ORNL/SUB-03-19XSY163/01

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FINAL REPORT FOR 1997 TO 2001

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Date Published: May 2003

Prepared for
U.S. Department of Energy
Office of Biomass
Budget Activity No. EB 52 03 00 0

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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TEN-YEAR SUMMARY

Recommendations for reliable establishment and management are crucial if switchgrass is to become a successful biofuels crop. Under our conditions, we have shown that no-till plantings produce very successful stands using commonly available farm implements. Timely planting (delay until soil is adequately warm) is important. Insect pests must be controlled if seedling damage occurs. We have also shown that seed quality (overcoming dormancy) is an important aspect of establishment. Seed dormancy can be broken by stratification and/or afterripening. Afterripening using elevated temperatures and controlled seed moisture appears to have promise as a means for large-scale commercial dormancy breaking.

Management studies at eight locations showed that lowland varieties when harvested once at the end of the growing season produce high sustainable yields if N fertilizer is properly managed. Upland varieties yield slightly more if harvested twice, but the increased yield is likely not economically significant. Nutrient element removal is generally greater than the amount applied. Still, stands were highly productive after ten years and appeared to have truly perennial yielding potential. Soil P averaged 12 ppm in 2001 (an increase of 4 ppm since 1992), and soil K averaged 40 ppm in 2001 (a decrease of 39 ppm since 1992) for the eight locations after ten years of growth. A negative correlation indicates that the lower the element the higher was the yield. This negative relationship occurred many times in the ten-year study.

Over ten years, all varieties maintained excellent production where yields were mainly influenced by location and timeliness of summer rainfall. Very thin stands (few tillers per m^{-2}) developed when cut once per season at most locations, an effect that was probably compounded by higher than optimal N application during the first five years. A reduction of N application rate during the last five years maintained high yields and increased stand density. Application of N to achieve maximum short-term yields may greatly reduce long-term yields and allow weeds to encroach when harvested once during the season. When cut twice in the season, stands were excellent at all locations for all varieties.

Sound fertilizer recommendations will be based in part on good stewardship of the soil and the environment and in part on economics. The soil should be tested using a 0 to 10-cm sample depth. Apply 50 kg ha^{-1} of P when the soil-P test is low and 100 kg ha^{-1} of K when the soil-K test is low-plus to medium (considering the typical soil test basis for agronomic crop recommendations). No limestone would be needed if the soil pH is above 5. Limestone and P move downward in the soil very slowly; thus a shallow soil sample is needed to properly assess their needs, assuming they are not present in occluded rooting regions of the soil. Nitrogen should be used at a somewhat limiting rate as far as short-term yield goals are concerned in order to achieve good stands that will have maximum long term-yield potential. While we do not have direct experimental evidence for such, our observations lead us to believe many soils may not need any N for several years after planting when using a one-cut (November) harvest management, since much of the N located in the herbage is translocated to the crown/root system at the end of the growing season. Thus, no more than 50 kg ha^{-1} N may be needed for sustained yields. For a two-cut management, 50 kg ha^{-1} N in the spring and 50 kg ha^{-1} N after the first harvest should be adequate.

PAST FIVE-YEAR PROJECT SUMMARY (1997 to 2001)

TASK ONE (VARIETY/MANAGEMENT STUDY)

A 1992 planting of six varieties/lines at a range of locations across the northern tier of the southeastern United States was continued. Two lowland varieties (Alamo and Kanlow) responded similarly and the two upland varieties (Cave-in-Rock and Shelter) responded similarly; so our summaries will mostly involve these groupings.

When cut twice in the season, upland and lowland varieties had similar yields (Table 1). However, when cut only once during the season, lowland varieties had higher yields when compared to upland varieties and yields equivalent to their own two-cut management. These data indicate that one harvest per year can achieve high biomass yields and that the lowland varieties would be preferred since they could also be used for flexible cutting schedules. A comparison of yields with total annual rainfall showed no relationship for either one- or two-cut managements when considering eight locations and eight years of data. We thought that the June to September rainfall may be critical to yields. When considering June through September rainfall, there is a nonsignificant but negative association with November yields for the two-cut management (p = -0.61); however, there is a significant negative influence of rainfall on November yields of the one-cut management (p = -0.08). Off-season winter rainfall at these locations is normally enough to bring the entire rooting zone to field capacity. Since

Table 1. Seasonal yields averaged over three years (1994 to 1996) and averaged over five years (1997 to 2001) from two upland varieties (Cave-in-Rock and Shelter) and two lowland varieties (Alamo and Kanlow) of switchgrass at eight locations when harvested once (in November) or twice (first cut in early heading stage and second cut in November)

Years	Cutting mgt	Yield		
		Upland	Lowland	Average
		--------- Mg ha^{-1} yr^{-1} ---------		
1994 to 1996	Once	10.8d*	14.8c	12.8B
(three years)	Twice	15.0b	16.4a	15.7A
	Average	12.9B	15.6A	14.2
1997 to 2001	Once	11.9c	15.6a	13.7B
(five years)	Twice	14.5b	15.3a	14.9A
	Average	13.2B	15.4A	14.3
1994 to 2001	Once	11.5d	15.3b	13.4B[1]
(eight years)	Twice	14.7c	15.7a	15.2A
	Average[1]	13.1B	15.5A	14.3

*Means among varieties and managements within three-, five-, or eight-year averages, followed by similar lowercase letters do not differ at the 0.05 level. Means for paired averages followed by similar uppercase letters do not differ at the 0.05 level.
[1]Averages of 1024 values (eight locations, four varieties, eight years, and four replications) LSD 0.05 = 0.09.

switchgrass does not develop foliage and use water until much later in the spring than cool-season grasses, there is typically adequate moisture to sustain growth without water stress until harvested for the first time (in late anthesis) of the two-cut management.

Rainfall to support regrowth prior to the second harvest in November was apparently adequate for maximum growth but not so excessive as to cause yield reduction due to lodging as occurs with the one-cut management.

Table 2. Alamo switchgrass root mass (Mg ha^{-1}) at 0 to 30 cm (average of three locations) [Organic matter percentage (OM) in the Ap horizon (average of eight locations) and biomass contributed to the Ap horizon. Planting was in 1992 and samples were taken in fall 1996 (five years) and in fall of 2001 (ten years) after a one-cut harvest management. Differences were calculated using 1992 and 2001 data.]

Year	Layer of soil (cm)			Ap horizon[3]	
	0 to 15	15 to 30	0 to 30	Biomass[4] contributed	OM
	---------- Root mass (Mg ha^{-1}) ----------				%
1992	0.0b[1]	0.0c	0.0c	0.0b	1.4b
1996	5.7a[2]	2.6b	8.3b	--	--
2001	6.2a	5.2a	11.4a	18.4a	2.0a
Diff	6.2	5.2	11.4	18.4	0.7

*Means within columns followed by similar letters do not differ at the 0.05 level.

[1]Switchgrass root mass before planting in the spring of 1992.

[2]Roots were washed from the soil, and data are reported on an ash-free basis.

[3]The Ap horizon ranged from 10 to 30 cm at different locations (average depth was 22 cm).

[4]Organic matter contributed by switchgrass root growth was calculated: BD times percentage increase in OM times profile depth times a factor of 1000 to express data as Mg ha^{-1}.

Root growth and resultant increases in organic matter, as roots turnover, improve soil quality and sequester C. During the first five years of growth, root mass increase in the 0- to 15-cm depth was more than twice that in the 15- to 30-cm depth (Table 2). Organic matter increased in the Ap horizon (average depth of 22 cm) for all locations, which again is evidence that C is continually increasing at soil depths where turnover is not as great as near the soil surface. If 10 Mg ha^{-1} of roots are produced and turned over (in the upper 30-cm of the profile) each year, then soil OM would increase about 0.2% per year in a typical mineral soil (depending on the bulk density). Organic matter does not accumulate at the 0.2% rate; however, because of continual mineralization of the OM. An equilibrium develops that is driven in large part by soil temperatures. Thus a species such as switchgrass that generates OM from roots growing deep in the profile will have a greater net contribution for soil OM increase.

TASK TWO (SCREENING NEW GENETIC MATERIALS)

These studies showed that biomass increases can be achieved by plant breeding/selection. Nine experimental lines from the Oklahoma State breeding program and three commonly used varieties were successfully established in 1998. The experimental lines had less lodging than the traditional varieties, especially Cave-in-Rock, which had considerable lodging in this one-cut management. Weeds were not a problem. No disease was noted on any selection. The SL lines (from southern lowland sources) had higher yields (averaging 16.4 Mg ha^{-1} yr^{-1}) than the NL lines (from northern lowland sources) (averaging 13.0 Mg ha^{-1} yr^{-1}. The SL lines were superior to the common varieties of Alamo, Kanlow, and Cave-in-Rock.

TASK THREE (N, P, AND K REMOVAL/RECOMMENDATIONS)

Our studies suggest leaf blade tissue concentrations of 1.5% N, 0.23% P, 1.4% K, and 0.44% Ca (when collected at a late boot stage) would indicate adequate nutrition for maximum yields. At this maturity stage, whole-plant tissue samples were 1.03% N, 0.18% P, 1.27% K, and 0.25% Ca when averaged over eight locations and five years (Table 3). Whole-plant tissue showed 0.45% N, 0.09% P, 0.52% K, and 0.30% Ca in the November harvest when averaged over eight locations and five years. Soil P averaged 12 ppm in 2001 (an increase of 4 ppm since 1992) and soil K averaged 40 ppm in 2001 (a decrease of 39 ppm since 1992) for the same eight locations

Table 3. Nutrient element concentration in the whole-plant biomass and nutrient quantity removed and applied during five years (1997 to 2001) for Alamo switchgrass cut once or twice each year

(Yields and nutrient removal are averaged over eight locations and five years. Nutrients applied are averaged over locations each year.)

Nutrient	Application		Concentration			Removal			
			One cut	Two cut		One cut	Two cut		
	One cut	Two cut		First	Last		First	Last	Total
	-- kg ha^{-1} yr^{-1} --		--- % ---			---- kg ha^{-1} yr^{-1} ----			
N	40	80	0.45c*	1.03a	0.62b	68B*	81A	48C	129
P	8	8	0.09b	0.18a	0.11b	14A	14A	8B	22
K	12	12	0.52b	1.27a	0.57b	93A	98A	45B	143
Ca	0	0	0.31b	0.30b	0.38a	42A	24B	29B	53

*Means within rows followed by similar lower case letters or by similar upper case letters do not differ at the 0.05 level.

[1]No N was applied to any location in 1997. In 1998, one half of all reps received no N and one half received the full yearly amount (50 and 100 kg ha^{-1} for the one and two-cut managements, respectively). The full yearly amount was received by all reps in the last three years.

after ten
years of growth. A 10-cm sample depth was adequate to indicate the nutrient elements available for plant growth at all locations. When averaged over all eight locations, nutrient removal (N, P, K, and Ca) exceeded input each year for ten years, and still yields were high and stands were adequate to excellent.

Fertilizer recommendations should be based in part on good stewardship of the soil and the environment and in part on economics. The soil should be tested using a 0 to 10-cm sample. Apply 50 kg ha^{-1} of P when the soil-P test is low and 100 kg ha^{-1} of K when the soil-K test is medium-minus to medium (considering the typical basis for agronomic crop recommendations). No limestone would be needed if the soil pH is above 5. Limestone and P move down in the soil very slowly, thus a shallow soil sample properly assesses need.

Nitrogen should be used at a somewhat limiting rate as far as short-term yield goals are concerned. Rates that give maximum yields in the first few years will thin stands and may result in low future yields and possible weed completion in the thinner stand. Although we do not have sufficient data to be definitive on this point, we feel that many soils may not need any N for two or three years after planting when using a one-cut (November) harvest management, since much of the N located in the herbage is translocated downward to the crown/root system at the end of the growing season. Our observations lead us to believe plants may obtain sufficient N from mineralized forms and that they may be able to conserve or recycle that N during their annual growth cycle. No more than
50 kg N ha^{-1} may need to be applied after full productivity is established. For a two-cut management 50 kg ha^{-1} N in the spring and 50 after the first harvest should be adequate.

TASK FOUR (SWITCHGRASS ESTABLISHMENT/YIELD STUDY AT DUCK RIVER)

Excellent stands and yield potential developed on all of the several fields we planted in 1997 (when assessed in November 1998). These plantings were made on farm-size fields with readily available farm equipment, without excessive costs, and by personnel who had the typical experience of local farmers.

ADDITIONAL TASKS (SEED PRODUCTION, ROOT MASS ESTIMATIONS, C SEQUESTRATION, AND N MOBILIZATION)

Seed Production

In small-plot/clonal studies, application of “Banner” (a triazol fungicide (Propiconazol at 1.4 kg a.i ha^{-1}) along with a commercial plant-growth stimulant (1.8 kg ha^{-1} of product) increased seed yields by 66% in 1997, 45% in 1998, and 33% in 1999. The humic acid and seaweed extract that make up the growth-stimulant is 2.5% humic acid and 5% Fe.

Carbon Sequestration (A Preliminary Study)

The stable C_{12}:C_{13} isotope ratios under switchgrass (a C_4 species) show the fraction of the soil C that was contributed by switchgrass at different depths of the soil profile. In the 0- to 10-cm depth, 39% of the soil C (1.00 Mg ha^{-1}) was from switchgrass root growth during the previous seven years (1992 through 1998). At the 60- to 90-cm depth, the percentage soil C contributed by switchgrass was higher than at the 30- to 60-cm depth. The high dC_{13} value indicated that switchgrass roots are penetrating through the 60- to 90-cm portion of the profile and contributing to a buildup of soil C. This deep placement of C will remain unmineralized longer (slower turnover rate) than C sequestered in the upper profile.

Soil Sample Preparation for Root Mass, Om, C, and N Determination

A "dry-sieving method" of root mass determination caused a loss of 57% of switchgrass roots and 80% of tall fescue roots when compared to a "wet-sieving method." Any determination of root mass will be greatly underestimated if done using a dry preparation method, with the error being larger for the finer roots of tall fescue than the larger, coarser switchgrass roots.

Late-Season N Accumulation in Belowground Plant Parts

We know that plants have the ability to translocate N from old leaves to newly developing leaves during the growing season; thus a physiological mechanism for translocation of N exists in plants. Since our data show aboveground N in herbage decreases and root/crown N increases during a time when soil available N would be lowest, the indirect evidence points toward translocation of N from aboveground parts (and not coming from the soil). Crown/rhizome tissue N increased in concentration by 0.37% between October 1 and November 1. Assuming a conservative 10 Mg ha^{-1} of storage tissue, there would be 37 kg of N ha^{-1} translocated belowground not susceptible to leaching from winter rainfall and available for retranslocation to new aboveground biomass in the following season.

FIRST FIVE-YEAR PROJECT SUMMARY

OBJECTIVE ONE (VARIETY-SCREENING, HARVEST-MANAGEMENT STUDY)

Objective one involved planting several varieties at a range of locations across the northern tier of the southeastern United States. The sites were planted in 1992 and managed with moderate levels of inputs (fertilizers and pesticides as needed). Subplots were harvested either once or twice annually (Fig. 1). Accumulative influences of management, location, and variety were measured with yield comparisons. Soil characteristics were examined at the end of five years.

Fig. 1. Switchgrass biomass in January 1997 showing accumulated growth following no harvest during the 1996 season. No lodging had occurred. Princeton, Kentucky

Averaged across varieties and years, the highest yields (21.2 Mg ha^{-1}) were from the two-cut management system at Knoxville, Tennessee, and the lowest yields (11.0 to 11.8 Mg ha^{-1}) were from the one-cut management at Blacksburg, Virginia, (Site B), Jackson, Tennessee, and North Carolina (Table D1). Both upland varieties [Cave-in-Rock (CIR) and Shelter] responded similarly to cutting management and location as did the four lowland varieties (Alamo, Kanlow, NC1, and NC2). Thus, data for upland types were combined and lowland types were combined for the purposes of this overall summary. Also yields during 1994, 1995, and 1996 have been averaged as an indication of variety and management responses (only 1995 and 1996 data were used from the Kentucky location). The lowland varieties yielded about one-third more than the upland varieties when cut once and 12% more when cut twice in the season. The two-cut management had about 37% higher yields than the one-cut management for upland types. The two-cut advantage was 6% for the lowland types except for the lowland types cut once at West Virginia and Kentucky. At West Virginia and Kentucky, the one-cut averaged 20% more than the two-cut management. Both West Virginia and Kentucky had good stands of these varieties, and the soils had poor drainage as compared with other locations.

Based on findings from eight locations and three years, we made the following observations/ generalizations:

- Lowland varieties produce about one-third more biomass than upland varieties when cut once per season.
- Lowland varieties produce slightly more biomass than upland varieties when each is cut twice per season.
- A two-cut management will yield one-third more biomass than the one-cut management with upland types. A two-cut management may produce slightly more biomass than the one-cut management of lowland types; but two cuts may, under some circumstances, reduce seasonal yields.

- Sixty-seven percent of the biomass was removed in the first harvest of the upland types, and 60% of the biomass from the lowland types was removed in the first harvest of the two-cut system.

Stands were poor and tiller density was low for the one-cut as compared with the two-cut management; thus yield potential in the next seasons may show even greater management differences. A stand of CIR adjacent to our West Virginia experiment receiving no N and cut once per season had a good stand, while, in the experimental area where N was applied, there was a poor stand. This observation and our data that show approximately 38% of the N applied was removed by a one-cut management, leads us to predict that lower N rates might improve stands and sustain higher long-term yields. Future decisions should consider each management as an individual system to be fertilized according to yields attained.

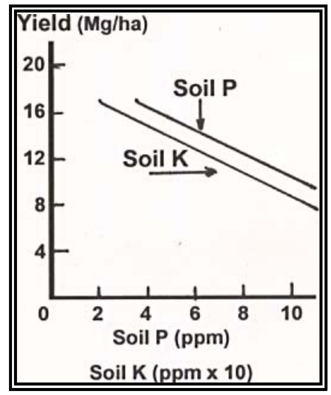

Fig. 2. Yield response to soil P and K levels. P and K levels were after five years of growth. Yields are average for three years (1994–1996).

Soil testing at the end of five years showed increased soil C, decreased bulk density, and a large amount of root mass where switchgrass had been grown. The highest yields were correlated with the lowest levels of P and K (Fig. 2). These data indicate that the soil nutrients (ranked as "low" to "medium" in standard agronomic tests) were adequate for maximum yields (within limitations of the environment and other factors) and that the harvests removed measurable amounts of P and K. This removal was confirmed by tissue tests and calculations of amounts removed. Our data indicate that optimum available soil P may begin at or below 5 ppm, and optimum available soil K may be below 20 ppm when using the soil test procedures at Virginia Tech. These levels are considered as "low" levels of potential soil productivity for most crops using the current calibrations and recommendations

Low N removal (38% of applied N) by biomass in the one-cut system, thinning stands, and accumulation of N in the roots prior to senescence seem to indicate that much less N should be applied. We recommend that harvesting be continued for this study but reduce N application. Also there is a need for calibration of tissue and soil tests with yields so that fertilizer recommendations can be based on switchgrass requirements rather than currently used cool-season crop references.

