

Evaluation of Warm Season Grass Species and Management Practices to Improve Biomass Production Potential in the Mid-South

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INTRODUCTION

Planting perennial crops to produce biomass for energy production can reduce erosion on marginal croplands in the southeastern United States (Goodman et al., 1991). Plant biomass can be utilized by thermochemical conversion, where it is burned in energy production plants to derive heat, like coal. It can also be converted into chemicals such as ethanol, which can be used as a clean-burning fuel additive or for other uses (U.S. Department of Energy, 2003). Research on suitable plant species and cropping systems to produce maximum amounts of biomass is needed before a marketing system for bioenergy crops can be developed for the Southeast.

The USDA-Natural Resources Conservation Service, Jamie L. Whitten Plant Materials Center (PMC) in Coffeerville, Mississippi began working with the U.S. Department of Energy's (DOE) Biomass Power and Biofuel Feedstock Development Program in 2000. Activities included reviewing literature to determine potential herbaceous plant candidates for use as biomass crops and evaluating cultural specifications for maximizing biomass production of selected candidates.

Switchgrass (*Panicum virgatum* L.) is considered to be the "model" herbaceous biomass energy crop (Sanderson et al., 1996), but there is risk involved in relying on a single species for this use. Different plants have evolved to take advantage of different combinations of soil and climatic conditions and development of additional species could extend the range and profitability of biofuel production systems (USDA, 1992). A thorough literature review suggested that eastern gamagrass [*Tripsacum dactyloides* (L.) L.], Caucasian bluestem [*Bothriochloa bladhii* (Retz.) S.T. Blake], and weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees.] have demonstrated high enough productivity potentials in forage production systems for consideration as biofuel crops (Douglas, 2000; Edwards, 2000; Grabowski, 2000). These grasses are adapted to the wide range of soils and climatic conditions indigenous to the southeastern states (Alderson and Sharp, 1994; Leithead et al. 1976; Ball et al., 1991). There was also interest in bermudagrass [*Cynodon dactylon* (L.) Pers.] because large acreages of this grass have been established in the Southeast for forage production (Ball et al., 1991) and, if it were shown to be acceptable for biofuel production, a percentage of these acres could be converted to this alternative use with few additional inputs.

Seed of weeping lovegrass, bermudagrass, and Caucasian bluestem is available through commercial seed dealers. Although eastern gamagrass seed is commercially available (USDA-NRCS, 2002), seed of 'Highlander' eastern gamagrass (NRCS accession 9062680), the high yielding selection released by the PMC in 2003, is not. Seed is currently being increased at the PMC for commercial growers and it should be available in the next 3 to 5 years. Successful establishment methods have been developed for switchgrass (Vassey et al., 1985), weeping lovegrass (Staten and Elwell, 1944), and Caucasian bluestem, although Caucasian bluestem does require a grass drill equipped with a fluffy seed box for proper seed metering (Hodges and Bidwell, 1993; Dalrymple, 1991). Eastern gamagrass is somewhat difficult to establish from seed (Ahring and Frank, 1968); however, the PMC is examining methods that can be used to improve establishment success of Highlander seed. All these grasses are compatible with field production and harvesting equipment commonly used for forage production in the Southeast (Belesky and Fedders, 1995).

Since eastern gamagrass, Caucasian bluestem, weeping lovegrass, and bermudagrass have not previously been examined as bioenergy crops, PMC research was directed towards cultural specifications specifically tailored for biomass production of these species. Additional testing of switchgrass was also warranted to confirm its response to various management regimes in the mid-South region. Results of research on eastern gamagrass seeding depth and seed treatments, also funded under this contract, will be presented in separate publications.

METHODS AND MATERIALS

Plots of ‘Alamo’ switchgrass, Highlander eastern gamagrass and ‘Tifton 44’ bermudagrass were established in 1994 at the PMC in Coffeerville, Mississippi for a previous forage production study and had been harvested from 1996-1998 (Edwards et al., 1999). The soil was an Oaklimeter silt loam with less than 1% slope. Caucasian bluestem and ‘Ermelo’ weeping lovegrass were planted in May of 2000 at a rate of 2.2 kg ha⁻¹ PLS (pure live seed) using a Marliss no-till drill with 20 cm row spacing. Caucasian bluestem seed was mixed with rice hulls at a ratio of 5:1 (v/v) hulls to seed to ensure the proper amount of seed was planted. The soil type was a Grenada silt loam with less than 1% slope for the Caucasian bluestem plots. Weeping lovegrass was planted on an Oaklimeter silt loam with less than 1% slope. Stands were poor, so the plots were replanted in June and the seeding rate was doubled to 4.4 kg ha⁻¹ PLS (pure live seed). Stands of weeping lovegrass were very thin, even after the second planting attempt, so this species was dropped from further consideration. Weeping lovegrass does not appear to be well adapted to soils that remain wet throughout the winter and this limits its long term persistence in many sections of the mid-South (Scott Edwards, personal observation). Climatological data for the planting site is presented in Table 1.

Table 1. High and low temperatures and rainfall recorded for the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi, 2000-2002.

