mississippi, but the EPA could grant registration if there is a need in the future as laws and regulations change.

Weed Management

If certain grass weed populations are high enough to compete with switchgrass during the establishment year, the benefit of a weed-control system that includes nicosulfuron, such as Accent or Pastora, will outweigh the risk of injury to switchgrass seedlings.

A label is not currently approved for the use of these two herbicides in switchgrass for the state of Mississippi, but the EPA could grant registration if there is a need in the future as laws and regulations change.

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