OBJECTIVE TWO (ESTABLISHMENT STUDIES)

This objective was addressed in a series of field and laboratory experiments at Blacksburg. Insecticide and herbicide influences on establishment were examined using plots within a fairly large-scale planting. Seed dormancy and dormancy-breaking treatments were examined to seek ways to overcome the problem of poor stand establishment with fresh (neoteric) seedlots.

The establishment studies revealed several important parameters related to seed dormancy. We have made good progress toward developing practical solutions to overcoming switchgrass seed dormancy, which may be the number one factor of importance in establishment. We now have developed procedures for growers to use in overcoming serious seed dormancy problems on a large scale. Bulk stratification recommendations from this work are being used by farmers. Studies using several combinations of seed storage times, temperatures, and moisture contents have revealed methods that can be used by seedsmen and planters to enhance seed quality and germination.

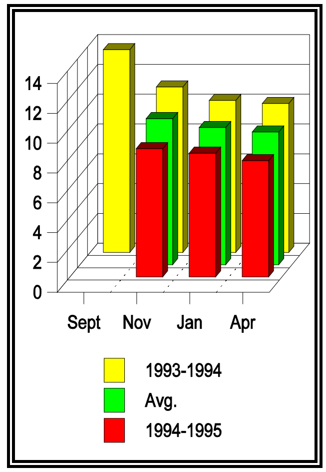

Fig. 3. Yields at several dates for delayed harvest. Data are averages of two locations.

Weed control, insect control, date of planting, seed treatments, and seedbed conditions can all be crucial in achieving good establishment. This project allowed us to test a repertory of management tools and strategies over a fairly broad range of sites, and the results are quite encouraging. Critical components of successful establishment include testing for germinability (and subsequent stratification if needed), use of no-till planting methods, herbicides to minimize weed competition, planting only after soil is fully warmed, and use of an insecticide where warranted. The techniques have been scaled-up and work in a broad range of environments. A Cooperative Extension bulletin has been published that details establishment and management. Many farmers have successfully established switchgrass in fields throughout Virginia using our recommendations.

OBJECTIVE THREE (DELAYED-HARVEST STUDY)

This objective was carried out at two locations within Virginia for two production cycles. Well-established stands of switchgrass were harvested at the end of the season or on a monthly schedule through the fall and winter. Changes in harvestable biomass were determined.

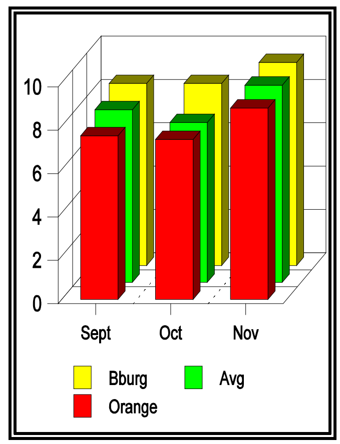

Fig. 4. Yield of switchgrass in November 1994 after 1993 harvests on September 1, October 1, or November 1, 1993.

The potential for delaying harvests into the winter, showed promising results. Harvesting the crop at monthly intervals for two winters revealed that yields did not drop significantly between November and April (Fig. 3). There did appear to be some yield decrease between September and November harvests. Harvesting once in September, instead of November, gave lower yields the following year, however (Fig. 4). This suggests that waiting for the plants to mature at the end of the season will provide a long-term yield advantage and compensate for the slight reduction in dry matter within a season. Of special importance is the documentation that considerable N is mobilized from the top growth to the root system between early September and the end of the season. Such an accumulation or "storage" of N will minimize N losses to ground water and ensure a supply for growth in the following year.

FIVE-YEAR PROJECT REPORT (1997 to 2001 DETAILS)

PROJECT TASKS AND APPROACH

Task One. Variety/management study. Evaluate the productivity of switchgrass varieties adapted to the upper Southeast when managed under two harvest regimes. (This is a continuation of a five-year study: 1992 to 1996).

Task Two. Screening of new genetic material. Evaluate new experimental lines provided by the plant breeding effort at Oklahoma State University.

Task Three. N, P, and K balance studies. Determine N, P, and K removal in biomass harvested and establish recommendations for limestone, N, P, and K applications.

Task Four. Establishment/Duck River Study. Demonstrate and evaluate establishment procedures and estimate production potential on small fields prior to scale-up plantings of larger areas.

SUMMARY

Over the last five years, all varieties maintained excellent yields that were mainly influenced by location and timeliness of summer rainfall. Yields were consistently above 15 Mg ha^{-1} when averaged over all locations, with no tendency to decline during the ten years of the study. These data (when averaged over eight locations and eight years) indicate that one harvest per year can achieve high yields if lowland ecotypes are used and that the lowland varieties would be preferred, since they could also be used for flexible cutting schedules. If properly managed, these stands appear to be truly perennial. New genetic lines show great promise to improve biomass yields beyond that of currently available varieties.

Elemental concentrations of single leaves and whole-plant tissue were obtained, and element removal/balance was calculated. Correlations between yields and element concentrations in the soil and plant tissues were low and often negative. Even plants grown hydroponically with no fertilizer added (from vegetative propagules) had element concentrations near those found in some field samples where yields were high.

The fertilizer recommendations growing out of this work are based in part on good stewardship of the soil and and environment and in part on economics. The soil should be tested using a 0 to 10-cm sample depth. Apply 50 kg P ha^{-1} when the soil-P test is low and 100 kg K ha^{-1} when the soil-K test is low-plus to medium (considering the typical basis for agronomic crop recommendations). No limestone may be needed if the soil pH is above 5.

Nitrogen should be used at a somewhat limiting rate as far as short-term yield goals are concerned. Rates that give maximum yields in the first few years after planting cause stands to thin and may result in lower future yields with possible weed completion in the thinner stand. Many soils may not need applied N for two to three years after planting when using a one-cut (November) harvest management, since much of the N located in the herbage is conserved by

translocation to the crown/root system at the end of the growing season. Thus, no more than 50 kg N ha^{-1} may need to be applied each year if the biomass is harvested once per year in November. For a two-cut management, 50 kg N ha^{-1} in the spring and 50 after the first harvest should be adequate for maintaining long-term yields.

Switchgrass establishment for this ten-year study was successful for each variety/line at all eight locations as well as in the numerous other plantings made during these ten years. Switchgrass planted into four long-term neglected fields at the Duck River Project near Columbia, Tennessee, on July 18, 1997, had excellent production and stands during 1998. This study demonstrated that any farmer (in the upper Southeast USA) using conventional equipment should be able to establish switchgrass economically if recommended practices are followed, including good quality seed and timely planting.

Root mass of switchgrass increased with time at all depths in the 90-cm soil profile. Deep-rooted switchgrass should have an advantage in carbon sequestration over shallow-rooted tall fescue at 30 to 90-cm depth due to slow turn over of organic matter by mineralization. At the end of the first five years, there were 14.5 Mg ha^{-1} of switchgrass roots in the 0- to 90-cm profile. There were 11.2 Mg ha^{-1} of roots in just the upper 30 cm of the soil profile at the end of the ten years of this study. Organic matter did not increase in the 0 to 10-cm depth when compared with tall fescue, which may result from upper soil layers being at an OM equilibrium governed by soil temperatures. Organic matter did increase in 15- to 30-cm depths and in the Ap soil horizon (average of the 0 to 22 cm depth at eight locations). Organic matter increased by 0.7% in the Ap horizons (averaged over eight locations) during ten years, which is equivalent to 18.4 Mg OM ha^{-1}.

INTRODUCTION

The management of switchgrass harvests is important. Frequency and timing of harvests can have agronomic, processing, and ultimately economic consequences. Will two harvests per season yield more biomass than one? Can they do so with sustainability? Is there enough yield benefit to economically justify a second harvest? What nutrient removal occurs and what replenishment will be needed? Can there be an accumulation of soil organic mater that will benefit soil quality and sequester carbon? At the onset of this study, we knew of no work that addressed these questions systematically on a long-term basis.

Virginia Tech began a series of studies in 1992 to answer key agronomic questions about using switchgrass as a biofuels feedstock. Our experience and that of others had suggested that more long-term information was needed on switchgrass management and biology before it could be widely adopted as a biofuels crop. This study was managed with low to moderate levels of inputs. Fertilizer P and K were applied in spring 1997 to those locations with soils testing below a medium production potential based on samples taken in fall 1996 (Appendix Table A-9). Nitrogen was applied at 100 kg ha^{-1} for the one- and two-cut managements during the 1993 to 1996 seasons. No N was applied in the 1997 season. In 1998, no N was applied to two replications, and two replications received the full yearly amount (100 kg ha^{-1} N in a split application for the two-cut management and 50 kg ha^{-1} N in the spring for the one-cut management). The 50 (for the one-cut) or 100 (for the two-cut) amount was applied to all replications in the last three years. Yields (Appendix Tables A-10 to A-28) and plant tissue analyses (Appendix Tables A-29 to A-33) provided biomass production data for calculating nutrient removal (Appendix Tables A-34 to A-40). Soil samples taken in fall 1996, 1998, and 2001 were used to follow fertility trends (Appendix Tables A-41 to A-52).

STATISTICS

Interactions involving locations and years were occasionally significant at the 0.10 level or lower, but the significance was due to the magnitude of change and low experimental errors. In order to condense a wealth of data, we sometimes averaged data across years and locations. Thus, our summaries consider location and years as random variables rather than fixed variables. This is considered a conservative selection of error terms that includes interactions involving years and locations in the error term. As random variables, predictions for future years and other locations are more accurate than if years and locations were considered in a fixed model

TASK ONE (VARIETY MANAGEMENT STUDY)

Location and Growing Conditions

This multi-site variety/management study included eight locations [in Virginia (three sites), Tennessee (two sites), West Virginia, Kentucky, and North Carolina], six varieties/lines, (two upland and four lowland entries), and two management systems (one or two cuts per season). Soil characterization (classification), actual and long-term rainfall, and mean temperatures as well as geographic location have been carefully documented, so that a yield database can be established. The locations ranged from 39º 37'N to 35º37N and from 88º50'W to 78º07'W (Table 4). Elevation ranged from 120 to 600 m. Long-term rainfall for the June through September portion of the growing season averaged 39.5 cm (range of 37 to 57 cm during 1997 to 2001) with a long-term mean temperature of 23.0º C (range of 21.4 to 29.4º C during 1997 to 2001).

Rainfall and mean temperatures for each location and all five years are reported in Appendix Tables A-1 to A-7. Soil samples taken at each site before planting in 1992 were used to classify and describe the soil. Information on soil morphology and soil chemical and physical characteristics are in Appendix Tables A-4 to A-25 of the 1996 final report on the previous project. Soil test data reported chemical analyses as influenced by five years of switchgrass growth between 1992 and 1996 (Appendix Tables A-26 to A-31 of the 1996 final report).

Average corn yields for 1993 to 2000 are reported for comparisons with switchgrass yields (Appendix Table A-8). These county-wide data are from agricultural statistic reports. Also, estimated corn yields for soils similar to that used for the switchgrass studies are given based on soil classification capability classes developed by Soil Conservation Service personnel for average growing conditions. These estimated yields are based on soil productivity traits and ranged from a low of 5.7 Mg ha^{-1} at Jackson, Tennessee, and Raleigh, North Carolina, to a high of 8.1 Mg ha^{-1} at Blacksburg, Virginia (Site B), and Princeton, Kentucky.

Table 4. Location, elevation, rainfall (accumulated for June through September) and mean temperature (average of June through September) when averaged over three years from 1994 to 1996 and for five years when averaged over 1997 to 2001

State	Town	Location		Elev (m)	Rainfall (cm)			Temp(°C)		
		Lat N	Long W		1994 to 1996	1997 to 2001	Long term	1994 to 1996	1997 to 2001	Long term
VA	Orange	38º13'	78º07'	156	58	37	40	22.3	22.1	22.5
	B'burg	37º11'	80º25'	600	36	37	35	20.2	20.8	20.1
TN	Knox	35º53'	83º57'	250	35	41	38	22.6	23.1	23.3
	Jack	35º37'	88º50'	120	44	42	39	24.3	25.1	24.4
WV	Morg	39º37'	79º55'	378	47	35	40	20.2	21.0	20.9
KY	Prince	37º06'	87º49'	173	38	39	39	24.0	24.4	23.9
NC	Raleigh	35º43'	78º40'	120	47	57	40	25.1	24.0	24.3
Average		--	--	–	43	41	39	22.6	22.9	22.7

Results and Discussion

Two lowland varieties (Alamo and Kanlow) responded similarly, and the two upland varieties (Cave-in-Rock and Shelter) responded similarly; so our summaries will mostly involve these groupings (Table 5). Most data for summaries included only the two named lowland types because they are familiar, they are widely available varieties, and statistical comparisons among means having similar "n" values were straight forward. The two experimental lines from North Carolina used in the study were lowland types (without any wide-spread comparative data) and responded similarly to Alamo and Kanlow. Where soil or tissue assays were made, only the Alamo variety was considered.

When cut twice in the season, upland and lowland varieties had similar yields (Tables 5, 6, and 7). However, when cut only once during the season, lowland varieties averaged 22% greater yields when compared to upland varieties (Tables 6 and 7). When averaged over eight locations and eight years, these data indicate that one harvest per year can achieve high yields if lowland types are used and that the lowland varieties would be preferred, since they could also be used for flexible cutting schedules.

A comparison of yields with annual rainfall shows no relationship for either one- or two-cut managements when considering data for eight locations and eight years (multiple regression removed effects of years and locations). We thought that the June through September rainfall would be more critical to yields than annual rainfall. When considering June through September

Table 5. Seasonal yields averaged over three, five, or eight years from two upland varieties (Cave-in-Rock and Shelter) and two lowland varieties (Alamo and Kanlow) of switchgrass at eight locations when harvested once (in November) or twice (first cut in early heading stage and second cut in November)

Years	Cuts	Yield		Average
		Upland	Lowland	
		--------- Mg ha^{-1} yr^{-1} ---------		
1994 to 1996	Once	10.8d*	14.8c	12.8B
(three years)	Twice	15.0b	16.4a	15.7A
	Average	12.9B	15.6A	14.2
1997 to 2001	Once	11.9c	15.6a	13.7B
(five years)	Twice	14.5b	15.3a	14.9A
	Average	13.2B	15.4A	14.3
1994 to 2001	Once	11.5	15.3	13.4
(eight years)	Twice	14.7	15.7	15.2
	Average[1]	13.1	15.5	14.3

*Means among varieties and managements within three-, five-, or eight-year averages followed by similar lower case letters do not differ at the 0.05 level. Means for paired averages followed by similar upper case letters do not differ at the 0.05 level.
[1]Averages of 1024 values (eight locations, four varieties, eight years, and four replications) LSD 0.05 = 0.09.

rainfall, there is a nonsignificant but negative association with November yields for the two-cut management (p = -0.61); however, there was a significant negative influence of June through September rainfall on November yields of the one-cut management (p = -0.08). Winter/early spring rainfall at these locations is typically enough to bring the entire rooting zone to field capacity. Since switchgrass does not develop foliage to use soil water until much later in the spring than cool-season species, there is usually adequate moisture to sustain growth without water stress through first harvest in the two-cut management. This water usage pattern is similar to that of winter wheat, where winter rainfall may be adequate to produce wheat yields even on dry sites or when spring rainfall is limited. Rainfall for switchgrass regrowth for the second harvest in November was apparently adequate for maximum growth but not so excessive as to cause yield reduction due to lodging as occurs with the single harvest of the one-cut management. The negative correlation (p = -0.08) between June through September rainfall and the one-cut management indicates that there is enough rainfall to cause yield reductions, probably due to deterioration that comes after lodging. New genetic lines may have less lodging and may reduce the negative influence of rainfall.

Table 6. Seasonal yields averaged over five years (1997 to 2001) from two upland varieties (Cave-in-Rock and Shelter) and two lowland varieties (Alamo and Kanlow) of switchgrass at eight locations when harvested once (in November) or twice (first cut in early heading stage and second cut in November

(Differences are calculated between one-cut and two-cut managements and expressed as percentages of the one-cut management yields.)

Cuts	Variety	Yields								
		Blacksburg, VA		Orange, VA	Tennessee		WV	KY	NC	Av
		Site A	Site B		Knox	Jack				
		-- $Mg\ ha^{-1}$ --								
	Upland	11.9	14.1	11.7	13.7	9.0	13.4	11.9	9.1	1.0
Once	Lowland	13.2	18.7	16.9	20.0	11.5	16.4	14.6	13.5	15.6
	Av	12.5	16.4	14.3	16.8	10.2	14.9	13.3	11.3	13.7
	Upland	16.0	18.3	13.7	17.1	12.4	13.1	12.1	13.0	14.4
	Lowland	16.0	20.2	15.1	16.1	12.6	13.1	14.8	14.7	15.3
Twice	Av	16.0	19.2	14.4	16.6	12.5	13.1	13.4	13.8	14.9
	LSD	0.8	1.1	0.8	0.8	0.8	0.8	0.8	0.8	
		-------- *Differences in $Mg\ ha^{-1}$ between one and two-cut managements* --------								
	Upland	4.1	4.2	2.0	3.4	3.4	-0.3	0.2	3.9	2.6
	Lowland	2.8	1.5	-1.8	-3.9	1.1	-3.3	0.2	1.2	-0.3
		-------------------------------- *Percentage difference* --------------------------------								
	Upland	34	30	17	25	38	-2	2	43	22
	Lowland	21	8	-11	-19	10	-20	1	9	-2

*LSD values are for comparison of varieties within and between cutting managements.
The one-cut management received 50 kg N ha^{-1} in the spring, and the two-cut management received 50 kg in spring and again after the first harvest.

Table 7. Yields (averaged over eight locations) from two upland varieties (Cave-in-Rock and Shelter) and two lowland varieties (Alamo and Kanlow) of switchgrass at eight locations when harvested once (in November) or twice (first cut in early heading stage and second cut in November) for five years

[Differences are calculated between one-cut and two-cut managements (two-cut minus one-cut) and expressed as percentages of the one-cut management yields.]