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	High (°C)	----	----	21	22	28	31	34	36	31	27	15	7
	Low (°C)	----	----	7	8	17	19	20	21	17	9	3	-5
	Rain (mm)	----	----	136	194	40	158	42	4	37	0	251	70
2001	High (°C)	9	16	16	25	28	29	32	32	28	23	22	15
	Low (°C)	-3	3	3	12	14	18	22	21	16	7	4	3
	Rain (mm)	161	219	106	197	102	118	91	138	130	121	266	184
2002	High (°C)	13	13	16	25	26	31	33	33	31	24	----	----
	Low (°C)	0	-2	2	11	14	14	18	21	18	12	----	----
	Rain (mm)	245	104	154	218	228	61	155	136	282	189	----	----

Cultural specifications focused on yield responses for one- and two-cut systems for all species, except bermudagrass, where two- and three-cut systems were tested. Each replication of switchgrass, eastern gamagrass, and bermudagrass consisted of a single block, approximately 5.5 m x 5.5 m in size. After several years of plot maintenance, they were no longer exactly square and were measured at each harvest to ensure correct yield calculations. These blocks were split, with the two cutting regimes randomly assigned to either side of the block. The harvest area was rotated 90 degrees from that of the previous forage study to minimize carryover effects on yields from treatments used in that study.

There were four replications of each cutting treatment. Each block of eastern gamagrass contained four rows of plants. The second row from the edge of each block was harvested, leaving a border row to the outside and a portion of the plant clump towards the inside of the block as borders. Figure 1 shows one of the eastern gamagrass blocks in the foreground after the two-cut treatment had been harvested for the first time and both borders had been cut down. Eastern gamagrass plants were harvested using a hand-held hedge trimmer at a height of approximately 10 cm. Bermudagrass and switchgrass essentially formed a solid stand in the plots and were harvested using a walk-behind sicklebar mower (cutting width 1 m) at a height of 10 cm, leaving a border to either side of the harvested area that was cut and removed immediately after the harvest data was taken. Caucasian bluestem plots were approximately 6.1 m x 1.8 m and the cutting regimes were assigned in a randomized complete block with four replications. The plots were harvested with the sicklebar mower described above at a height of 10 cm. Harvest dates for all species are listed in Table 2. Samples were taken at each harvest and dried at 60°C for dry matter determination and chemical analyses were performed to determine percentages of nitrogen and ash in the tissue. Season total yields were subjected to an analysis of variance using MSTAT-C (Michigan State University, 1988) and significance was determined at P<0.05.



Fig. 1 Two-cut eastern gamagrass plots following the first cutting

Table 2. Dates biomass production plots were harvested at the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi.

Year	Alamo		Highlander		Caucasian		Tifton 44		
2000	14-Sep		14-Sep		14-Sep		13-Jun	14-Sep	
	13-Jun	14-Sep	13-Jun	14-Sep			20-May	17-Jul	14-Sep
2001	12-Sep		8-Aug		24-Jul		19-Jun	12-Sep	
	19-Jun	12-Sep	18-Jun	12-Sep	29-May	15-Aug	29-May	24-Jul	12-Sep
2002	9-Sep		6-Aug		6-Aug				
	19-Jun	9-Sep	19-Jun	9-Sep	2-Jul	9-Sep			

Switchgrass, eastern gamagrass, and bermudagrass plots were burned annually in late February. Caucasian bluestem plots did not have a sufficient amount of residue to carry a fire. Atrazine (1.7 kg a.i. ha⁻¹) was applied on all plots in the spring to control weed competition. Fertilizer for all four species was

broadcast at an annual rate of 134 kg ha⁻¹ of N and 67 kg ha⁻¹ of both P₂O₅ and K₂O. The nitrogen rate was halved on the two-cut plots and one half was applied in April after the plants began active growth and the other after the first cutting, and split in thirds on the three-cut bermudagrass plots, with applications made after spring regrowth reached approximately 7 cm and after the first two cuttings. Nitrogen was applied in a single application in April on the one-cut plots. Phosphorus and potassium were applied when the first nitrogen applications were made.

The PMC also conducted performance trials on experimental switchgrass lines from Oklahoma State University (OSU) that were bred for improved biomass production potential. Seed of nine lines (SL 92-1, SL 93-1, SL 93-2, SL 93-3, SL 94-1, NL 92-1, NL 93-1, NL 93-2, and NL 94-1) were received from OSU and Alamo and 'Kanlow' were used as standards of comparison. Plots were planted in the spring of 1999 at a rate of 9 kg ha⁻¹ PLS using an Almaco plot drill with a 15 cm row spacing on a Grenada silt loam soil with less than 1% slope. Plot size was 2 m x 4.9 m and they were arranged in a randomized complete block with four replications. Plots were burned annually in late February. Phosphorus and potassium were maintained at a medium to high level according to soil test recommendations. Nitrogen was applied in one application at a rate of 90 kg ha⁻¹ in May of each year. Plots were harvested on 18 September, 2000, 17 September, 2001, and 23 October, 2002. A 1 m wide swath running the entire length of the plot (~4.9 m) was harvested from the center of each plot using a sicklebar mower. Samples were collected for dry matter determination and dry matter yields were calculated for each plot. An analysis of variance procedure was performed on the yield data using MSTAT-C and significant means were separated by least significant difference (LSD) at P<0.05 (Michigan State University, 1988).

Cultural Specification Testing

Switchgrass

Both one and two-cut harvesting systems have demonstrated varying degrees of success for maximizing switchgrass biomass yields depending on cultivar and location. Timing of the last harvest is critical for long-term sustainable yields in either system (Sanderson et al., 1996; Sladden et al., 1994). Walker et al. (1995) showed that both multiple cuttings and a single cutting made later than September reduced yields of Alamo switchgrass at Stephenville and Dallas, Texas. Peak biomass production of Alamo in Alabama has been reported to occur in mid-August (Sladden et al., 1994). To maximize biomass production, it is necessary to harvest after this peak biomass production period; however, switchgrass plants need adequate time for regrowth before frost, thus, providing the plants with a protective insulation for the winter months and reducing late winter and early spring weed competition. Also, excessive soil moisture in the late fall and early winter generally restricts field activities in the Southeast (Table 1). For these reasons, plants in this study were clipped no later than early to mid-September (Table 2). The first clipping of the two-cut system occurred at approximately the late boot to early flowering stage.

There were no significant differences in season total dry matter yield between systems in 2000; however; in the two subsequent years, yields for the one-cut system were significantly higher than for the two-cut system (Fig. 2). Growth

rate of the plants in both treatments appeared to be reduced by lack of rainfall during July and August of 2000 (Table 1). In 2001 and 2002, there was ample rainfall after the first clipping, but yields were still significantly decreased for the two-cut treatment compared to the one-cut treatment. Belesky and Fedders (1995) found that switchgrass showed little regrowth after the first clipping, even though conditions were still favorable for growth. Our results indicate that the one-cut treatment was the optimum management practice to maximize biomass of Alamo switchgrass at this location. Not only were yields improved by this treatment, but harvesting expenses would be lower for the single harvest operation. Yields of both treatments were reduced in 2002. This could not be explained by environmental conditions or any change in harvesting procedures. The plants in these plots had been initially established in 1994 and overall growth may have been decreased by the almost continuous harvest pressure they had been subjected to since 1996 (Edwards et al., 1999).

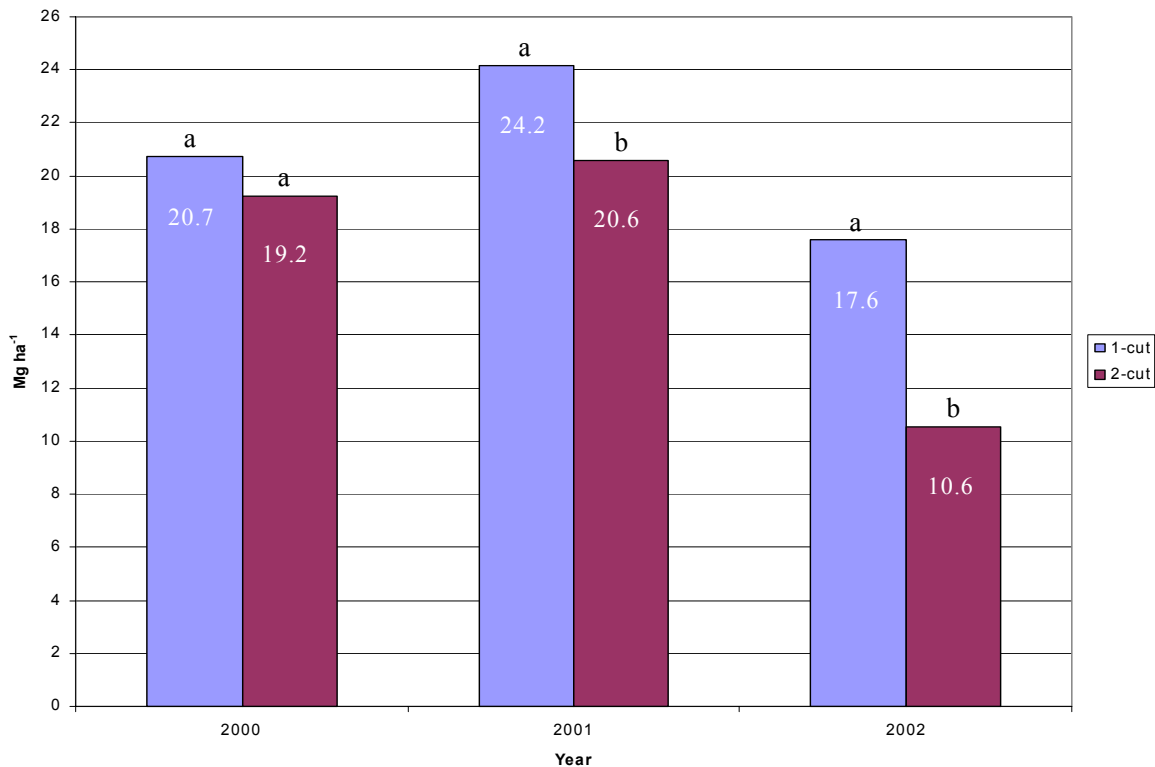


Fig. 2. Alamo switchgrass annual dry matter yields. Columns within each pair (harvest year) with different letters are significantly different at $P < 0.05$.