Cuts	Variety	Annual yield					Yield 1997 to 2001	
		1997	1998	1999	2000	2001	Total	Average
		-- Mg ha^{-1} --						
Once	Upland	11.0	13.3	12.2	11.3	11.7	58.1	11.9
	Lowland	14.0	17.5	15.0	15.2	16.6	76.5	15.6
	Average	12.5	15.4	13.6	13.2	14.1	67.3	13.7
Twice	Upland	11.4	16.9	13.7	15.5	14.6	70.7	14.5
	Lowland	12.2	18.1	14.7	16.6	15.0	74.9	15.3
	Average	11.8	17.5	14.2	16.1	14.8	72.8	14.9
	LSD 0.05*	0.7	0.7	0.7	0.7	0.9	--	0.3
		--------- *Differences in Mg ha^{-1} between one and two-cut managements* ---------						
	Upland	0.4	3.7	1.5	4.3	2.9	12.6	2.6
	Lowland	-1.8	0.6	-0.4	1.4	-1.6	-1.6	-0.3
		------------------------------------- *% Difference* -------------------------------------						
	Upland	4	28	12	38	25	22	22
	Lowland	-13	3	-3	9	-10	-2	-2

*LSD values are for comparison of means between varieties within and between cutting managements.

Rainfall did not seem to be a major influence on yields, yet some locations had low yields during a season with average rainfall and vice versa. This may indicate that timeliness of the rainfall during critical parts of the growing season is more important than amount. The physiology of switchgrass helps to provide efficient dry matter production per unit of rainfall. Switchgrass roots grow deeper than many other crops and can capture moisture to carry the plant over until the next rain event. We have shown that cyclic soil moisture stress can cause acclimation to water stress with improved photosynthetic efficiency (Kiss and Wolf 2001). Efficiency of biomass production per unit of June through September rainfall averaged 383 kg ha^{-1} cm^{-1} (range from 275 to 502 kg ha^{-1} cm^{-1})
(Table 8).

Soil characteristics varied widely among locations but did not influence productivity greatly except at Jackson, Tennessee, and Blacksburg, Virginia, Site A. The Jackson, Tennessee, site had a shallow soil depth, which would limit water-holding capacity. Thus, rainfall timing/frequency was a possible yield limiting factor. The Blacksburg, Virginia, Site A had a rocky subsoil and considerable slope, so that rainfall runoff might have limited available soil moisture. In some years, rainfall at some locations was low enough that corn crops in the county failed, yet switchgrass yields were near normal.

Table 8. Switchgrass yields for one-cut management (averaged over all varieties and eight years), June to September rainfall (averaged over eight years), and production efficiency from rainfall (kg of biomass ha^{-1} cm^{-1} rainfall)

Location	Yield	Efficiency	Rainfall
	Mg ha^{-1}	kg ha^{-1} cm^{-1}	cm
Virginia			
Blacksburg (Site A)	12.1	368	38
Blacksburg (Site B)	15.1	437	38
Orange	14.1	343	45
Tennessee			
Knoxville	18.0	502	38
Jackson	11.0	282	40
Princeton, KY	13.5	382	37
Morgantown, WV	15.1	446	36
Raleigh, NC	12.6	274	53
Average over all locations	14.0	383	41
LSD 0.05	(1.5)	(47) [17]*	--

Stand Rank/Density as Affected by Cutting Frequency and/or N

Stand ratings of the two-cut management, as visually estimated by percentage of stubble cover after the November harvest, increased between 1996 and 2001 (Table 9). All varieties at all locations had tiller populations that would not limit production potential. However, at some locations varieties under the one-cut management had sparse stands in 1996 that thickened during the subsequent five years of management. We speculate that the high N application during the first five years (100 kg N ha^{-1} yr^{-1}) for the one-cut management caused the stand reductions and that using less N between 1997 and 2001 allowed some rejuvenation in stands. Even though stands of the one-cut management seemed sparse, yields may not have been reduced, since correlations between yields and stand estimates as well as between yields and

stubble density were negative. This seems to indicate that the fewer larger tillers will give high yields in thin stands. These data support the conclusion that, if managed properly, high production can continue indefinitely
(Fig. 5). Stubble density (a time consuming measurement) was predicted by the relationship with an easily obtainable visible stand estimate. For the one-cut management, regression analysis showed stubble density = 51 + 48 times stand estimate ® = 0.71, $p < 0.01$); and for the two-cut management: stubble = -790 + 171 times stand estimate ® = 0.38, p = 0.38).

Table 9. Stand ranking[1] in November 2001 for upland varieties (Cave-in-Rock and Shelter) and lowland varieties (Alamo and Kanlow) of switchgrass and stubble density[2] in November 2001 for Alamo switchgrass at eight locations when harvested once (November) or twice (first cut in early heading stage and second cut in November) for nine years after the establishment in 1992

[Differences are calculated using similar ratings made in November 1996 (2001 minus 1996 data).]

Treatment		Variety			Alamo switchgrass stubble density[2]
Cuts	**Year**	**Upland**	**Lowland**	**Average**	
		-------- Stand rank (0 to 10)[1] --------			----- Tillers m^{-2} -----
Once	1996	6.8	6.5	6.7	338
	2001	7.1	7.3	7.2	388
Twice	1996	7.4	7.6	7.5	730
	2001	9.5	9.4	9.4	832
	LSD 0.05*	0.3		0.2	55

*LSD values are for comparison of means between varieties within and between cutting managements.
[1]Stand rankings were a visual score (0 to 10) based on the stubble density.
[2]Stubble density was determined by counting the tiller stubs that supported growth at the last harvest in November 2001.

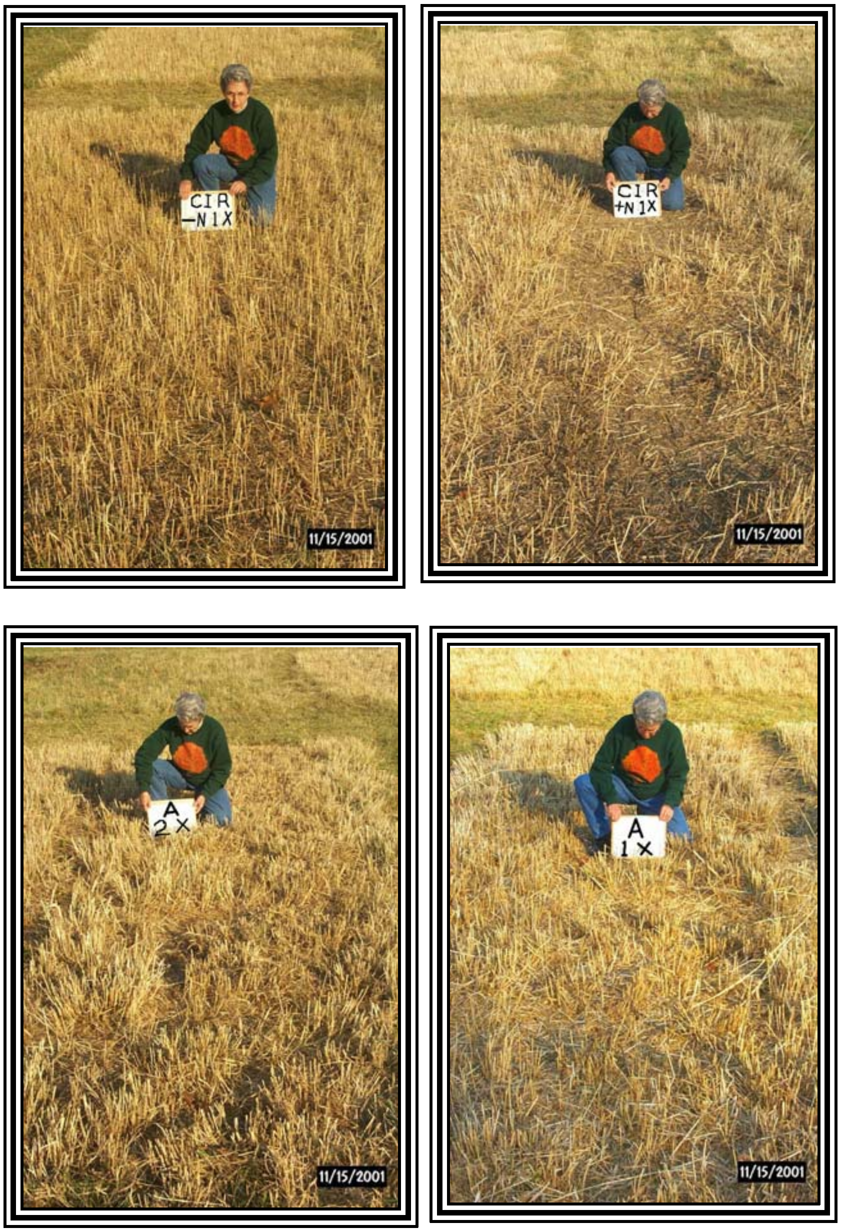

Fig. 5. Stubble density after the November 2001 harvest at Morgantown, West Virginia. Upper is Cave-in-Rock: left shows dense stand with low N, and right shows sparse stand with high N (one-cut management for both). Lower is Alamo: left shows dense stand with two-cut management, and right shows sparse stand with one-cut management (high N for both).

Root Mass/Organic Matter

Root growth and resultant increases in organic matter improved soil quality and sequestered C. During the first five years of growth, root mass increase was more than double in the 0- to 15-cm depth as compared with the 15- to 30-cm depth (Tables 10 and 14). During the next five years, there was an equilibrium reached in the root mass at the upper depth, which is reflected in no organic matter gain between 1996 and 2001 for the 0- to 10-cm depth (Table 16). Organic matter turnover rate, which is regulated largely by soil temperature, was rapid enough that large increases do not occur in the upper soil profile. Switchgrass roots continued to increase in the 15- to 30-cm depth in the last five years. Organic matter increased in the Ap horizon (average depth of 22 cm) for all locations, which again is evidence that C is continually increasing at greater soil depths where turnover is not as great as near the soil surface (Tables 10 and 15). With a 0.7% increase in organic matter for the Ap horizon in ten years, we calculate that 18.4 Mg ha^{-1} of partially decomposed roots were needed to achieve the increase.

Soil Test Values (1992 to 2001)

Soil pH declined during ten years but appeared to be stabilizing in the last three years (Table 11 and Fig. 6). Yields remained high, so soil pH did not appear to be yield limiting. A decrease in soil pH did not occur in adjacent tall fescue areas, because no N fertilizer was applied as was done for the switchgrass areas. Increased soil P reflected applied P in excess of removal even though little was applied during the ten years. Soil P remained unchanged during the ten years under the adjacent nonfertilized tall fescue areas. With no statistical correlation between soil P and yields over a wide range of soil P values, we conclude that soil P at a low to medium productivity level is adequate for maximum switchgrass yields. Soil K and soil Ca declined during the ten years but did not become low enough to limit yields. Soil K and soil Ca did not change during the ten years under adjacent tall fescue areas. Soil OM in the 0- to 10-cm layer declined during the last five years of the study under switchgrass but not under tall fescue. Tall fescue has a majority of its roots near the soil surface,

Table 10. Alamo switchgrass root mass (Mg ha^{-1}) at 0 to 30 cm (average of three locations) [Organic matter percentage (OM) in the Ap horizon (average of eight locations) and biomass contributed to the Ap horizon. Planting was in 1992 and samples were taken in fall of 1996 (five years) and in fall of 2001 (ten years) after a one-cut harvest management. Differences were calculated using 1992 and 2001 data. Data details are in Tables 16 and 17).]

Year	Layer of soil (cm)			Ap horizon[3]	
	0 to 15	15 to 30	0 to 30	Biomass[4] contributed	OM
	-------- Root mass (Mg ha^{-1}) --------				%
1992	0.0[1]	0.0	0.0	0.0	1.4
1996	5.7[2]	2.6	8.3	--	--
2001	6.2[2]	5.2	11.4	18.4	2.0

[1]Switchgrass root mass before planting in the spring of 1992.
[2]Roots were washed from the soil and data are reported on an ash-free basis.
[3]The Ap horizon ranged from 10 to 30 cm at different locations (average depth was 22 cm).
[4]Organic matter contributed by switchgrass root growth was calculated: BD times percentage increase in OM times profile depth times a factor of 1000 to express data a Mg ha^{-1}.

while switchgrass roots are distributed to greater depths. We have found in other studies that root mass of tall fescue is greater in the upper 10 cm of the soil than switchgrass. Organic matter in the upper level for switchgrass is becoming stable at a new equilibrium and probably will not continue to decline.

Table 11. Soil test values for Alamo switchgrass when sampled in the spring of 1992 (before planting) and in the fall of 1996, 1998, and 2001

(Managements included one cut and two cuts per season. The productivity potentials are soil test values that are recommended to achieve low, medium, and high yields of agronomic crops. Data are averaged over eight locations. Soil samples were taken from a depth of 0 to 10 cm[1]. Values in parentheses are for non-harvested, non-fertilized tall fescue located near the switchgrass plots. Data for each location can be found in Tables 47 and 48.)

Year	Cuts		Cuts		Cuts	
	Once	**Twice**	**Once**	**Twice**	**Once**	**Twice**
	---------- pH --------				----- K (ppm) ------	
1992	6.1				79	
1996	5.8 (6.0)	5.8	7 (6)	6	56 (46)	36
1998	5.5 (5.9)	5.5	14 (5)	13	72	51
2001	5.4 (5.9)	5.3	12 (5)	11	48 (88)	32
LSD 0.05	0.3		4		20	
---------------------------------- *Productivity potential based on field crops* ----------------------------------						
Low	?				8 to 28 ppm	
Medium	?				51 to 75 ppm	
High	?				106 to 140 ppm	
	----- Ca (ppm)[3] ----				--- Yield (Mg ha^{-1}) ---	
1992	651				.	
1996	693 (727)	659	2.9 (2.9)	2.8	14.8	16.4
1998	702 (822)	727	2.8 (3.1)	2.8	17.1	17.7
2001	497 (718)	371	2.4 (2.8)	2.5	16.4	15.1
LSD 0.05*	137			0.35		
---------------------------------- *Productivity potential based on field crops* ----------------------------------						
Low	121 to 240 ppm					
Medium	481 to 600 ppm					
High	841 to 960 ppm					

[1]Fertilization application (see Table 3) averaged 10 kg ha^{-1} of P and 20 kg ha^{-1} of K with no added limestone for 10 years. Some locations had no P of K applied in the last five years. Soil test values were much lower at all depths below 10 cm when compared to the 0- to 10-cm depth.
[2]P from Raleigh, NC, was not included in averages because of unusually high values.
[3]Ca from Princeton, KY, was not included in averages because of unusually high values.
?Indicates that no potential productivity values are established.

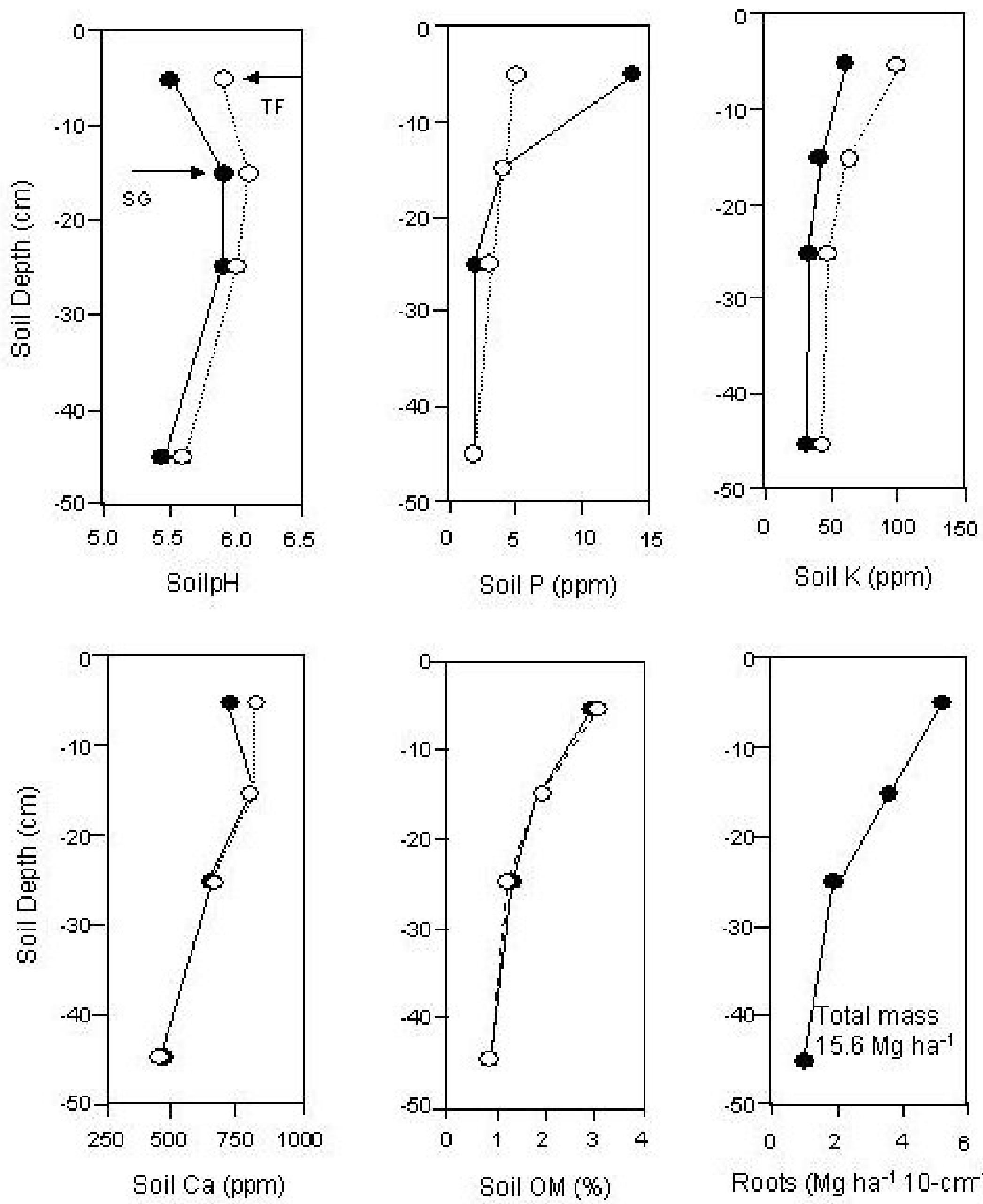

Fig. 6. Soil test values and root mass of switchgrass and tall fescue in 1998. Data are averaged over two cutting managements and eight locations. Vertical lines indicated low and medium productivity levels for agronomic crops.

Root Mass/nutrient Distribution with Soil Depth

All soil test values except soil K declined with increasing depth in the 90-cm soil profile when tested during seven years of switchgrass growth at the four locations sampled in 1998 (Table 12). Soil K was uniform throughout the 90-cm profile. Soil samples taken at eight locations from 10-cm depths showed similar trends (Table 13). These data show that routine soil sampling for fertilizer recommendations can come from the upper 10 cm. Seventy one percent of the roots were located in the upper 30 cm, but there were 1.3 Mg ha^{-1} in the 60 to 90-cm depth. The deep-rooting nature will likely sequester significant C where turnover will be reduced.