Ash and nitrogen content are two estimates of biofuel quality that DOE requested we measure for each species and management regime. Species that showed significant potential as bioenergy crops could have actual firing tests performed by DOE farther along in the development process. An “ideal” biofuel for direct firing systems would have low nitrogen and ash, because high levels of these constituents adversely affect energy output (Madakadze et al., 1999). A single cutting of switchgrass is the “model system”, any values that were equal to or lower than those for the one-cut switchgrass treatment in this study would probably be acceptable.

Both nitrogen and ash content were higher for the first cutting of the two-cut switchgrass treatment than for the one-cut system (Table 3). This is not surprising because the plants were still actively growing at the time they were cut and nitrogen had been applied to the plots in April. In September, when the plants were harvested for the one-cut treatment and the second cutting of the two-cut treatment, they had begun to senesce, with some structural materials being broken down and nutrients transported from the shoots to the underground portions of the plant to prepare for dormancy. Madakadze et al. (1999) suggest that if this biomass were left in the field over the winter months, the nitrogen levels could be reduced even further; however, retrieving this material in the spring might prove to be more difficult in the Southeast than in Canada where their research was conducted. Whether material from the first cutting of the two-cut system could be cut and stockpiled in the field to reduce nitrogen levels without reducing biomass yield or adversely affecting other important biofuel constituents might be an area for future research.

Table 3. Average tissue analysis values for Alamo switchgrass biomass from two harvest regimes at the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeeville, Mississippi, 2000-2002.

Year	1-cut		2-cut			
	Nitrogen	Ash	Nitrogen		Ash	
	-----g kg ⁻¹ -----					
2000	3	26	7	5	39	34
2001	6	32	9	8	43	33
2002	7	34	11	12	41	51

Eastern Gamagrass

Highlander eastern gamagrass was selected for release as a forage crop for the southeastern states because of its wide range of adaptation, yields, and resistance to disease. Eastern gamagrass yield and stand persistence have been shown to be influenced by clipping frequency, with a minimum of 45 days recommended between forage harvests (Edwards et al., 1999). This frequency would correlate to three harvests per year in most of the Southeast. Management for biomass production would have different objectives than forage production, wherein minimizing the number of harvests while still producing maximum biomass would be desirable to reduce production costs. Therefore, one- and two-cut systems were chosen for testing.

The harvest date of the one-cut system was initially planned for early to mid-September; however, during the first year of the study, it became apparent that the plants began to lose much of their structural integrity after seed maturation during the summer. Therefore, this cutting was completed earlier in the two subsequent years (Table 2). Annual dry matter yields of the two-cut system were higher in all years than for the one-cut treatment, but the differences were only significant in 2000 and 2002 (Fig. 3). Yield of the one-cut system increased dramatically in 2001, when the harvest date was moved up to August; however, this trend was not seen in 2002. The reason for this is unknown because rainfall and temperatures were adequate in 2002 to promote biomass production.

Perhaps the plants were suffering from prolonged harvest stress as theorized earlier for the Alamo plants. Although the one-cut system provided comparable yields to the two-cut system in one study year, it appears that two cuttings will be required to consistently achieve maximum biomass production of Highlander.