Soil C and Soil N Distribution with Depth

Organic matter is theoretically 58% carbon. Soil C determined by a combustion method times 1.72 will estimate the OM percentage. This value will not always be the same as organic matter determined by a wet digestion method such as the Walkley/Black procedure, since any oxidizing material will appear as C equivalent. Poorly drained soils, Cl, Fe, and Mn will interfere with the test, causing over estimates of OM. Also the C may not be completely oxidized by this Walkley/Black test. It is generally assumed that 70% of the C is oxidized and that there are no nonorganic oxidizing substances in the sample. Thus, C as determined by the Walkley/Black method is multiplied by a factor of 2.46 when reported by the Virginia Tech soils lab. We found that this overestimated the OM percentage as determined by combustion and that a conversion factor of about 2 indicated that nearly all of the C in the OM was digested (see our further discussion at the end of this section).

Table 12. Root mass, percentage root distribution, and soil chemical analyses of the soil profile under switchgrass

[Data averaged for four locations (Blacksburg, VA; Morgantown, WV; Knoxville, TN; and Jackson, TN). Sampled in fall of 1996.]

Soil depth	Roots (ash-free)		Soil pH	Soil nutrient				Soil OM
	Mass	Distribution		P	K	Ca	Mg	
-- cm --	-- Mg ha^{-1} ---	-- % --		----------- ppm ----------				-- % --
0 to 15	7.8	52	6.0	4.0	35	783	103	2.9
15 to 30	2.6	19	6.3	2.0	27	672	126	1.9
30 to 45	1.7	12	5.7	1.8	34	435	152	1.2
45 to 60	1.2	8	5.5	0.8	34	351	151	0.9
60 to 75	0.8	6	5.2	0.5	37	327	145	0.9
75 to 90	0.5	4	5.3	0.0	35	297	138	0.8
Total	14.5	100	--	--	--	--	--	–

Table 13. Soil characterization (averaged over two cutting managements and eight locations) for several layers of soil under Alamo switchgrass after seven years of growth (1998 samples)

(The productivity potentials are soil test values that are recommended to achieve low , medium, and high yields of agronomic crops.)

Depth	Soil pH[1]	Soil composition (ppm)[2]			
		P	K	Ca	Soil OM[1]
--- cm ---		---------- ppm ----------			--- % ---
0 to 10	5.5	14	62	715	2.8
10 to 20	5.9	4	41	760	1.9
20 to 30	5.9	4	33	634	1.3
0 to 30	5.8	7	45	703	2.0
30 to 60	5.5	2	32	458	0.8
60 to 90	5.2	2	34	389	0.9
LSD 0.05	0.2	2	6	63	0.2
---------- *Productivity potential based on field crops (ppm)* ----------					
Low	?	2 to 4 ppm	8 to 28 ppm	121 to 240 ppm	?
Medium	?	11 to 15 ppm	51 to 75 ppm	481 to 600 ppm	?
High	?	28 to 34 ppm	1.6 to 140 ppm	841 to 960 ppm	?

[1]Indicates that no potential productivity value has been established.
[2]Routine soil test at VA Tech.

Soil C, soil N, and percentage roots declined with increasing soil depth (Table 17). These data show 1900 kg ha^{-1} of N in the top 10 cm of the soil profile and 7100 kg ha^{-1} in the 0 to 90-cm profile. With the rather low amount of N needed, the slow rate of N needed, and end-of-season translocation from tops to roots, mineralization of soil N may supply adequate N nutrition for switchgrass grown for biomass.

Table 14. Alamo switchgrass root mass ($Mg\ ha^{-1}$) at two depths and three locations

[Planting was in 1992 and samples were taken in fall of 1996 (five years) and in fall of 2001 (ten years) after a one-cut harvest management[1]. Differences were calculated using 1996 and 2001 data.]

Location	Year	Root mass		
		0 to 15 cm	**15 to 30 cm**	**0 to 30 cm**
		-------------------- $Mg\ ha^{-1}$ --------------------		
Blacksburg,	1992[2]	0.0	0.0	0.0
VA (Site B)	1996	5.0	2.2	7.2
	2001	4.2	4.4	8.6
Morgantown,	1992[2]	0.0	0.0	0.0
WV	1996	4.5	2.1	6.6
	2001	6.4	5.5	11.9
Knoxville,	1992[2]	0.0	0.0	0.0
TN	1996	7.5	3.4	10.9
	2001	8.0	5.6	13.6
Average	1992[2]	0.0b	0.0c	0.0c
(n = 8)	1996	5.7a	2.6b	8.2b
	2001	6.2a	5.2a	11.4 a

*LSD 0.05 for differences: n of 4 = 1.4; n of 8 = 0.8.
Averages within columns followed by similar letters do not differ at the 0.05 level.

[1]Harvest was taken in the fall about November 1 of each year. Roots were washed from the soil and data are reported on an ash-free basis.

[2]Switchgrass root mass before planting in the spring of 1992 was zero.

Table 15. Soil organic matter (OM)[1] in the Ap horizon of Alamo switchgrass plots sampled in spring of 1992 before planting and again in the fall of 2001 after ten years of an annual single fall harvest (one-cut management)

Location	Ap horizon depth	Year sampled		Increase	Bulk density	OM from roots
		1992	2001			
	-- cm --	-- Organic matter (%) --				-- Mg ha^{-1} --
Blacksburg, VA (Site B)	0 to 20	0.8	1.8	1.0	1.50	30.0
Orange, VA	0 to 10	3.0	4.6	1.6	1.20	19.2
Knoxville, TN (Reps 1 and 2)	0 to 30	1.0	1.3	0.3	1.50	13.5
(Reps 3 and 4)	0 to 15	1.9	2.2	0.3	1.58	7.1
Jackson, TN	0 to 25	0.8	1.6	0.8	1.57	31.4
Morgantown, WV	0 to 20	1.0	1.6	0.6	1.49	17.9
Princeton, KY	0 to 30	1.0	1.4	0.4	1.67	16.7
Raleigh, NC	0 to 25	1.5	1.8	0.3	1.52	11.4
Average	0 to 22	1.4	2.0	0.7	--	18.4

[1]Organic matter was determined by the Walkley/Black method.

Table 16. Soil organic matter (OM)[1] in the upper 10 cm of the profile in Alamo switchgrass plots sampled in the fall of 1996, 1998, and 2001

[Harvesting was an annual single fall harvest (one-cut management). Tall fescue was sampled in alleyways where no switchgrass was allowed to grow.]

Species	Location	1996	1998	2001	1996 vs 2001
		--------------- Organic matter (%) ---------------			
Switchgrass	Blacksburg, VA (Site A) (site	3.2	3.2	2.5	-0.7
	Blacksburg, VA (Site B)	2.6	2.6	2.0	-0.6
	Orange, VA	4.8	4.4	4.1	-0.7
	Knoxville, TN	3.0	3.1	2.3	-0.7
	Jackson, TN	2.2	2.0	1.9	-0.3
	Morgantown, WV	2.4	2.4	2.1	-0.3
	Princeton, KY	2.8	2.8	2.1	-0.7
	Raleigh, NC	1.9	2.0	1.9	0.0
	Average (n = 32)	2.9	2.8	2.4	-0.5
Tall fescue	Blacksburg, VA (Site A)	3.2	3.6	3.1	-0.1
	Blacksburg, VA (Site B)	2.6	2.7	2.6	0.0
	Orange, VA	5.0	4.1	5.2	0.2
	Knoxville, TN	3.1	4.2	3.0	-0.1
	Jackson, TN	2.0	2.2	1.8	-0.2
	Morgantown, WV	2.6	2.7	2.3	-0.3
	Princeton, KY	2.8	3.1	2.5	-0.3
	Raleigh, NC	2.0	2.3	1.8	-0.2
	Average (n = 32)	2.9	3.1	2.8	-0.1
	LSD 0.05 for n = 4	0.3	0.4	0.4	--

[1] Organic matter was determined by the Walkey/Black method.

Table 17. Soil C and soil N percentage and stock C and N ($Mg\ ha^{-1}$ for each soil layer) averaged over two cutting managements and eight locations for several layers under Alamo switchgrass after seven years of growth

[Root mass in the 0 to 90-cm profile is in brackets. (Fall 1998 samples)]

Depth	Soil C[1]	Soil N[1]	C:N ratio	Stock soil C[1]	Stock soil N[1]	Root mass
-- cm --	---------- % ----------			------------ $Mg\ ha^{-1}$ ------------		---- % ----
0 to 10	1.51	0.14	10.8	20.6	1.9	38
10 to 20	0.93	0.09	10.3	14.4	1.4	30
20 to 30	0.56	0.06	9.3	9.3	0.9	20
0 to 30	1.00	0.10	10.0	44.3	4.2	87
30 to 60	0.23	0.04	6.6	11.0	1.7	10
60 to 90	0.16	0.03	6.6	8.0	1.2	4
0 to 90				63.2	7.1	[16.0 $Mg\ ha^{-1}$]

[1]Soil C and soil N were determined by a combustion method (Leco) at Oak Ridge National Laboratory.

TASK TWO (SCREENING NEW GENETIC MATERIALS)

Switchgrass plots (nine experimental lines from the Oklahoma State breeding program and three commonly used varieties) were planted in mid-June 1998. Establishment was highly successful. The land area where this planting was located has a low productive potential for row crops. Nitrogen, P, and K were applied at 50, 24, and 46 kg/ha, respectively, in early May 1999, 2000, and 2001. Yields were taken in late October of each year. After four years of growth, all selections had excellent stands as judged by tiller numbers. Yields were measured using a one-cut management system. The experimental lines had less lodging than the traditional varieties, especially Cave-in-Rock, which had considerable lodging. No disease was noted on any selection.

The five SL lines (from southern lowland sources with an average of 16.4 $Mg\ ha^{-1}$ for three years) had higher yields than the four NL lines (from northern lowland sources with an average of 13.3 $Mg\ ha^{-1}$ for three years) (see Table 49). The SL lines were superior to the commonly used varieties of Alamo, Kanlow (both lowland types with 14.0 $Mg\ ha^{-1}$ for three years) and especially Cave-in-Rock (an upland type with 8.5 $Mg\ ha^{-1}$ for three years). These data show that biomass increases can be achieved by plant breeding/selection.

TASK THREE (N, P, AND K REMOVAL AND FERTILIZER RECOMMENDATIONS)

Leaf blade tissue concentrations of 1.5% N, 0.23% P, 1.4% K, and 0.44% Ca when collected at a late boot stage indicated adequate nutrition for high yields. At this maturity stage, whole-plant tissue was 1.03% N, 0.18% P, 1.27% K, and 0.25% Ca when averaged over eight locations and five years (Table 18 and Table 3 in previous sections). Whole-plant tissue showed 0.45% N, 0.09% P, 0.52% K, and 0.30% Ca in the November harvest when averaged over eight locations and five years. Soil P averaged 7 to 8 ppm, and soil K averaged 32 to 48 ppm for the same eight locations after ten years of growth.

If present, correlations between any of these elements and yields could be used as a basis for making fertilizer recommendations. The correlations between yields and whole-plant or soil element concentrations were very low in 1997, probably due to the application of fertilizer in spring 1997 at locations where fall 1996 soil tests indicated a low productivity potential (Table 19) Correlations improved each year, with 2001 data having the most significant values. Whole- plant P showed a significant negative correlation with yields in the 2001 harvests. Only whole plant tissue K had a significant positive relationship (in 2001) with yield (Table 19). Thus, the higher the yield the greater was the tissue K; but, since there was no relationship between soil K and yields, the soil K was not yield limiting. All other tissue and soil test factors showed negative regression values. A negative correlation indicates that the lower the element concentration in plant tissue the higher was the yield. This negative relationship occurred many times in the ten-year study. If there was adequate nutrition for maximum growth, the negative values for soil elements would occur when the highest yields removed the highest quantity of a nutrient. This could continue to happen until the soil supply was low enough to cause a yield limitation. Soil P, soil K, and soil Ca had negative correlations with yields (Table 20). At Site B in Blacksburg, Virginia, a yield of 27 Mg ha^{-1} occurred with a pH of 4.8 in 2001. Knoxville, Tennessee, often had the highest yields of all locations, yet soil P was 2 ppm (considered very low for agronomic crop productive potential), and soil K was less than 30 ppm (considered low agronomic crop productive potential). Soil samples taken to a depth of 90 cm did not show occluded nutrients at any depth that could be tapped and that would mask the expected response as indicated by the shallow soil sample elements available for plant growth at all locations. When averaged over all eight locations, nutrient removal (N, P, K, and Ca) exceeded input each year for ten years and still yields were high and stands were adequate to excellent (Table 21).

Fertilizer recommendations will be based in part on good stewardship of the soil and the environment and in part on economics. The soil should be tested using a 0- to 10-cm sample. Apply 50 kg P ha^{-1} when the soil test is low and 100 kg K ha^{-1} when the soil K test is low-plus to medium (considering the typical basis for agronomic crop recommendations). No limestone would be needed if the soil pH is above 5. Limestone and P move down in the soil very slowly, thus a shallow soil sample is needed to properly assess these needs.

Nitrogen should be used at a somewhat limiting rate as far as short-term yield goals are concerned. Rates that give maximum yields in the first few years will thin stands and may result in low future yields with possible weed completion in the thin stand. Many soils may not need any N for two or three years after planting when using a one-cut (November) harvest management, since much of the N located in the herbage is translocated to the crown/root system at the end of the growing season. Thus, no more than 50 kg N ha^{-1} may be needed for the one-cut management. For a two-cut management 50 kg N ha^{-1} in the spring and 50 after the first harvest should be adequate.

Table 18. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations averaged over 1997 to 2001

Location	Concentrations, June				Concentrations, Nov.				Yield (unit)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Annual
	---------------------------------- %				----------------------------------				------ Mg ha^{-1} ------		
					One-cut management						
Blacksburg, VA											
Site A	--	--	--	--	0.61	0.10	0.67	0.36	--	12.3	12.3
Site B	--	--	--	--	0.69	0.08	0.94	0.40	--	18.0	18.0
Orange, VA	--	--	--	--	0.56	0.08	0.72	0.40	--	17.6	17.6
Knoxville, TN	--	--	--	--	0.33	0.07	0.44	0.28	--	21.0	21.0
Jackson, TN	--	--	--	--	0.38	0.10	0.61	0.25	--	11.1	11.1
Princeton, KY	--				0.36	0.10	0.40	0.30	--	14.6	14.6
Morgantown,WV	--	–	–	--	0.28	0.08	0.50	0.21	--	14.0	14.0
Raleigh, NC	--	--	--	--	0.44	0.14	0.67	0.31	--	13.6	13.6
Average[1]					0.45	0.09	0.62	0.31	--	15.0	15.0
					Two-cut management						
Blacksburg, VA											
Site A	1.35	0.19	1.33	0.33	0.82	0.10	0.66	0.42	6.5	8.5	15.0
Site B	1.46	0.18	1.69	0.31	0.85	0.10	0.86	0.42	9.0	12.0	21.0
Orange, VA	1.28	0.19	1.56	0.38	0.71	0.09	0.67	0.44	6.5	9.0	15.5
Knoxville, TN	0.89	0.11	0.73	0.28	0.50	0.09	0.41	0.38	10.5	6.3	16.8
Jackson, TN	0.78	0.15	1.23	0.26	0.54	0.11	0.58	0.29	7.8	4.8	12.6
Princeton, KY	0.88	0.21	1.14	0.32	0.45	0.10	0.22	0.34	6.6	8.7	15.3
Morgantown,WV	0.79	0.19	1.24	0.25	0.53	0.12	0.51	0.33	7.85	7.6	15.5
Raleigh, NC	0.84	0.20	1.14	0.31	0.55	0.19	0.65	0.41	9.2	5.3	14.5
Average[1]	1.03	0.18	1.27	0.30	0.62	0.11	0.57	0.38	7.9	7.6	15.5
LSD 0.05*	0.09	0.02	0.12	0.03	0.07	0.01	0.11	0.03	1.4	1.9	

*LSD values are for comparison of means for locations across managements.
[1]Averages within columns followed by similar letters do not differ at the 0.05 level.

Table 19. Probabilities of "b" values from multiple regression to predict switchgrass yields from element concentrations of whole plants sampled at the time of harvest [Multiple regression removed variances due to eight locations and two cutting managements. (n=64)]

Element in tissue	Year				
	1997	**1998**	**1999**	**2000**	**2001**
	-- Probability of a significant estimate --				
N	-0.76*	-0.48	0.81	-0.50	0.18
P	-0.90	-0.45	-0.44	-0.02	-0.01
K	0.71	0.20	0.64	0.18	0.06

N, P, K Fertility Study at Blackstone, Virginia; 1997 and 1998 Seasons

Applications of N, P, and K were made in the spring of 1997 and 1998 to an established stand of Cave-in-Rock switchgrass. Harvests were made in mid-June when in early heading stage and again in late August.

This study was repeated in 1998 with K fertilization rates doubled, since the rates used in 1997 showed little soil test response by November in this sandy soil. Yields were not increased by applied P or K in 1997 or 1998 (Table 22); but N increased yields in 1998 by 57%, which was greater than the 19% response observed in 1997. Increasing soil P from 10 ppm (low-plus productivity) to 26 ppm (high productivity) did not increase yields (Table 23). Likewise, increasing soil K from 50 ppm to 71 ppm did not increase yields. Leaf-tissue P of 0.24% and leaf-tissue K of 1.40% were enough to maximize yields (Tables 22 and 23). The very high K rate applied (255 kg ha^{-1}) did not result in much of an increase in soil K in this soil (sampled 0 to 10 cm) (Table 24). Soil samples taken to a 90-cm depth did not reveal accumulations of P or K at depths below that considered for routine soil testing (0 to10 cm) (data not shown).

Table 20. Probabilities of "b"' values (regression slope) from multiple regression to predict switchgrass yields from element concentrations of whole plants sampled at the time of the 2001 harvest and from soil test values taken in the fall (2001) after ten years of growth [Multiple regression removed variances due to eight locations. Cutting management included one and two harvests per year. (n=32)]

Element/ pH or OM	Cuts		Observed values		
	Once	**Twice**	**Min**	**Max**	**Av**
	---- Probability ----		----- Percentage -----		
Tissue N	-0.22*	-0.00	0.27	0.94	0.53
Tissue P	-0.31	-0.21	0.04	0.13	0.08
Tissue K	0.16	0.01	0.11	0.96	0.54
Tissue Ca	-0.82	-0.17	0.17	0.50	0.32
Soil pH	-0.50	-0.08	4.7	6.4	5.4
	---- Probability ----		----- ppm -----		
Soil P	-0.03	-0.74	1.0	30.0	10.6
Soil K	-0.50	-0.44	13.0	86.0	36.9
Soil Ca	-0.26	-0.78	196.0	925.0	490.0
Soil OM	0.16	0.84	1.5	4.2	2.3

*A negative value indicates a yield decrease as nutrient concentration increased.

Table 21. Nutrient elements removed in Alamo switchgrass biomass cut once or twice each year

(Yields and nutrient removal are averaged over eight locations. Total nutrients applied are averages over eight locations for five years. Changes in soil nutrients are differences between soil test values of samples taken in the fall of 1996 and five years later in the fall of 2001.)

Element	Cuts	Years of harvesting					Total	Average	Total applied	Change in soil
		1997	1998	1999	2000	2001				
		------------Nutrient elements removed each year ------------								(ppm)
		---------------------------- (kg ha^{-1}) -----------------------------								
N	One	48	77	81	60	74	340	68	200	--
	Two	97	132	138	144	183	694	139	400	--
	Diff	49*	55*	57*	84*	109*	354	71	--	--
P	One	12	14	14	14	15	69	14	52	5
	Two	14	25	25	26	29	119	24	52	5
	Diff	2	9*	9*	12*	14*	46	9	--	K
K	One	51	112	89	107	108	467	93	125	-8
	Two	65	161	189	167	164	746	149	125	-4
	Diff	14	49*	100*	60*	56*	279	56	--	.Ca
Ca	One	48	48	41	47	46	230	46	0	-96
	Two	45	51	54	62	80	292	58	0	-125
	Diff	-3	3	13*	15*	34*	62	12	--	--
		----------------------------- Yield (Mg ha^{-1}) -----------------------------								
	One	14	17	14	15	16	77	15	--	--
	Two	12	18	15	17	15	77	15	--	--
	Diff	-2	1	1	2	-1	1	0	--	

*Indicates no difference between one and two cuts.

Table 22. Cave-in-Rock switchgrass yields and associated nutrient values in June 1997 as influenced by K and N (Blackstone, VA) [Soil test data are from samples taken in November 1997. No K or N yield response was found in the August 25, 1997 (second) harvest (average 2.3 Mg ha^{-1}).]

K rate	Nitrogen rate (kg ha^{-1})		
	0	55	Average
kg ha^{-1}	------------- Mg ha^{-1} -------------		
0	8.7	9.7	9.2a*
44	8.6	10.6	9.6a
88	8.5	9.9	9.2a
132	9.1	10.3	9.8a
Average	8.7a	10.4a	9.4
	------ Leaf tissue K (%) ------		
0	1.31	1.40	1.36a
44	1.36	1.43	1.40a
88	1.38	1.49	1.44a
132	1.41	1.41	1.41a
Average	1.36a	1.43a	1.40
	---------- Soil K (ppm) ----------		
0	53	48	50a
44	60	47	54a
88	64	60	62a
132	77	65	71a
Average	63a	55a	59
	-------- Leaf tissue N (%) --------		
0	1.39	1.79	1.59a
44	1.50	1.89	1.70a
88	1.58	1.76	1.67a
132	1.48	1.79	1.64a
Average	1.49b	1.81a	1.65

Table 23. Cave-in-Rock switchgrass yields and associated nutrient values for 1997 as influenced by P and N (Blackstone, VA) [No P or N yield response was found in the August 25, 1997 (second) harvest (average 2.3 Mg ha^{-1}).]

P rate	Nitrogen (kg ha^{-1})		
	0	55	Average
kg ha^{-1}	---------- Mg ha^{-1} ----------		
increased	8.5	9.7	9.2a
48	9.2	10.6	9.6a
Average	8.7	10.4	9.4
	---------- Soil P (ppm) ----------		
0	12	7	10a
48	32	26	26b
Average	22	16	18
	------- Leaf tissue P (%) -------		
0	0.23	0.23	0.23a
48	0.27	0.25	0.26a
Average	0.25	0.24	0.24
	---- Leaf tissue Ca (ppm) ----		
0	286	268	288a
48	328	340	334a
Average	307	302	312
	------- Leaf tissue N (%) -------		
0	1.58	1.76	1.67a
48	1.71	1.79	1.75a
Average	1.64	1.78	1.71

Note: LSD 0.05 = 1.2 Mg ha^{-1} for yields.

Table 24. Total yields and soil test data from switchgrass receiving N, P, and K fertilization in the spring of 1998 (Blackstone, VA)

(Nitrogen rates were 0 or 110 kg/ha.)

Fertilizer applied		Soil P		Soil K		Soil Ca		Soil pH		Yields	
P	**K**	**- N**	**+ N**	**- N**	**+ N**	**- N**	**+ N**	**- N**	**+ N**	**- N**	**+ N**
--- kg/ha ----		----------------------- ppm		---------------------------						--- Mg/ha ----	
0	0	5	8	48	44	270	162	5.6	5.4	9.4a*	13.4a
0	85	6	7	81	59	270	186	5.6	5.4	8.6a	14.1a
0	170	5	6	87	74	282	222	5.8	5.6	9.7a	14.8a
0	255	7	6	86	90	252	210	5.7	5.6	8.5a	14.1a
	Av	6A	7A	75A	67B	268A	195B	5.7A	5.5B	9.0B	14.1A
48	170	--	24	--	81	--	277	--	5.6	--	12.1a

*Means followed by similar lower case letters in columns or upper case letters in rows do not differ at the 0.05 level.

[1]Fertilizer P, K, and N were applied in the spring of 1997 also. The first harvest was taken in mid-June and the second harvest was taken in late August of 1997 and 1998.

N, P, K Study at Blacksburg, Virginia

Blackwell switchgrass was planted in June 1993. Growth in 1994, 1995 and 1996, was burned the following spring. Fertilizer P and K were applied in the spring of 1997. No N was applied. Leaf and whole-plant tissue were taken when yields were measured in late June. Cattle grazed the regrowth in July and August, therefore no late season yields were measured. No P or K fertility treatments increased yields, thus 7 ppm soil P, 0.30% leaf P, 87 ppm soil K and 1.25% leaf K were sufficient for production of high yields (Table 25). Soil P ranged from 9 to 48 ppm, leaf P ranged from 0.29% to 0.38%, soil K ranged from 74 ppm to 204 ppm, and leaf K ranged from 0.84% to 2.03% without significant yield increases or correlation with yield.

Soil pH and Yield

Cave-in-Rock switchgrass was planted in 1994 at Orange, Virginia, into a field where soil pH differentials had been maintained for many years. Establishment was very successful with few weeds being able to develop at the lower pH levels, while at the higher pH levels weed competition was great enough that in the spring of 1995 atrazine was applied for weed control. Maximum yields were achieved from the 4.8 pH soil with no increase at higher levels (Table 26).

Table 25. Blackwell switchgrass yields on June 27, 1997, as influenced by three P levels at three K levels (Blacksburg, VA) No N was applied. Soil samples were taken in November 1997.)

P rate	K rate ($kg\ ha^{-1}$)			
	0	67	134	Av
$kg\ ha^{-1}$		*Mg ha^{-1}*		
0	5.6	5.7	5.1	5.5
27	5.5	6.1	6.8	6.1
52	5.8	5.6	5.9	5.8
Av	5.7	5.8	5.9	
		Soil P (ppm)		
0	9	6	6	7
27	28	24	30	27
52	40	39	48	42
Av	26	23	27	
		Soil K (ppm)		
0	102	158	167	142
27	74	156	204	145
52	85	131	136	117
Av	87	148	169	
		Leaf P (%)		
0	0.294	0.290	0.305	0.296
27	0.329	0.376	0.351	0.352
52	0.318	0.335	0.338	0.330
Av	0.312	0.333	0.331	0.326
		Leaf K (%)		
0	1.27	1.36	1.49	1.37
27	1.20	1.47	1.54	1.40
52	1.29	1.32	1.50	1.37
Av	1.25	1.39	1.51	1.38

Note: LSD 0.05 for yield = 1.2 Mg ha^{-1} (n = 4)
for soil p = 11 ppm (n = 4)
for soil K - 36 ppm (n = 4)
for leaf p = 0.061% (n = 4)
for leaf K = 0.26% (n = 4)

TASK FOUR (SWITCHGRASS ESTABLISHMENT/ YIELD STUDY AT DUCK RIVER)

1996 Planting in the Silver Creek Area

About 10 acres were planted in 1996 in the Silver Creek area of the Duck River Project. When visited in June 1997, weed control and fertilizer were needed on some of the acreage. Our project funded ($339) weed control for the entire area and fertilizer ($335) for about one-third of the area. The intended rate was 82:48:176 kg ha^{-1} of N:P:K. Soil and plant tissue samples were taken for analyses. Plant height and yields were determined. Yields on June 17, 1997, ranged from 370 to 2300 kg ha^{-1} from different areas of the field. Soil test data were taken from the harvested area. No relationship was evident between yields and soil pH, P, or K, which were at medium levels (Table 27). A similar lack of relationship between yields and soil test data has been found in other studies with medium P and K levels. Since the data from the Silver Creek area were taken in early season, soil moisture would not be expected to have caused such widely different yields. The most likely limitation was from low soil N.

Yields and associated soil samples were taken on October 30, 1997, from selected areas in the Silver Creek field. Alamo and Kanlow were sampled from the "bottom" portion of the field that received no fertilizer. Kanlow and CiR were sampled from the "upper" portion of the field (one sample each from a fertilized and an unfertilized area). Again, as in the June sample, no relationship was seen between yield and any tested soil nutrient level (Table 28). It seems that a low P (5 ppm) level and a medium K (44 ppm) level were adequate and that yields were influenced mainly by other factors (such as soil water and N). Fertilization of the upper portion of the field more than doubled the yields of Kanlow and CIR in 1997. The N must have caused the growth response. The entire field had an unusual lack of seed head development. In 1998, a farmer harvested the entire area for hay. Yields were estimated based on 1600 kg per large bale. The yield was 16.5 Mg ha^{-1}, which included the areas between switchgrass strips that were left in tall fescue with low contributing yields.

Table 26. Cave-in-Rock switchgrass yield on September 7, 1995, after seeding (June 1994) into soil that had been maintained at several pH levels for many years prior to planting

Year of soil test		Yield
1989	1995	September 1995
---------- pH ----------		------- Mg ha^{-1} -------
4.6	4.8	5.6*
5.2	5.2	5.8
5.7	5.6	5.8
6.3	6.0	5.2

*No significant differences among yields.

Table 27. Alamo switchgrass growth and associated soil test data for three areas selected with different plant heights

(Data were taken June 17, 1997, from a planting made in 1996 at the Silver Creek area of the Duck River Project.)

Sample area	Plant growth		Soil tests[1]				
	Height	Yield	pH	P	K	Ca	Mg
	cm	Mg ha^{-1}		--------------------- ppm	----------------------		
A	25	0.4	5.2	10(m-)	45((m-	504(m)	75(h-)
B	46	1.0	5.5	8(m-)	45(m-)	600(m)	65(m+)
C	71	2.3	5.4	8(m-)	61(m)	540(m)	60(m)

[1] Letters m and h indicate medium- and high-productive potentials for commonly grown agronomic crops (Virginia Tech soil lab data and calibrations).

Switchgrass in the Silver Creek area had excellent stands, and weeds were adequately controlled by the combination of 2,4-D, Banvel, and Simizine herbicides. Soil P and K were adequate and not limiting growth. Nitrogen enhanced yields. Even where growth was greatest, the plant yields and height in 1997 were much less than expected. The number of tillers per unit area was very high, and very few seed heads had developed, which leads to the suspicion that there was "over-crowding." Other studies and experience show that low soil N can lead to high tiller population, few seed heads, and low yields. One hypothesis is that the high organic matter (root mass and debris accumulated from past growth) has tied up plant-available N. Burning or removal of biomass along with somewhat high N application would be recommended as experimental treatments in such a setting. Low temperature with high rainfall until mid-June was followed by very dry conditions until October 1997. The unusual weather events might also have contributed to the unusual type of growth in 1997.

1997 Plantings

Four areas were selected to be used as demonstration plantings. An insecticide was applied either with the pre-plant herbicide or mixed with the seed at planting. All establishment procedures and equipment used were common to conventional farming operations in the area. Soil pH and

Table 28. Switchgrass growth and associated soil test data from several portions of the Silver Creek area of the Duck River Project

[Data were taken October 30, 1997, from fertilized and unfertilized areas. Plantings were made in 1996. Yield in 1998 from the entire area was 16.5 Mg ha^{-1} (harvested in July and September).]

Variety[1]	Fertilizer applied	Plant growth		Soil	Soil concentration[2]			
		Height	Yield	pH	P	K	Ca	Mg
		cm	Mg ha^{-1}		------------------------ ppm	------------------------		
Alamo (B)	No	102	7.4	5.8	5(L)	45(m-)	540(m)	66(m+)
Kanlow (B)	No	112	7.6	5.7	5(L)	44(m-)	420(m-)	56(m)
Kanlow (U)	No	66	4.2	5.3	15(m)	58(m)	348(L+)	56(m)
	Yes	109	8.2	5.4	16(m)	83(m+)	408(m-)	57(m)
CiR (U)	No	51	2.0	5.6	9(m-)	64(m)	444(m-)	57(m)
	Yes	79	6.6	5.5	15(m)	98(h-)	384(m-)	49(m)

[1] (B) indicates samples were taken from the bottom portion, and (U), from the upper portion of the field.
[2] Letters L, m, and h indicate low, medium, and high productive potentials for commonly grown agronomic crops (Virginia Tech soil lab data and calibrations).

nutrients were adequate for the establishment year (Table 29). Each area was evaluated, and site-specific pre-plant recommendations were made using advice and experience of the Duck River Agency personnel. Alamo switchgrass was planted on July 18 at about 13 kg ha^{-1}. Stratified seed had about 38% germination. Seed was light and had about 880,000 per kg. Plant development and establishment success was determined in November 1997. The spring (until late June) was very cold, with more than average rainfall. This prevented timely pre-plant preparation such as burning and herbicide application. After late June, rainfall was low, which resulted in some very dry planting conditions. Seed placement and germination were not ideal. Some seeds did not germinate until rains occurred in early September. Even small seedlings when observed on October 30 had a few daughter tillers, which indicated that the plant was mature enough to survive the winter. Yields in November 1998, the year after planting, were remarkably high.

Table 29. Soil test data for four locations at the Duck River Project where Alamo switchgrass was planted in July 1997

(Soil samples were taken June 17, 1997. Yield samples were taken November 5, 1998.)

Location	Soil concentration[1]					Yields in 1998
	pH	P	K	Ca	Mg	
	---------------------------- ppm				----------------------------	$Mg\ ha^{-1}$
Lofton Road	6.4	27(h)[1]	66(m)	2740(vh)	184(vh)	15.0
Negro Creek	5.5	34(h+)	85(m+)	816(h+)	77(h-)	5.7
Howard Bridge	5.6	13(m)	58(m)	1404(vh)	120(vh)	7.7
Tom Hitch	5.8	68(vh)	157(vh)	1208(vh)	140(vh)	10.5

[1]Letters in parentheses indicate levels of potential plant growth: m = medium; h = high; vh = very high.

Lofton Road Location. This area required some hand cleanup of brush. Most of the area was an old dump/work site during dam construction. Soil nutrients were high in terms of potential field crop production. The area was sprayed with Roundup and Lorsban prior to planting. The stand was good over all but excellent on 70% of the area. On October 30, growth was 10 to 40 inches tall. In short-thin areas, some broadleaf weeds were evident. Biomass yield was 15.0 $Mg\ ha^{-1}$ in November 1998.

Negro Creek Location. This area required extensive brush cleanup. Thus soil preparation was a clean seedbed but was quite firm from the machine operations. An excellent stand resulted, but plant height was less than expected. Some foxtail was present. This area had granular Counter (a systemic insecticide) placed with the seed at planting. Soil pH was 5.5 with P and K very adequate for excellent plant growth. Nitrogen was needed in 1998 but not applied, thus yields are lower than expected. Biomass yield was 5.7 $Mg\ ha^{-1}$ in November 1998.

Howard Bridge Location. This area was bushhogged and Gramoxone was applied, and then Roundup (plus Lorsban) was applied before planting. The switchgrass stand was excellent. Nitrogen would have been advisable in 1998. Biomass yield was 7.7 $Mg\ ha^{-1}$ in November 1998.

Tom Hitch Location. Soil fertility was excellent. This area had severe pre-plant weed problems and accumulated trash from previous growth on the surface. Ideally some smother crop should have been grown in the previous year as a pre-plant conditioning. The area was burned and Roundup was applied twice before planting. Weed control (especially thistle and Johnson grass) was poor, so herbicides were applied in early spring 1998 to control broadleaf and grassy weeds. The plant population over the entire area was low but, with weeds controlled, there were enough plants to develop a surprisingly good stand. Biomass yield was 10.5 Mg ha^{-1} in November 1998.

Conclusions

Four fields planted to Alamo switchgrass July 18, 1997, had excellent production and stands during 1998. This study demonstrates that any farmer in this area using conventional equipment can establish switchgrass economically if recommended practices are followed.

ADDITIONAL TASKS

Seed Production

Spaced clusters of Cave-in-Rock switchgrass were established and treated with a spray solution in a late boot stage and again in an early head stage for three years. Seed was collected and cleaned in mid-October of each year. Application of "Banner" (a triazol fungicide Propiconazol at 1.4 kg a.i ha^{-1}), along with a commercial plant-growth stimulant (1.8 kg ha^{-1} of product) increased seed yields by 66% in 1997, 45% in 1998, and 33% in 1999 (Table 30). Weight per seed and plant biomass were not influenced by the treatment. "Banner" and "Tilt" (from Novartis) both contain the same active ingredient (Propiconazol). Humic acid and seaweed extract make up the growth-stimulant "3-D," a product of the Plantwise Biostimulant Company (2.5% humic acid and Fe).