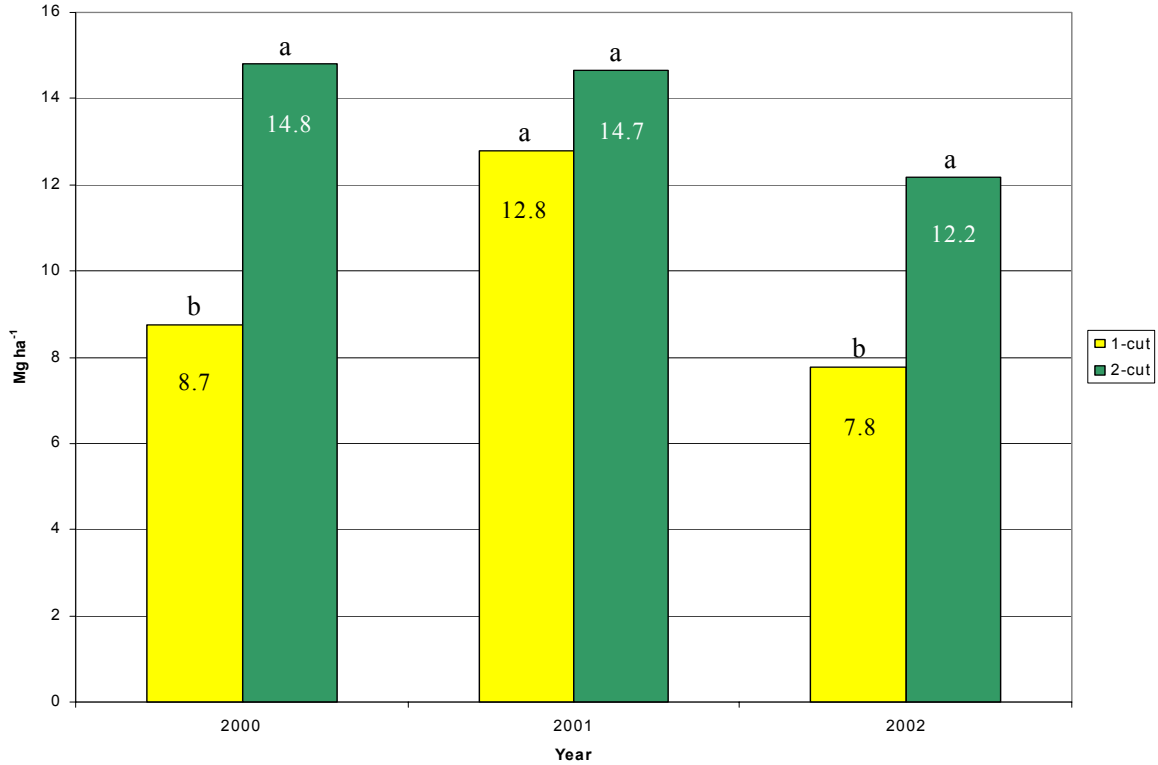


Fig. 3. Highlander eastern gamagrass annual dry matter yields. Columns within each pair (harvest year) with different letters are significantly different at $P < 0.05$.

Nitrogen and ash concentration were not measured for the first cutting of the 2-cut system in 2000. Overall, the values of both parameters were slightly higher than values for the one-cut switchgrass treatment (Table 3). This is probably because all cuttings of both treatments had more green, actively growing tissue at the time they were harvested than the switchgrass plants had when harvested for the one-cut treatment.

Table 4. Average tissue analysis values for Highlander eastern gamagrass biomass from two harvest regimes at the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi, 2000-2002.

Year	1-cut		2-cut			
	Nitrogen	Ash	Nitrogen		Ash	
----- g kg ⁻¹ -----						
2000	7	47	NA	7	NA	51
2001	9	40	10	10	40	47
2002	15	41	12	16	32	52

Caucasian Bluestem

Caucasian bluestem is an introduced warm season grass. It is a more common forage crop in the southern Great Plains than the Southeast; however, the PLANTS database (USDA-NRCS, 2002) indicates that it occurs as far south as Florida and Louisiana. There are no improved cultivars of Caucasian bluestem; however, there are several cultivars of related *Bothriochloa* species that are grown in the United States (Alderson and Sharp, 1994).

It was possible to make a small harvest in the year the plots were established (Fig. 4), which would not be feasible for the native grasses due to their slower establishment rates. This is even more remarkable when the lack of rainfall during the summer of 2000 (Table 1) and the need for a second planting is taken into account. Caucasian bluestem plants did not begin to green-up until April, but grew quickly thereafter. Yields of the two-cut system were significantly higher than the one-cut system in both years that the full harvest system could be tested (Fig. 4). By the fall of 2002, obvious stand depression was noted in the one-cut plots (Fig. 4), and estimated stands averaged only 70 percent over the four replications. Repeated defoliation of Caucasian bluestem plants has been shown to increase tiller populations, forming a dense plant canopy (Belesky and Fedders, 1995). In the one-cut plots, shoot growth became so dense that it inhibited photosynthesis and promoted disease growth inside the canopy. This probably also had an adverse effect on yields for this treatment. It does not appear that a one-cut system would be sustainable for long-term biomass production of Caucasian bluestem.



Stand thinning in Caucasian bluestem one-cut plots noted in the fall of 2002

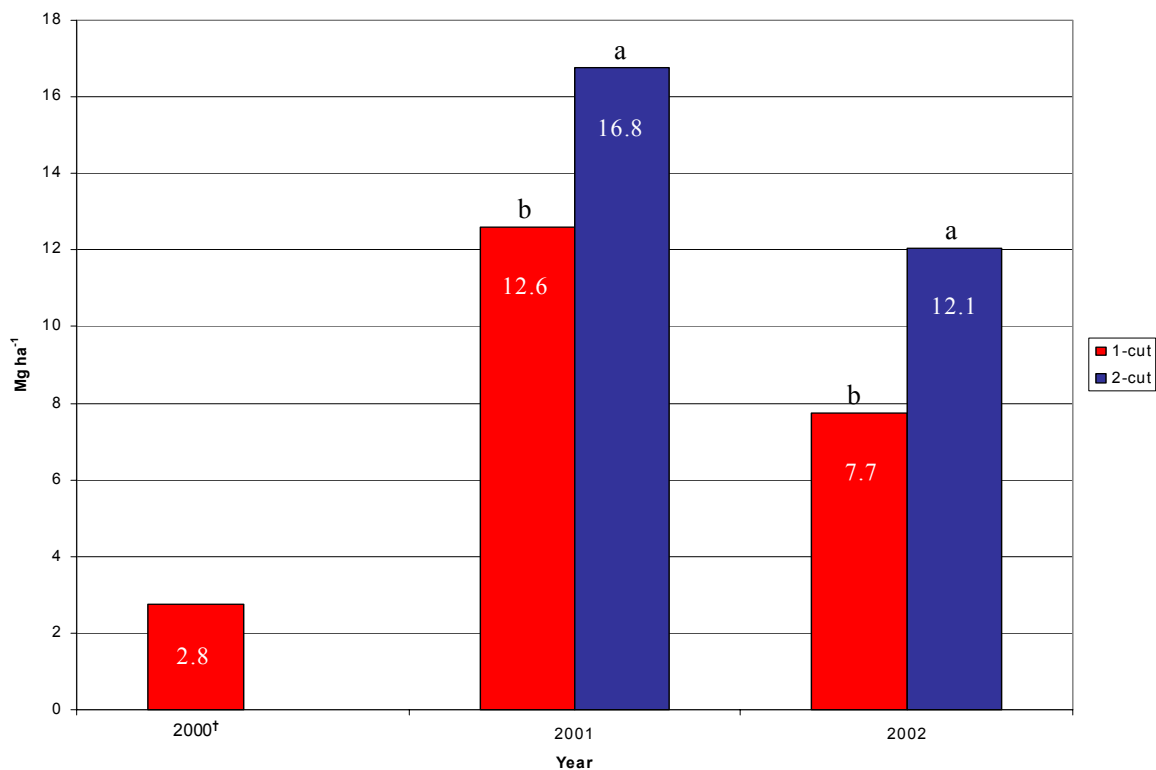


Fig. 4. Caucasian bluestem annual dry matter yields. Columns within each pair (harvest year) with different letters are significantly different at $P < 0.05$. [†] 2000 was the year these plots were initially established. A single harvest was made in the fall and the management regimes were implemented the following year.

The first harvest of the two-cut system in 2001 was taken in late May when the plants had appeared to reach maximum size, but the leaves were still very green and succulent, which resulted in fairly high nitrogen contents (Table 5). In 2002, the first clipping was delayed until early July when the plants had begun to senesce. Nitrogen levels were reduced by the delayed clipping (Table 5), however, yields were also reduced (Fig. 4). Nitrogen and ash were somewhat higher than the values recorded for the one-cut switchgrass treatment (Table 3). It appears that using a two-cut system for Caucasian bluestem produces ample biomass for bioenergy systems; however, further testing would be necessary to determine the appropriate timing of these harvests to optimize both biomass production and levels of chemical constituents in the tissues.

Table 5 Average tissue analysis values for Caucasian bluestem biomass from two harvest regimes at the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi, 2000-2002.

Year	1-cut		2-cut			
	Nitrogen	Ash	Nitrogen		Ash	
----- g kg ⁻¹ -----						
2000[†]	11	52	---	---	---	---
2001	6	46	16	8	65	44
2002	8	39	9	12	38	40

[†] 2000 was the year these plots were initially established. A single harvest was made in the fall and the management regimes were implemented the following year.

Bermudagrass

Current management techniques in bermudagrass forage production systems strive for a balance between yields and forage quality. To achieve this, bermudagrass should be harvested every 4 to 5 weeks to maintain optimum quality (Ball et al., 1991). However, there is limited information on the yield potential of bermudagrass when forage quality is not a concern. Bermudagrass, like Caucasian bluestem, forms a dense plant canopy and plant stands can be adversely affected if not cut or grazed on a regular basis (Belesky and Fedders, 1995). The limited number of plots available from the previous forage production study dictated that only two management systems could be tested, and the need for frequent defoliation led to the choice of a two- and a three-cut system, rather than one- and two-cut systems.

Yields were higher for the three-cut system in both years, but the difference was significant in 2000 and non-significant in 2001, even though the magnitude of the yield difference between the two systems in 2001 was somewhat greater than in the previous year (Fig. 6). In 2000, yields of both the first and third harvests were much smaller than the second one, whereas in 2001, yields of the second and third harvests were fairly comparable and that of only the first harvest was smaller (Table 6). Lack of rainfall during the summer of 2000 (Table 2) probably reduced yield for the third harvest. Almost ideal growing conditions in 2001 (Table 2) led to somewhat higher annual yields of both systems (Fig. 6). Yields of both cuttings in the two-cut system were fairly similar in both years (Table 6). The nominal increase in yield does not appear to warrant the cost or time associated with the additional spring harvest of the three-cut system; however, the duration of this study was not sufficient to determine if there would be adverse effects on plant stands from less frequent cuttings.