Table 30. Seed yields per cluster of tillers in three years as influenced by foliar application of a fungicide and a growth stimulant

Treated	Yield		
	1997	1998	1999
	-------- g per cluster ---------		
No	32b	159b	168b
Yes	53a	230a	224a

Nutrient Concentrations in Different Plant Parts (Information Useful in Standardizing Tissue Testing for Deficiencies)

Alamo switchgrass tillers (in a mid-boot growth stage) were collected at the Princeton, Kentucky; Knoxville, Tennessee; and Blacksburg, Virginia (Site B); locations in 1999 and at the Princeton, Kentucky; Knoxville, Tennessee; Jackson, Tennessee; Orange, Virginia; and Blacksburg, Virginia (Sites A and B); locations in 2000. Tillers were separated into leaf and internodes (stem) (Fig. 7). Each leaf, with a fully exposed collar, was separated into blade and sheath components. Sheaths of leaves with exposed collars were composited. The first leaf was always attached to the uppermost palpable node. Within the sheath of this leaf were the growing point and newly developing, partially exposed leaf blades and sheaths. Since it was very difficult to separate the parts within this bundle of blades/sheaths, one of the component parts was collectively called the "upper bundle of sheaths" and included the sheath from the leaf with the first exposed collar, the growing point, possibly some blades that had not begun to expand, and sheaths of the whorl leaves. There were generally two new leaf blades emerging from the uppermost bundle of leaf sheaths and these are referred to as "whorl" leaf blades. The whorl leaf blades and the uppermost bundle of sheaths were the samples that had the least opportunity to accumulate Ca through the transpiration process and were the closest plant part to the physiological site where Ca would be critically needed for new growth processes.

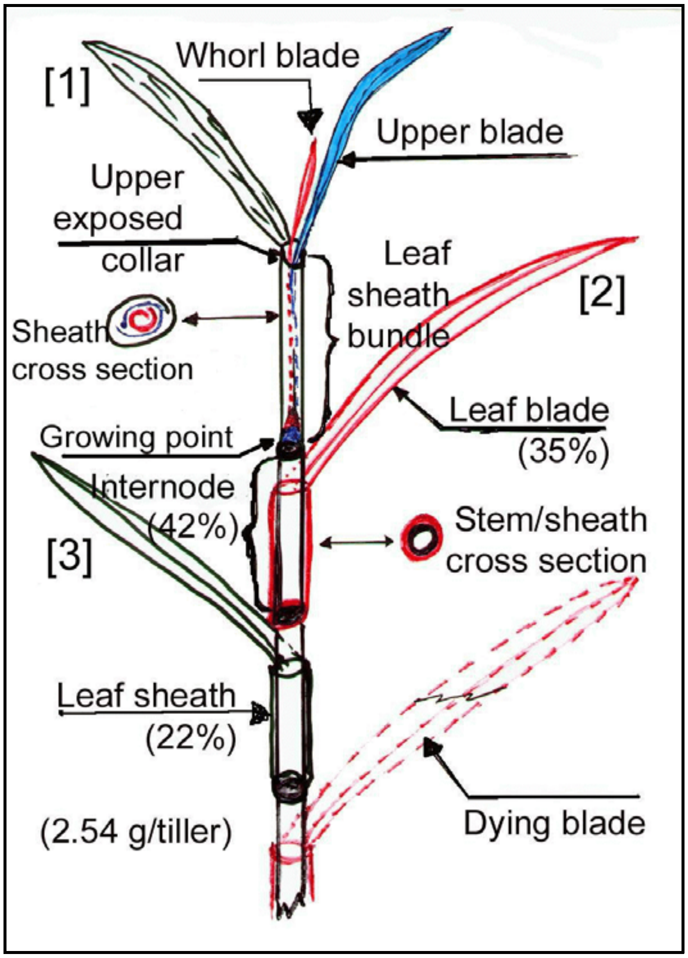

Fig. 7. Sketch of a tiller in boot stage of development showing various parts. Numbers in brackets indicate leaves with exposed collars. Numbers in parentheses are percentages of total mass as blade, sheath, and stem (internode) (average of 1999 and 2000 data).

The first leaf was attached to top-most palpable node. Thus internode (stem portion) number one was immediately below the growing point (between the upper-most two palpable nodes). Only the upper three fully expanded leaves and upper three internodes were considered, even though some tillers had four or five leaves and internodes.

Tissue was weighed to determine weight proportions and total tiller mass. Tissue was ground and tested for N (only 2000), P, K, and Ca concentrations. Elemental concentrations of whole leaf, whole stem, and whole tiller were calculated using weighted values of mass and concentration. In 2000, soil samples (0 to 10 cm) were taken from each plot in which tillers were sampled. Soil testing gave concentrations of soil P, K, and Ca. Tissue for each tiller component was composited across reps for each location before doing chemical analyses to give six observations per location. Soil tests and yields from each location were averaged over reps for each location. Correlations were calculated for both soil test and yields vs. element concentrations for each tiller component.

Tiller weights were less in 1999 than 2000, but proportions of mass contributed by components parts were very similar. The average weight of a tiller was 3.15 g. Leaves accounted for 60.1% (38.3% blade and 21.7% sheath) of the tiller mass, and the internodes (stem) were 39.9% (Table 31). The whorl-leaf blades (8.5%) and upper bundle of sheaths (11.9%) were a relatively small part of the total tiller weight. Nutrient concentrations of each component allowed us to composite different plant parts to determine their percentage composition. Calculated concentration of N, P, K, and Ca for the whole tiller was very similar to the concentrations found in whole plant tissue taken at the same time as a subsample at the June harvest.

Table 31. Partitioning (by percentage and weight) of Alamo switchgrass tillers and nutrient element concentrations of each portion

[Data are averages of 1999 (four locations) and 2000 (six locations) tests. (Sampled at late boot stage in late June)]

Tiller portion	Tiller partition		Nutrient concentration			
	by %	by weight	N	P	K	Ca
		mg tiller^{-1}	---	%	---	
Leaf blade						
Whorl	8.5	267	1.66	0.23	1.65	0.18
First	11.5	362	1.86	0.23	1.36	0.37
Second	10.3	326	1.76	0.23	1.27	0.54
Third	8.1	255	1.60	0.19	1.16	0.69
All blades	38.3	1209	1.73	0.22	1.36	0.44
Leaf sheath						
Upper bundle	11.2	355	1.02	0.22	2.70	0.19
All others	10.8	340	0.52	0.14	1.79	0.32
All sheaths	21.9	685	0.74	0.18	2.24	0.26
Leaf (blade + sheath	60.2	1894	1.34	0.21	1.68	0.38
Stem internode						
First	10.4	327	0.66	0.16	2.11	0.11
Second	14.9	469	0.39	0.11	1.19	0.07
Third	14.7	464	0.31	0.09	0.82	0.06
All stem	39.9	1260	0.43	0.12	1.29	0.07
Whole tiller	100.0	3154	0.98	0.17	1.52	0.25

Note: Calculated values for whole tillers agree with concentrations obtained from whole-plant analyses taken at first harvest.

A curious difference between years involved K concentrations. In 1999, leaf blade K was higher than in 2000, which might indicate that available soil K was being depleted. However, for internodes the K concentration was lower in 1999 than 2000. So, when whole tiller concentration was calculated, the K for 1999 and 2000 were very much the same. Stage of maturity at sampling was similar each year. The 1999 rainfall prior to the June sampling was much less than in 2000 (tiller weight was smaller in 1999 than 2000). Perhaps the difference between years in growth rate and soil moisture influenced K uptake and concentration. Nevertheless the differences may be only academic, since these K concentrations are not near limiting values.

N: Nitrogen declined with leaf blade > leaf sheath > internodes. The older the leaf blade or internode the lower was the N concentration. Sampling the uppermost leaf blade with an exposed collar would be recommended for testing tiller N concentration. The newly emerging whorl-leaf blades had slightly lower N than the upper-most fully exposed leaf blade. Sampling this portion might have a high variability, since some leaf blades can be very long before the collar emerges.

P: Phosphorus also declined with leaf blade > leaf sheath > internodes. All leaf blades had similar P concentrations. Sampling the upper-most fully exposed leaf blade would be suitable for testing tiller P concentration as well as N.

K: Potassium increased with leaf blade < internodes < leaf sheath. Potassium decreased with the age of the leaf and internode. The whorl leaf blades and the upper bundle of leaf sheaths had highest K concentration. Due to the difficulty for defining and obtaining a sample above the upper-most leaf collar, the upper-most leaf blade would still be recommended for testing tiller K concentration.

Ca: Calcium is a relatively immobile element, and the concentration is largely dependent on the transpiration rate and duration. Thus, Ca was highest for leaf blade > leaf sheath > internodes. Furthermore, the older the leaf the higher the Ca concentration (greatest transpiration rate and duration). Since Ca is most likely to be limiting in regions of the tiller where cell division and expansion (above the growing point) are occurring, that is the tissue that should be sampled for diagnostic tests. The whorl leaf blades and the upper bundle of leaf sheaths had the lowest Ca and thus would be the most likely to be related to growth response. Therefore, sampling for Ca diagnosis would best be done using tissue sampled from above the upper-most fully exposed leaf collar.

Correlations of Tissue and Soil Tests

Correlation coefficients ("r" values) were generally not significant at a level below 10%. Leaf-blade P and Ca were not correlated with either soil P or yields. The failure of a correlation when considering yields may mean that soil P and Ca are high enough that they are on a plateau and not in a yield-limiting range. Correlations between yields and soil P were rather high (p = 18%) but with a negative "r" value. Leaf-blade K however was correlated with soil K, which suggests that soil K might be at a level that will influence uptake. As with P and Ca, the available soil K, may be above the limiting level and there is no correlation with yields. In fact most correlations of K concentration and yields were negative, which means that the lower the tissue K the higher will be the yields. This negative relationship has been observed for other comparisons in other years for this study.

When sampling plant tissue that will be tested for nutrient concentration and used to predict yield or relate to plant growth response, one should consider the specific plant part that will give the most sensitive value. The plant part selected will depend on factors such as mobility of the element and the site of maximum physiological activity. A wise compromise for tissue sampling that would give an adequate sample for these elements would be the blade of the upper-most leaf with an exposed collar. Such a sample is easy to describe and select, and it is possibly best related to soil test and yield differences.

Conclusions. A soil test of low-plus for P (6 ppm) and medium-minus for K (44 ppm) was apparently adequate for maximum yields. This corresponded to leaf tissue concentrations of 0.23% P and 1.4% K. Leaf-tissue N of 1.5% showed a slight N deficiency (as determined by yield) with 1.8% being the highest observed.

Fig. 8. Switchgrass growth in soilless medium nine weeks after placing vegetative propagules into water (no nutrients added).

Growth in a Soilless Medium

Vegetative propagules of switchgrass were collected from a vigorous field stand in January 2001 and placed in a large pan of water. Propagules included a portion of crown/rhizome tissue with associated buds but were washed free of all soil. After nine weeks, some tillers were 80 cm tall. Leaf blades and tillers were sampled and tested for N, P, K, and Ca. Tillers showed no visible signs of any nutrient deficiency and had a typical light green-color (Fig. 8).

Leaf blade and whole-plant element concentrations were somewhat lower for the switchgrass grown without soil/nutrients in the greenhouse when compared to the average of six field locations (Table 32). There were lower values for each nutrient at some locations, however, indicating that, even without soil or added nutrients, switchgrass can maintain normal levels and rather substantial growth. Enough nutrients were apparently contained in the propagule (roots and crown) and translocated to provide for good growth. These greenhouse data are higher than expected for plants grown from a small propagule at what might be considered zero nutrient application. This observation suggests that attempts to relate plant nutrient concentration with yield in a prediction equation may be futile.

Late-season N Accumulation in Belowground Plant Parts (1997 Season)

Nitrogen was applied at 0, 55, and 110 kg ha^{-1} in the spring of 1997 to an established stand of Cave-in-Rock switchgrass at Orange, Virginia. No N was applied after the first harvest of the two-cut management. Two harvest managements included two cuts per season (late June and early
November) and one cut per season (late November). Whole-plant tissue and soil (0 to 10 cm) were sampled on June 24, October 1, and November 1; and N, P, and K concentrations were determined in whole-plant tissue and soil. Leaf-blade tissue was collected only on June 24 and

Table 32. Elemental concentrations in switchgrass leaf blades (upper three blades) and whole tillers sampled from the field (average of six locations, collected in late June 2000) and from the greenhouse (grown from propagueles held in a water-filled tray)

(Field grown tillers were 150 cm tall, averaged 3.8 g/tiller, and were in the boot stage. Propaguels were collected in November after all top growth had died. Greenhouse tillers were 85 cm tall and averaged 1.4 g/tiller when sampled.)

Portion of plant	N		P		K		Ca	
	Field	GH	Field	GH	Field	GH	Field	GH
	---------- % ----------							
Leaf blade	1.81	1.68	0.21	0.19	1.18	0.96	0.46	0.27
Whole tiller (average)	1.11	1.06	0.18	0.16	1.33	1.16	0.32	0.22
Lowest value[1]	0.67	--	0.12	--	0.85	--	0.18	--
Highest value[2]	1.51	--	0.21	--	1.80	--	0.40	--

[1]The lowest value from the six locations in the average of tillers.
[2]The highest value from the six locations in the average of tillers.

subsequently tested for N, P, K, and Ca. Representative portions of sod were removed to about a 15-cm depth on October 1 and November 1, 1997. After the soil was washed free, some of the large roots that were extending below the sod were clipped off and will be referred to as a root sample. The old stems were trimmed very close to their bases. The intact crowns (along with associated roots and rhizomes) were sub sampled and are referred to as crown/rhizome tissue. Nitrogen was determine in both the root and crown/rhizome samples.

Yields in 1997 for the one-cut management were not increased by N fertilization; but for the two-cut management, yields were increased by 24% (Table 33). This same response has been seen with Cave-in-Rock in our other studies. Percentages of N, P, and K in plant tissue and P and K in the soil decreased during the season under both managements (Tables 34 and 35). Removal of N, P, and K by harvested biomass was greater for the two-cut management than the one-cut management. About 6 and 26 kg of P ha^{-1} were removed with the one- and two-cut managements, respectively. About 41 and 217 kg of K ha^{-1} were removed with the one- and two-cut managements, respectively. About 47 and 149 kg of N ha^{-1} were removed with the one- and two-cut managements, respectively, at the higher rate of applied N.

Plants collected for assay on October 1 had a normal green color with very few dead leaves. At this time, whole-plant tissue ranged from 0.48 to 0.78% N depending on N rate and management. Plants on November 1 had no green leaves. Whole-plant N concentrations (high N application treatments) decreased by 0.24% for the one-cut management and 0.38% for the two-cut management during October. If one assumes that no yield increase occurred during October (this assumption is supported by previous data), the two-cut management lost (or translocated) 21 kg N ha^{-1}, and the one-cut management lost 28 kg N ha^{-1} from the aboveground biomass. During this time (October), the crown/rhizome plant fraction gained 0.37% N. Some N might have begun accumulating before the October 1 sampling. Belowground plant fractions in the one-cut management gained more N than did the two-cut management.

Removal of N in the harvested biomass for the one-cut management averaged 46 kg ha^{-1} (0.39% N times 11.9 Mg ha^{-1} yield). This amount of N could readily be supplied by N from the belowground plant parts at the beginning of the year. We do not know how much of the N in the crown/rhizome system is available for early season growth; but, if 0.8% of the 1.81% (present in November) were available, it would require less than 6 Mg ha^{-1} of crown/rhizome to supply the yearly needs. The belowground portion of the plant consisting of crown/rhizome/roots from a dense sod (929 cm^2 sampled to a 20-cm depth showed an equivalent of 26.6 Mg ha^{-1} of dry matter). [After cleaning, drying, and weighing, this sod sample was ashed to be sure that no soil was contributing to the belowground mass.]

Table 33. Nitrogen concentration in whole-plants, leaf blades, crown/rhizome, and roots of switchgrass as influenced by N applied in the spring of 1997 [Harvest managements included one cut (in early November) and two cuts (one in June, when in late boot stage, and one in early November). Differences are between October 1 and November 1.]

Harvest mgt	Date	N applied (kg ha^{-1})		
		0	55	110
		N (% in crown/rhizome)		
Once	Oct. 1	1.32	1.17	1.44
	Nov. 1	1.41	1.40	1.81
	Diff	+0.09	+0.23	+0.37
Twice	Oct. 1	0.70	0.69	0.83
	Nov. 1	0.97	0.89	1.20
	Diff	+0.27	+0.20	+0.37
		N (% in roots)		
Once	Oct. 1	0.80	0.78	0.94
	Nov. 1	0.92	0.92	1.22
	Diff	+0.12	+0.14	+0.28
Twice	Oct. 1	0.57	0.50	0.62
	Nov. 1	0.68	0.66	0.75
	Diff	+0.11	+0.16	+0.13
		N (% in whole-plant)		
Once	June 24	--	--	--
	Oct. 1	0.60	0.48	0.66
	Nov. 1	0.40	0.36	0.42
	Diff	-0.20	-0.12	-0.24
Twice	June 24	0.77	1.10	1.45
	Oct. 1	0.55	0.60	0.78
	Nov. 1	0.34	0.33	0.40
	Diff	-0.21	-0.27	-0.38
		N (% in leaf-blade)		
Twice	June 24	1.55	1.92	2.19
		*Yield (Mg ha^{-1})**		
Once	June 24	--	--	--
	Nov. 1	12.0	11.8	11.9
	Total	12.0	11.8	11.9
Twice	June 24	6.9	8.0	8.6
	Nov. 1	4.7	5.6	5.9
	Total	11.6	13.6	14.4
		N removal		
Once	June 24	--	--	--
	Nov. 1	48	42	50
	Total	48	42	50
Twice	June 24	53	88	125
	Nov. 1	16	18	24
	Total	69	106	149

*Yields are averages of 1997 and 1998 data.

Data from an Iowa publication "Design and placement of a multispecies riparian buffer strip system" indicates 11.8 Mg ha^{-1} of roots (0 to 43-cm depth) for switchgrass, 1.7 Mg ha^{-1} for pasture, and 0.3 Mg ha^{-1} for corn. At the 43 to 76-cm depth, switchgrass had 1.0 Mg ha^{-1} of roots and pasture had 0.3 Mg ha^{-1}. Considering that N is also available from the root portion and that atmospheric contributions of N may be in excess of 20 kg ha^{-1}, there is ample evidence that a switchgrass stand may be nearly self-sustaining in regard to N.

In sum, advantages in regard to N needs for switchgrass when grown as a biofuels crop are: (1) it has C_4 metabolism requiring less N for protein used in photosynthesis; (2) it does not begin growth until the soil is warm enough for mineralization of organic forms of N (there may be several thousand kg ha^{-1} of N in a soil with 2% organic matter); (3) having a full season to grow, the N supply need is low and spread over a long time period; and (4) it can conserve ("recycle") N between roots and shoots, which has clear advantages agronomically and perhaps to feedstock value when harvested only once after tops have senesced.

Table 34. Concentration of P and K in whole-plants of switchgrass as influenced by N applied in the spring of 1997 [Harvest managements included one cut (in early November) and two cuts (one in June, when in late boot stage, and one in November). Differences are between October 1 and November 1.]