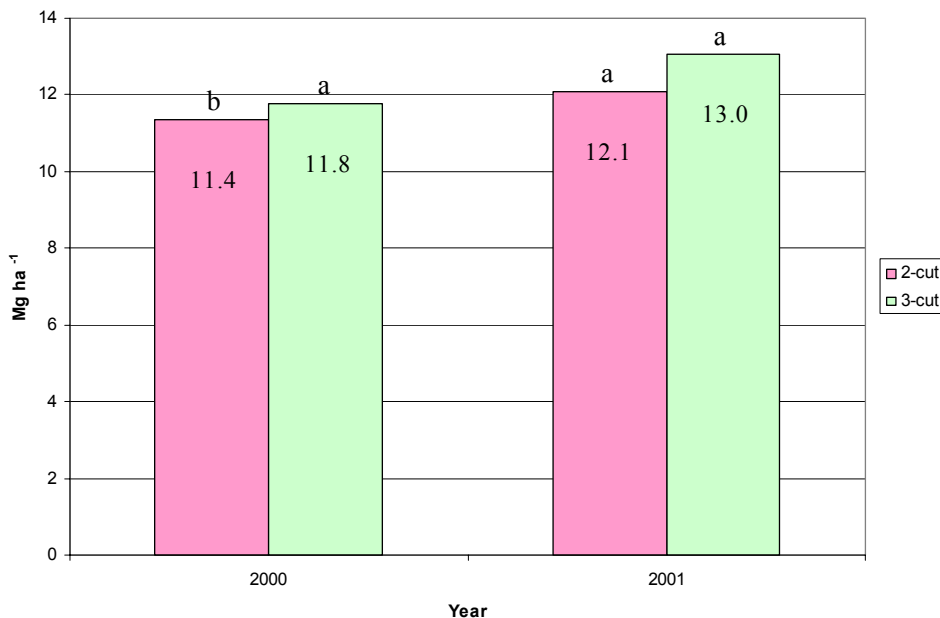


Fig. 6. Tifton 44 bermudagrass annual dry matter yields. Columns within each pair (harvest year) with different letters are significantly different at $P < 0.05$.

Table 6. Dry matter yields of Tifton 44 bermudagrass subjected to two management regimes at the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi, 2000-2001.

Management Regime	2000	2001
	-----Mg ha ⁻¹ -----	
Two-cut	5.6	5.7
	5.7	6.3
Three-cut	1.9	2.7
	7.1	5.2
	2.8	5.2

Tissue analyses were not performed for the final harvests of both systems in 2001. Nitrogen contents were fairly high for the first cutting of both systems (Table 7). This is again probably due to the large amount of green tissue present at harvest. Nitrogen appeared to decrease for both the second harvest of the two-cut system and the second and third harvests of the three-cut system (Table 7); however, it would be advisable to perform further testing to confirm this trend. Ash contents of all cuttings were higher (almost double) (Table 7) those of the one-cut switchgrass treatment (Table 3). This might present a problem if bermudagrass biomass was used in direct firing systems.

Table 7. Average tissue analysis values for Tifton 44 bermudagrass biomass from two harvest regimes at the USDA- NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi, 2000-2001.

Year	2-cut				3-cut					
	Nitrogen		Ash		Nitrogen			Ash		
	----- g kg ⁻¹ -----									
2000	9	6	58	69	17	8	9	60	61	75
2001	11	NA	45	NA	13	8	NA	56	54	NA

Performance Trials

These experimental breeding lines from OSU were also tested at PMCs in Booneville, Arkansas and Manhattan, Kansas, as well as the breeding location at Stillwater, Oklahoma. Results presented in this publication may not be representative of their performance at these other locations or their overall performance at all locations. The highest yielding of the germplasm sources were SL 93-3 in 2000, SL93-1 in 2001, and NL92-1 in 2002 (Table 8); however, only SL93-1 in 2001 yielded significantly more biomass than Alamo. Research on biomass production conducted at several southern locations has shown Alamo to be the highest yielding commercial cultivar of switchgrass (Sanderson et al., 1996). Kanlow, with origins in Oklahoma, is not as well adapted to growing conditions in

Mississippi as Alamo from Texas (Alderson and Sharp, 1994). Yields of Alamo were generally higher than yields of Kanlow, but the increase was not significant. In fact, Kanlow was one of the lowest yielding cultivars, with the exception of 2002, where it yielded slightly more biomass than Alamo.

Table 8. Annual dry matter yields of nine experimental switchgrass lines and two cultivars at the USDA-NRCS Jamie L. Whitten Plant Materials Center, Coffeerville, Mississippi.

Germplasm	2000	2001	2002	3-yr Average
Alamo	10.9	14.9	17.5	14.4
Kanlow	9.1	11.8	17.8	12.9
SL 92-1	12.5	13.2	15.2	13.6
SL 93-1	12.6	19.9	15.1	15.9
SL 93-2	12.9	13.3	13.7	13.3
SL 93-3	13.8	14.6	11.6	13.3
SL 94-1	11.2	15.3	14.9	13.8
NL 92-1	12.2	14.9	18.3	15.1
NL 93-1	11.7	15.4	15.3	14.1
NL 93-2	9.1	14.3	15.3	12.9
NL 94-1	13.4	14.6	17.1	15.0
LSD (0.05)	2.9	3.4	3.3	NS

When the dry matter yields were averaged over the three harvest years, there were no significant yield differences between any of the germplasm sources (Fig. 7). Lines SL93-1, NL92-1, and NL94-1 produced slightly higher yields than Alamo, and all but NL93-2 out-yielded Kanlow. It appears that several of these lines might hold promise for exceeding biomass production of Kanlow and possibly Alamo, but variability in yields between years at this location does not allow identification of a single superior line. Perhaps results from the other testing locations would help narrow the field of potential candidates for commercial release.

SUMMARY

Yields were not statistically compared across species due to variations in management regimes. However, it is important to see the relative performance of each to judge their suitability for use as bioenergy crops, so Figure 8 is presented as a visual aid to summarize the cultural specification results. Switchgrass is by far the most productive species. A single cutting in early fall was the optimal management regime for this species. A multiple harvest system was found to be better suited for eastern gamagrass, Caucasian bluestem, and bermudagrass. The two-cut system provided more consistent yields of eastern gamagrass when harvests were made in June and September. A two-cut system was also found to be suitable for maximizing yield of Caucasian bluestem; the second cutting should be made in early to mid-September, but further testing is needed to determine the appropriate timing of the first cutting. A three-cut system produced the highest bermudagrass yields, but increases over the two-cut regime were minimal and would probably not justify the additional expense. Timing of two cuttings for bermudagrass biomass production should be mid-June and early to mid-September. Ash and nitrogen percentages were lower for the systems with fewer harvests; however, these systems were not sustainable or practical for all species.

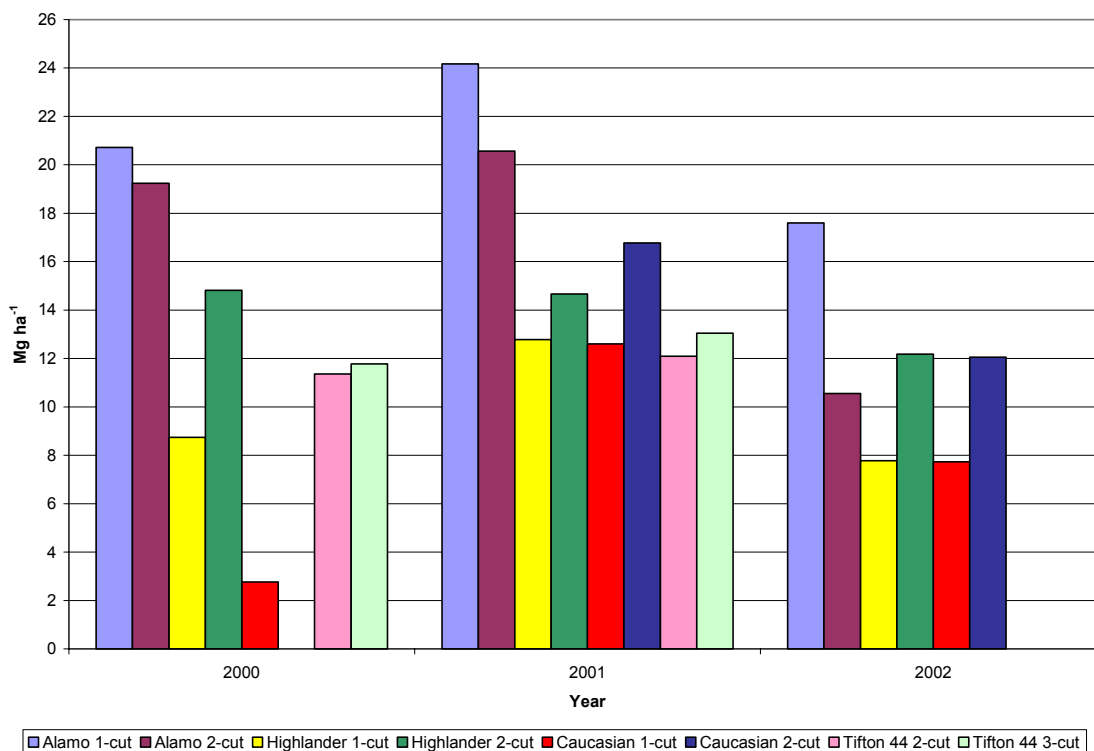


Fig. 8. Annual dry matter yields of all species and management regimes. No statistical inference can be made across species.

Both Caucasian bluestem and bermudagrass are non-native species. Bermudagrass is already so common in the Southeast, that planting it for bioenergy production would not constitute an introduction of this species into a new area. In fact, it is already so endemic, that it would probably not be necessary to plant it, just to alter management practices in current pastures to produce biomass instead of forage. Caucasian bluestem is not common in the Southeast and new fields would need to be established for bioenergy production. Caucasian bluestem is a copious seed producer and has the potential to spread from areas in which it was planted. For this reason, the native species which were tested are probably more desirable bioenergy candidates; however, it may be possible to utilize areas in the southern Great Plains that already contain Caucasian bluestem or related *Bothriochloa* species for this purpose. Although establishment problems prevented testing of weeping lovegrass at this location, it has been shown to produce ample biomass for bioenergy production; however, it is also non-native and would have the same disadvantages attributed to Caucasian bluestem.

Nine experimental switchgrass lines from an OSU breeding program were compared to Alamo and Kanlow for biomass production utilizing a one-cut harvest in September or October. All but one of these experimental lines produced yields equal to or greater than Kanlow and three produced greater yields than Alamo; however, none showed sufficiently improved biomass production to warrant recommending them for biofuel production in the Southeast.

Table 9. Factors to convert metric to English units

Conversion	Factor
mm to in	x 0.0394
°C to °F	9/5°C + 32
cm to in	x 0.394
m to ft	x 3.281
kg ha ⁻¹ to lb ac ⁻¹	x 0.891
Mg ha ⁻¹ to ton ac ⁻¹	x 0.446
kg ha ⁻¹ to %	x 0.1

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