Cuts	Date	N applied (kg ha^{-1})		
		0	**55**	**110**
		*P (% in whole-plant)**		
Once	June 24	0.27	0.33	0.29
	Oct. 1	0.09	0.07	0.06
	Nov. 1	0.05	0.06	0.04
	Diff	-0.04	-0.01	-0.02
Twice	June 24	0.27	0.33	0.29
	Oct. 1	0.11	0.11	0.08
	Nov. 1	0.06	0.05	0.04
	Diff	-0.05	-0.06	-0.04
		*K (% in whole-plant)**		
Once	June 24	2.38	2.85	2.53
	Oct. 1	1.52	1.09	0.79
	Nov. 1	0.37	0.45	0.20
	Diff	-1.15	-0.65	-0.59
Twice	June 24	2.33	2.85	2.53
	Oct. 1	0.77	0.68	0.74
	Nov. 1	0.18	0.15	0.18
	Diff	-0.59	-0.53	-0.56
		P (% in leaf blade)		
Twice	June 24	0.29	0.29	0.31
		K (% in leaf blade)		
Twice	June 24	1.32	1.46	1.45
		P Removal (kg ha^{-1})		
Once	June 24	--	--	--
	Nov. 1	6	7	5
	Total	6	7	5
Twice	June 24	19	26	25
	Nov. 1	3	3	3
	Total	22	29	28
		K (Removal kg ha^{-1})		
	Nov. 1	44	53	24
	Total	44	53	24
Twice	June 24	161	228	218
	Nov. 1	8	8	11
	Total	169	236	229

*For one-cut management, N was applied once in the spring; and for the two-cut mgt., N was applied in the spring and after the first harvest.

Soil N, Soil C, and C:N Ratio: Season Variation

The N variables described in the section above were imposed in 1998 also. In 1998 however, each N rate was split so that half was applied in early spring and again after the first harvest of the two-cut management. Soil samples were taken (0- to 10-cm depth) on May 5 (early season),

Table 35. Soil P and K as influenced by N applied to switchgrass in the spring of 1997 and 1998 [Harvest managements included one cut (in November) and two cuts (June, when in late boot stage, and November). Soil sampled on three dates in 1998.]

Cut	Sample date	N applied (kg ha^{-1}) 0	55	110
			Soil P *	
Once	May 5	12	15	11
	June 24	9	6	8
	Nov. 1	5	6	6
	Diff	-7	-9	-11
Twice	May 5	3	7	10
	June 24	6	5	5
	Nov. 1	5	2	4
	Diff	+2	-5	-6
			Soil K	
Once	May 5	133	129	117
	June 24	80	74	60
	Nov. 1	82	76	64
	Diff	-51	-53	-53

June 24 (at first harvest of the two-cut management), and November 1 (at the end of the season). Soil N and soil C were determined at ORNL (Table 36). The C:N ratios were calculated. Soil P and soil K were lower under the two-cut than the one-cut management during the year (Table 36). This reflects the higher removal amounts from the two-cut than the one-cut management, which has been shown in other studies. As with our other data, there was a negative correlation between yield and soil test values. This situation occurs when the fertility status is above threshold values. Soil K was lower where high N rates caused highest yields, which reflects removed quantities. Soil P was nearly at a low value (threshold) for productive potential by the end of the season. Even though soil P is low, we have not found much response to applied fertilizer P in past studies. Soil N did not reflect different rates of N at any collection date. An increase in soil N occurred with the two-cut management during the year (but not with the one-cut management). We need to point out that this was the second year for this study with a slight difference in N management from the first year. An explanation of the N dynamics is difficult, since even without added N there was an increase of 0.10% in soil N between May and November. There may be confounding factors. The higher yields from higher N application would remove more soil N and thus might negate any increase in soil N resulting from applied N. The answer may be associated with soil C and the resulting C:N ratio. There was a season-long increase in soil C from both management practices. The increase in soil C was about the same regardless of N fertilization rates. Thus, there was a large decrease in C:N ratio between June and November for the two-cut management and indicates a higher rate of N mineralization. Implications and practical value are elusive.

Study of C Sequestration (A Preliminary Study)

Root sampling included eight locations, two grass species (SG and TF), two managements (one and two cuts per season), and five profile increments to a depth of 90 cm. Measurements included determining stable isotope ratios for root tissue by combining the mass from all depths. The stable isotope ratio from switchgrass (-12.8 dC_{13} value) and tall fescue (-23.4 dC_{13} value) were very consistent among sites (Table 37). Only at the Jackson, Tennessee, site was the tall fescue value different from the average. At the Jackson, Tennessee site, the area sampled had almost no tall fescue, thus roots collected were largely of unknown species. This indicates that the isotope ratio may be used as an indicator of C source and a measure of C sequestration. Percentage OM from switchgrass ($\%C_4$) = (the dC_{13} for the soil sample being evaluated minus the dC_{13} value for a reference area) divided by (the dC_{13} value for switchgrass roots minus the

dC_{13} for reference area) times 100 where the reference area was a tall fescue area similar to the switchgrass area but with no history of any warm-season species.

Soil from the Princeton, Kentucky, location was tested for stable C ratios at several depths to evaluate the effectiveness of using C isotope ratios to confirm build up of organic matter contributed by switchgrass. Switchgrass contributed 23% of the organic matter in the upper 30 cm of the soil profile (Table 38). That represents 1.29 Mg ha^{-1} of organic matter contributed by turnover of switchgrass roots. The high accumulation of organic matter from switchgrass (18%) in the 60 to 90-cm layer indicates that C can be sequestered at greater depths than previously grown plants. This deep C source has slower turnover rates and would be expected to remain sequestered longer than C found near the soil surface.

Table 36. Soil N, soil C, and C:N ratio as influenced by N applied to switchgrass in the spring of 1997 and 1998 [Harvest managements included one cut (in November) and two cuts (June, when in late boot stage, and November). Soil sampled in 1998.]

Cut	Sample date	N applied (kg/ha)			Av
		0	55	110	
			Soil N (%)		
Once	May 5	0.15	0.18	0.16	0.16
	June 24	0.14	0.15	0.13	0.14
	Nov. 1	0.16	0.14	0.18	0.16
	Diff	+0.01	-0.04	+0.02	0.00
Twice	May 5	0.12	0.12	0.12	0.12
	June 24	0.14	0.14	0.15	0.14
	Nov. 1	0.22	0.25	0.16	0.21
	Diff	+0.10	+0.13	+0.04	0.09
			Soil C (%)		
Once	May 5	1.74	1.80	1.78	1.77
	June 24	1.76	1.73	1.60	1.70
	Nov. 1	2.20	1.95	2.00	2.05
	Diff	+0.46	+0.15	+0.22	0.28
Twice	May 5	1.31	1.29	1.36	1.32
	June 24	1.60	1.66	1.70	1.65
	Nov. 1	2.04	1.77	1.57	1.79
	Diff	+0.73	+0.44	+0.31	0.49
			C:N ratio		
Once	May 5	11.6	10.0	11.1	10.9
	June 24	12.6	11.5	12.3	12.1
	Nov. 1	13.8	13.9	11.1	12.9
	Diff	+2.2	+3.9	0.0	2.0
Twice	May 5	10.9	10.8	11.3	11.0
	June 24	11.4	11.9	11.3	11.5
	Nov. 1	9.3	7.1	9.8	8.7
	Diff	-1.6	-3.7	-1.5	-2.3

Soil Sample Preparation for Root Mass, OM, C, and N Determinations

Soil was sampled in triplicate from 0 to 10-cm, 10 to 20-cm, and 20 to 30-cm depths under switchgrass and tall fescue plots at the Orange, Virginia, site. Preparation method one. One matched set of soil samples was used to separate roots from soil using a water wash flotation method without previous drying. (The water wash method was hypothesized to cause least root mass loss.) Preparation method two. A second matched set of soil samples was dried and then had roots removed by sieving through a 10-mesh (2 mm) screen. (The dry method is assumed to collect only larger roots from the test sample.) Roots from this dry method were compared with the roots from the water wash method in order to determine the best procedure for determination of root mass. The soil was tested for OM and

C and was assumed to have the least possible roots left in the sample. Preparation method three. After drying, a third matched set of soil samples was prepared for testing by grinding and sieving through a 10-mesh (2 mm) screen such that no roots were removed from the samples. This is the routine for preparating samples in Virginia Tech's (and others) soil testing lab. Both air-dried sets of samples (preparations one and two) were tested for soil OM by the Virginia Tech soils lab using the Walkley-Black procedure, and both sets were tested for soil C by ORNL using a complete-digestion procedure. The purpose was to determine differences in soil C, soil OM, and soil N as influenced by screening or not screening dried soil during preparation for testing. Most soil testing labs (such as the one at Virginia Tech) use a one-step grinding and screening (method Three above using a 10-mesh screen) procedure when preparing a sample for testing, which will allow ground roots to pass through the screen. The procedure used by Soil Conservation Service in their standard procedures (method Two above) removes as many of the roots as possible before using the 10 mesh preparation screen.

Table 37. Stable isotope ratio dC_{13} and percentage N in root tissue for switchgrass (SG) and tall fescue (TF) at eight locations (Root tissue composited from all sample depths, 0 to 90 cm.)

Location	Species		Species	
	SG	TF	SG	TF
	--- Ratio dC_{13} ---		---- % N ----	
Blacksburg A	-12.8	-24.8	0.64	0.76
Blacksburg B	-12.5	-26.1	0.85	0.85
Orange	-12.8	-25.2	0.55	0.87
Kentucky	-12.7	-24.4	0.34	0.85
North Carolina	-13.1	-23.8	0.57	0.82
West Virginia	-12.3	-24.3	0.38	0.63
Knoxville TN	-13.2	-23.7	0.46	0.94
Jackson TN	-12.8	-18.7*	0.55	0.81
Average	-12.8	-24.6	0.54	0.82

The "dry method" of root determination caused a loss of 57% of the switchgrass roots and 80% of the tall fescue roots when compared to the "water wash method." Switchgrass had many large, tough roots that were retained by the dry screening, while nearly all the tall fescue roots were fine roots, many of which shattered and passed through with the dry soil when screened. Any determination of root mass will be greatly underestimated if done using a dry preparation method, with the error being larger for tall fescue than switchgrass.

Removing the roots before screening the soil decreased soil C (14%) , soil OM (15%), and soil N (24%) when compared to non-screened soil for tall fescue. For switchgrass; however, there were no significant differences between screened and non-screened soil. Again the fineness of the roots was the reason for the difference between switchgrass and tall fescue. These data indicate that roots retained by a 10-mesh screen should be removed during the soil sample preparation when testing for soil OM, C, and N or realize that results might be slightly high if many fine roots are in the sample.

Since OM and C were determined for each soil sample, we were able to calculate a factor that could be used to convert from OM to C and vice-versa (Table 39). (Theoretically the OM is 58% C only if complete conversion is assumed by the acidic treatment in the Walkley-Black

Table 38. Fraction and mass of the soil C as new C from switchgrass plants (% C_4) at several depths under switchgrass plots (Mass of soil organic matter (OM) was calculated from percentage OM and bulk density[1].)

Depth	Contributed by SG		Soil OM	
	Fraction	Mass	%	Mass
cm	% C_4	Mg ha^{-1}		Mg ha^{-1}
0 to10	39	1.00	1.76	2.38
10 to 20	23	0.50	1.30	2.17
20 to 30	14	0.19	0.82	1.05
0 to 30	23	1.69	1.29	5.60
30 to 60	9	0.19	0.39	1.66
60 to 90	18	0.30	0.32	1.69

[1] Data are from soil samples collected at the Kentucky site (two reps and two cutting managements averaged) in the fall of 1998 after six years of switchgrass growth.

method. Thus percentage OM matter times 0.58 would equal percentage C. Alternatively, percentage C times 1.72 would equal percentage OM. The presence of Cl, Fe, and Mn are known to interfere with this test. Poorly drained soils may have problems, but interferences are of little concern in well- drained agricultural soils.) Our data show a conversion factor of 0.61 for switchgrass and 0.64 for tall fescue, when roots were not screened during sample preparation. When roots were removed during sample preparation, the conversion factor was 0.49 for switchgrass and 0.64 for tall fescue.

Table 39. Multiplication factors to convert soil OM (as determined by the Walkley-Black procedure) to soil C as influenced by soil sample preparation method (large roots removed by screening or not removed during preparation) (Samples were taken at several depths under switchgrass and tall fescue plots. Soil OM ranged from 0.6% to 4.5%.)

Roots Screened	Switchgrass	Tall fescue
	------------------ Factor	------------------
No	0.61	0.64

ANNUAL REPORT FOR 2001

SUMMARY

Task One. Variety/management study. Productivity of switchgrass varieties adapted to the upper Southeast when managed under two harvest regimes was measured for the tenth year. Yields in 2001 ranged from a high of 27.4 Mg ha^{-1} (Alamo at Blacksburg, Virginia, Site B) to a low of 5.1 Mg ha^{-1} (Shelter at Raleigh, North Carolina). When averaged over all eight locations, the lowland and upland types when cut twice had similar yields. However; when cut once, the lowland types had 41% greater yields than the upland types. The same trend and magnitude of differences have occurred in most previous years.

Task Two. Screening of new genetic material. New experimental lines provided by the plant breeding effort at Oklahoma State University were evaluated. These data show that biomass increases can be achieved by plant breeding/selection. Several breeding lines were 10 to 25% more productive than named varieties.

Task Three. N, P, and K balance studies. Concentrations of whole-plant N, P, and K in the fall harvest (dead herbage) were about one half the concentrations when harvested in late June (at an early heading stage). These data indicate that soil P, K, and Ca (at the levels found in these soils) were not limiting biomass yields. The quantity of nutrient elements removed depended largely on the biomass yield, in that high yields resulted in high removal.

TASK ONE (VARIETY/MANAGEMENT STUDY)

Yields

Annual rainfall in 2001 was near or below normal for all locations except Raleigh, North Carolina, and Jackson, Tennessee (Appendix Table A-6). However, all locations had above-normal rainfall during the critical growth period of June through September (Appendix Table A-1). Our data in previous years have shown that the soil profile supporting roots is at field capacity each spring. Since switchgrass does not use soil water until much later in the spring than cool-season species soil moisture limitations on growth are not likely until June and later. The 2001 growth would not likely be seriously limited by soil moisture except for timeliness of rainfall events. Since the correlation between June through September rainfall and yield is not high, there may be some consideration that timeliness of rainfall is crucial (“a little will go a long way”).

Yields in 2001 ranged from a high of 27.4 Mg ha^{-1} (Alamo at Blacksburg, Virginia, Site B) to a low of 5.1 Mg ha^{-1} (Shelter at Raleigh, North Carolina) (Table 40). Upland varieties benefitted from the two-cut management when compared to the one-cut management but not the lowland types. When averaged over all eight locations, the lowland and upland types when cut twice had similar yields. However, when cut once the lowland types had 41% greater yields than the upland types. The same trend and magnitude of differences have occurred in most previous years.

Table 40. Seasonal yields in 2001 from six varieties of switchgrass at eight locations when harvested once (in November) or twice (first cut in early heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Cuts	Variety	Yield								
		Virginia			Tennessee		WV[1]	KY	NC	Average
		Blacksburg, VA		Orange, VA						
		Site A	Site B		Knox	Jack				
		------------------- Mg/ha^{-1} -------------------								
One	Alamo	10.6	27.4	17.6	24.8	11.6	18.2	13.6	7.4	16.4
	Kanlow	13.7	22.2	20.0	22.5	12.7	20.5	14.8	6.9	16.7
	Cave-in-Rock	9.6	18.4	12.6	13.8	8.2	15.7	13.2	6.2	12.2
	Shelter	9.6	15.7	12.2	11.2	8.7	16.6	10.6	5.1	11.2
	NC1	13.1	24.0	16.7	18.6	10.6	17.0	15.5	7.5	15.4
	NC2	11.1	21.2	16.2	18.4	10.2	17.0	15.5	7.1	14.6
	Average	11.3	21.5	15.9	18.2	10.3	17.5	13.9	6.7	14.4
Two	Alamo	13.7	19.7	15.1	18.1	16.6	13.0	15.2	9.7	15.1
	Kanlow	16.5	19.9	14.3	15.0	15.5	13.8	14.7	9.1	14.9
	Cave-in-Rock	14.6	16.7	15.5	17.1	16.9	15.6	13.6	10.2	15.0
	Shelter	14.8	18.7	14.2	16.6	13.9	13.3	13.1	8.8	14.2
	NC1	13.7	19.7	17.0	16.3	15.1	13.8	11.9	10.9	14.8
	NC2	14.4	18.8	15.0	16.4	15.1	14.3	13.2	10.2	14.7
	Average	14.6	18.9	15.2	16.6	15.5	14.0	13.6	9.8	14.8
	LSD 0.05*	2.2	4.7	3.6	3.0	2.8	2.3	2.3	1.6	2.8
Difference	Alamo	3.1	-7.7	-2.5	-6.7	5.0	-5.2	1.6	2.3	-1.3
	Kanlow	2.8	-2.3	-5.7	-7.5	2.8	-6.7	-0.1	2.2	-1.8
(Two minus one)	Cave-in-Rock	5.0	-1.7	2.9	3.3	8.7	-0.1	0.4	4.0	2.8
	Shelter	5.2	3.0	2.0	5.4	5.2	-3.3	2.5	3.7	3.0
	NC1	0.6	-4.3	0.3	-2.3	4.5	-3.2	-3.6	3.4	-0.6
	NC2	3.3	-2.4	-1.2	-2.0	4.9	-2.7	-2.3	3.1	0.1
	Average	3.3	-2.6	-0.7	-1.6	5.2	-3.5	-0.3	3.1	0.4

Table 40 (continued)

Cuts	Variety	Yield								
		Virginia			Tennessee		WV[1]	KY	NC	Average
		Blacksburg, VA		Orange, VA						
		Site A	Site B		Knox	Jack				
% Difference	Alamo	29	-28	-14	-27	43	-29	12	31	-8
	Kanlow	20	-10	-28	-33	22	-33	-1	32	-11
	Cave-in-Rock	52	-9	23	24	106	-1	3	65	23
	Shelter	54	19	16	48	60	-20	24	73	26
	NC1	5	-18	2	-12	42	-19	-23	45	-4
	NC2	30	-11	-7	-11	48	-16	-15	44	1
	Average	30	-12	-4	-9	50	-20	-2	47	3

*LSD values are for comparison of means for varieties within and between cutting managements.
[1]Varieties NC1 and NC2 were not present in the WV planting; therefore their estimated values were calculated as missing plots in order to compare across varieties. The one-cut management received only 50 kg of N per ha in the spring and the two-cut management received 50 kg in spring and again after the first harvest.

The goal for the two-cut management was to time the first harvest so that about one-half the seasonal production would be harvested in late June and about one-half at the end of the season (near
November 1). As in past years, somewhat more yield was removed on the first than the last harvest when averaged over all locations (Table 41). In years when adequate soil moisture is received, a harvest when switchgrass is in the late boot to very early seed head emergence will result in nearly one-half the yield in the June harvest. Since the two upland varieties developed seed heads early, this harvest date would be earlier than for the lowland varieties.

Tissue Element Concentration

Whole-plant N, P, and K were much greater in the herbage from the first than the last harvest (Table 42). The November harvest was made after the herbage was dead, and any possible translocation was complete; yet little loss from leaching was probable. Nitrogen in herbage from both cutting managements in the fall was very low (0.45% and 0.63% for the one and two-cut managements, respectively). Tissue P in the fall-harvested herbage at Raleigh, North Carolina, was double that from other locations. This was due to the very high (about 60x) soil P level. Tissue P in the first harvest was similar among locations even though soil P differed greatly.

Table 41. First harvest, second harvest, and total yields from six varieties of switchgrass grown at eight locations in 2001 when harvested twice (first cut in early heading stage and second cut in November)

(The first cut yields are also expressed as percentages of the total yields.)

Cut	Variety	Yield			Tennessee		WV[1]	KY	NC	Average
		Blacksburg, VA		Orange, VA						
		Site A	Site B		Knox	Jack				
		-- Mg ha^{-1} --								
First	Alamo	7.0	8.5	6.2	10.0	9.9	7.4	5.4	6.6	7.6
	Kanlow	9.2	9.6	8.2	9.0	10.4	9.1	6.9	6.5	8.6
	Cave-in-Rock	8.8	8.9	8.3	11.3	11.5	11.0	7.9	7.3	9.4
	Shelter	8.4	9.7	8.4	10.4	8.6	10.2	5.8	6.6	8.5
	NC1	7.6	8.2	7.0	9.6	8.4	8.3	5.2	7.2	7.7
	NC2	6.9	9.8	7.5	9.2	8.6	8.8	5.2	7.2	7.9
	Average	8.0	9.1	7.6	9.9	9.6	9.4	6.0	6.9	8.3
	LSD 0.05*	0.4	1.4	1.2	1.3	3.3	0.8	0.7	1.1	0.4
Last	Alamo	6.7	11.2	8.9	8.1	6.8	5.6	9.8	3.2	7.5
	Kanlow	7.4	10.3	6.1	6.0	5.1	4.7	7.8	2.6	6.3
	Cave-in-Rock	5.9	7.8	7.2	5.8	5.5	4.7	5.8	3.0	5.7
	Shelter	4.7	8.3	5.2	4.9	4.2	4.6	4.9	2.2	4.9
	NC1	7.2	10.4	7.2	7.1	5.5	5.0	7.9	3.6	6.7
	NC2	6.7	9.9	9.6	7.1	6.5	5.0	6.7	3.1	6.8
	Average	6.4	9.7	7.3	6.5	5.6	4.9	7.2	3.0	6.3
	LSD 0.05*	1.8	4.5	3.1	2.8	2.0	2.2	1.4	1.4	0.8
Total	Alamo	13.7	19.7	15.1	18.1	16.7	13.0	15.2	9.8	15.2
	Kanlow	16.6	19.9	14.3	15.0	15.5	13.8	14.7	9.1	14.9
	Cave-in-Rock	14.7	16.7	15.5	17.1	17.0	15.7	13.7	10.3	15.1
	Shelter	13.1	18.0	13.6	15.3	12.8	14.8	10.7	8.8	13.4
	NC1	14.8	18.6	14.2	16.7	13.9	13.3	13.1	10.8	14.4
	NC2	13.6	19.7	17.1	16.3	15.1	13.8	11.9	10.3	14.7
	Average	14.4	18.8	14.9	16.4	15.2	14.3	13.2	9.9	14.6
	LSD 0.05*	1.8	4.5	3.1	2.8	2.0	2.2	1.4	1.4	0.8

Table 41 (continued)

Cut	Variety	Yield								
		Blacksburg, VA		Orange, VA	Tennessee		WV[1]	KY	NC	Average
		Site A	Site B		Knox	Jack				
		------------------------- % of total yield in the first cut -------------------------								
% of total in the first cut	Alamo	51	43	41	55	59	57	36	67	51
	Kanlow	55	48	57	60	67	66	47	71	59
	Cave-in-Rock	60	53	54	66	68	70	58	71	62
	Shelter	64	54	62	68	67	69	54	75	64
	NC1	51	44	49	57	60	62	40	67	54
	NC2	51	50	44	56	57	64	44	70	54
	Average	56	48	51	60	63	66	45	70	57

*LSD values are for comparison of means for varieties within cuts or total means.
[1]Varieties NC1 and NC2 were not present in the WV planting; therefore their estimated values were calculated as missing plots in order to compare across varieties.

Table 42. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass when averaged over eight locations (2001 data)

Cutting management	June				Nov.				Yield (2001)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	---------------------------------- %				---------------------------------				------ Mg ha^{-1} ------		
Once	--	--	--	--	0.45b	0.09a	0.66a	0.28b	--	16.4a	16.4a
Twice	1.15	0.18	1.30	0.33	0.63a	0.10a	0.43a	0.36a	7.6	7.5b	15.2a

*Means within columns followed by similar letters do not differ at the 0.05 level.

Element Removal

Element removal was calculated using the concentration and yield. Total amount of elements removed were about double from the two-cut management when compared with the one-cut management (Table 43). The differences in element removal between locations and varieties were more dependent on yield than concentration differences. More of each element was removed than was applied during 2001.

Table 43. N, P, K, and Ca removed in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (2001 data)

Cuts	June removal				Nov. removal				Total removal			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	------------------------------------ kg ha^{-1} removed ------------------------------------											
Once	--	--	--	--	74b	15	108a	46b	74b	15b	108b	46b
Twice	87	14	99	25	96a	15a	65b	55a	183a	29a	164a	80a

*Means within columns followed by similar letters do not differ at the 0.05 level.

Stand/stubble Density

This was the tenth year of growth. Thus, future yield potential might be predicted from the appearance of the stand (ground cover and physical appearance) as well as density of the stubble left after the November harvest. Visual rankings of stands and stubble densities were always greater for the two- than the one-cut management (Table 44, 45, and 46). All varieties at all locations appeared to have strong stands that would continue to be productive for many years when managed as in the past with the first harvest in June and the second in November after top growth was dead. Visual ranking showed the one-cut management to have thin stands at most locations. At both Knoxville, Tennessee, and Morgantown, West Virginia (see Fig. 5), there were some extra border plots not receiving N but harvested as with the one-cut management. These plots had excellent stands. Thus the “pressure” from the N which causes growth that would lodge may have resulted in the thinning that was evident at the end of the first five years of harvest (Table 45). During the last five years, less N was applied and most of the stands were beginning to thicken and recover. Yields still remained high. These observations are the basis for our N recommendation. We feel that N should be applied at rates to achieve less that maximum short-term yields so that stands do not thin. Some soils may not need any N for two or three years. Then application of 50 kg N ha^{-1} for the soils and locations in this study may be adequate for maximum long-term production.

Table 44. Stand rating[1] in November 2001 for six varieties of switchgrass at eight locations when harvested once (November) or twice (first cut in early heading stage and second cut in November) for nine years after establishment in 1992

[Differences are calculated using similar ratings made in November 1996 (2001 minus 1996 data).]

Cuts	Variety	Stand visual rank (0 to 10)					WV[2]	KY	NC	Average
		Blacksburg, VA		Orange, VA	Tennessee					
		Site A	Site B		Knox	Jack				
		----------------- *December 2001* -----------------								
Once	Alamo	4.8	2.9	6.2	7.0	6.2	8.0	9.8	6.8	6.5
	Kanlow	6.9	3.5	6.6	7.5	8.2	9.5	10.0	8.2	7.6
	Cave-in-Rock	6.6	4.2	7.1	6.5	8.0	5.5	9.5	7.8	6.9
	Shelter	7.0	3.9	5.6	7.2	8.2	6.5	8.2	6.8	6.7
	NC1	6.2	2.8	6.6	6.2	7.0	8.0	8.5	6.0	6.4
	NC2	6.4	3.2	6.0	6.2	8.0	8.0	9.0	6.0	6.6
	Average	6.3	3.4	6.4	6.8	7.6	7.6	9.2	6.9	6.8
Twice	Alamo	9.8	8.6	8.9	9.2	8.8	10.0	10.0	9.5	9.4
	Kanlow	10.0	9.4	9.6	9.8	9.0	9.5	10.0	8.8	9.5
	Cave-in-Rock	9.6	8.6	9.2	9.5	9.2	8.5	10.0	9.5	9.3
	Shelter	9.8	9.1	9.1	9.8	9.5	9.9	10.0	9.2	9.6
	NC1	9.6	8.1	9.5	8.5	9.2	9.5	9.5	8.0	9.0
	NC2	9.5	8.5	9.1	8.5	6.5	9.5	10.0	7.8	8.7
	Average	9.7	8.7	9.2	9.2	8.7	9.5	9.9	8.8	9.2
	LSD 0.05*	0.8	1.2	1.5	1.8	1.5	1.4	0.8	1.3	0.4
		-------------------- *Difference between 1996 and 2001* --------------------								
Once	Alamo	1.8	0.9	0.6	0.0	-0.3	-0.5	1.8	2.0	0.8
	Kanlow	1.4	-2.7	-1.2	-1.0	-1.3	0.0	0.5	1.7	-0.3
	Cave-in-Rock	1.1	-0.6	1.5	2.7	2.5	2.5	0.0	5.3	1.9
	Shelter	2.2	-0.3	1.8	3.4	2.9	1.5	0.7	4.6	2.1
	NC1	3.4	-1.7	1.4	0.7	3.8	1.5	2.5	3.8	1.9
	NC2	2.6	0.0	1.9	1.7	4.5	0.5	2.5	3.5	2.2
	Average	2.1	-0.7	1.0	1.3	2.0	0.9	1.3	3.5	1.4
Twice	Alamo	-0.2	-0.6	1.0	0.0	-1.2	0.0	0.2	1.7	0.1
	Kanlow	0.5	-0.6	1.6	-0.2	-0.8	0.0	0.2	1.3	0.3
	Cave-in-Rock	0.8	0.1	2.1	2.0	1.7	-0.7	0.2	4.7	1.4
	Shelter	1.8	-0.4	1.9	1.8	1.3	1.7	0.5	5.7	1.8
	NC1	0.8	-0.4	2.9	1.0	2.2	2.5	2.5	4.0	1.9
	NC2	1.0	0.7	3.3	0.7	0.3	3.0	1.2	3.8	1.8
	Average	0.9	-0.2	2.1	0.9	0.6	1.1	0.8	3.5	1.2

*LSD values are for comparison of means for varieties within and between cutting managements.

[1]Ratings were a visual score (0 to 10) based on the stubble density. Alamo stand score of 6.5 equated to 386 stubs m^{-2} for the one-cut management and a stand score of 9.4 equated to 832 stubs m^{-2} for the two-cut management.

[2]Lines NC1 and NC2 were not present in the WV planting; therefore their estimated values were calculated as missing plots in order to compare across varieties.

Table 45. Stand ranking[1] in November 2001 for upland varieties (Cave-in-Rock and Shelter) and lowland varieties (Alamo and Kanlow) of switchgrass at eight locations when harvested once (November) or twice (first cut in early heading stage and second cut in November) for nine years after establishment in 1992

[Differences are calculated using similar ratings made in November 1996 (2001 minus 1996 data).]

Cuts	Variety	Virginia			Tennessee		WV	KY	NC	Av
		Blacksburg		Orange						
		Site A	Site B		Kno	Jack				
		--------------------- Stand December 2001(Visual rank 0 to 10)[1] ----------------								
Once	Upland	5.9	3.2	6.4	7.3	7.2	8.8	9.9	7.5	7.1
	Lowland	6.8	3.9	6.9	7.0	8.1	7.5	9.8	8.0	7.3
	Average	6.3	3.5	6.6	7.1	7.7	8.1	9.8	7.8	7.2
Twice	Upland	9.9	9.0	9.3	9.5	8.9	9.8	10.0	9.2	9.5
	Lowland	9.8	9.0	9.4	9.7	9.1	9.0	10.0	9.2	9.4
	Average	9.9	9.0	9.3	9.6	9.0	9.4	10.0	9.2	9.4
	LSD	0.6	0.8	1.0	1.3	1.2	1.0	0.6	1.0	0.3
		-------------- Differences between 1996 and 2001 ---------------------								
Once	Upland	1.6	-0.9	-0.3	-0.5	-0.8	-0.3	1.2	1.9	0.3
	Lowland	1.3	-1.7	0.2	0.9	0.6	1.3	0.3	3.5	0.8
	Average	1.4	-1.3	-0.1	0.2	-0.1	0.5	0.7	2.7	0.5
Twice	Upland	3.0	-0.9	1.7	1.2	4.2	1.0	2.5	3.7	2.1
	Lowland	2.4	-0.4	1.5	1.5	3.3	0.7	1.9	3.5	1.8
	Average	2.7	-0.6	1.6	1.4	3.7	0.9	2.2	3.6	1.9

*LSD values are for comparison of means of varieties within and between cutting managements.
[1]Stand rankings were a visual score (0 to 10) based on the stubble density. Switchgrass stand ranking of 6.5 equated to 386 stubs m^{-2} for the one-cut management and a stand score of 9.4 equated to 832 stubs m^{-2} for the two-cut management.

Table 46. Stubble density[1] in November 2001 for Alamo switchgrass at eight locations when harvested once (one cut in November) or twice (first cut in early heading stage and second cut in November) during nine years since establishment in 1992

(Differences are calculated using similar populations in November 1996.)

Cuts	Year	Virginia			Tennessee		WV[1]	KY	NC	Av
		Blacksburg		Orange						
		Site A	Site B		Knox	Jack				
		----------------------- Stubble density (number m^{-2}) ---------------------								
Once	1996	170	145	270	375	427	415	772	128	338
	2001	332	193	417	431	289	487	610	326	386
	Diff	162	48	147	56	-138	72	-162	198*	48
Twice	1996	750	447	420	808	1100	1007	900	405	730
	2001	789	500	893	1089	503	976	1284	621	832
	Diff	39	53	473	281	-597	-31	384	216	102
LSD 0.05	1996*	86	72	188	124	176	148	249	157	53
	2001*	106	145	152	239	153	248	158	78	56
	Diff**	96	109	170	182	165	198	204	118	55

*LSD values are for comparisons between cutting managements within years.
**LSD values for comparisons between differences within locations.
[1]Stubble density was determined by counting the tiller stubs that supported growth at the last harvest in November.

Soil Test Data

Soil samples were taken from the 0 to 10-cm depth in several years from the beginning of the study. No limestone was applied before or during the ten years of the study. Fertilization with P and K was minimal. Soil pH at all locations declined steadily during the ten years. Soil pH was below 5 at two locations, yet yields remained high (Table 47). Soil P and K reflected amounts of fertilizer applied but declined in years where there was no spring application (Table 47). Even though P tested in a range that is considered low for agronomic crop productivity, the switchgrass yields were high. Soil K was in a medium to medium minus productivity level at the end of the ten years. Soil P was very high at the Raleigh, North Carolina, location but did not appear to increase first cut whole plant tissue concentration even though there was a range of 2 to 115 ppm soil P among replications. Detailed sampling at the North Carolina site showed that a wide strip of some P source had been applied in years before this study was started, but no one at that location could recall the event. Soil P data from that location was omitted from averages. We noticed that even though this soil P was very high, the plant tissue P in the June harvest was normal when compared to that from other locations having very low soil P.

Soil Ca declined similarly to soil pH. Whole-plant tissue Ca did not reflect soil Ca even though there was a range of 212 to 1123 ppm for the 2001 testing. In fact the Princeton, Kentucky, location had very high soil Ca (so high these data were left out of overall averages), and its tissue Ca was among the lowest of all locations (Table 48). We conclude then that the levels of soil Ca at these locations were not growth limiting.

Table 47. Soil test values for Alamo switchgrass when sampled in the spring of 1992 before planting at several locations and the fall of several different years

(Managements included one cut and two cuts per season. The productivity potentials are soil test values that are recommended to achieve low, medium, and high yields of agronomic crops.)

Location	Year	Cuts		Cuts		Cuts	
		Once	Twice	Once	Twice	Once	Twice
		------ pH ------		---- P (ppm) ----		---- K (ppm) ----	
Blacksburg, VA (Site A)	1992	6.5		3		60	
	1996	6.4	6.1	10	5	56	25
	1998	6.3	5.7	29	30	101	73
	2001	5.8	5.2	13	12	42	23
Blacksburg, VA (Site B)	1992	6.0		4		80	
	1996	5.1	5.2	8	6	82	37
	1998	5.1	5.2	33	30	146	68
	2001	4.9	4.7	24	25	52	34
Orange, VA	1992	5.7		2		77	
	1996	5.1	5.2	6	6	63	59
	1998	5.0	5.0	5	6	50	45
	2001	4.8	4.8	14	18	62	50
Knoxville, TN	1992	5.6		7		62	
	1996	5.4	5.4	5	3	45	20
	1998	5.2	5.2	6	6	46	40
	2001	5.2	5.2	3	2	33	20
Jackson, TN	1992	5.8		12		90	
	1996	5.5	5.3	8	8	63	64
	1998	5.2	5.4	8	7	74	64
	2001	5.3	5.2	7	6	73	44
Princeton, KY	1992	6.7		15		101	
	1996	6.7	6.9	3	8	32	25
	1998	6.4	6.4	8	6	40	34
	2001	6.0	6.3	8	6	46	28
Morgantown, WV	1992	6.3		12		95	
	1996	5.7	6.0	10	6	40	27
	1998	5.5	5.5	12	8	54	31
	2001	5.2	5.3	14	10	38	36
Raleigh, NC	1992	6.3		--		70	
	1996	6.4	6.2	118	156	70	32
	1998	5.5	5.8	133	207	66	50
	2001	5.9	5.9	98	115	36	21
Average[1]	1992	6.1		8		79	
	1996	5.8	5.8	7	6	56	36
	1998	5.5	5.5	14	13	72	51
	2001	5.4	5.3	12	11	48	32

Table 47 (continued)

Location	Year	Cuts		Cuts		Cuts	
		Once	Twice	Once	Twice	Once	Twice
	LSD	0.3		4		20	
	Range	4.7 to 6.9		2 to 207		21 to 146	
Productivity potential	Low	?		2 to 4 ppm		8 to 28 ppm	
	Medium	?		11 to 15 ppm		51 to 75 ppm	
	High	?		28 to 30 ppm		106 to 140 ppm	

*LSD values are for comparisons within locations.
[1]P from Raleigh, NC, was not included in averages because of unusually high values.
?Indicates that potential productivity values are not known.

Soil organic matter in the 0- to 10-cm depth was lower in the switchgrass plots than in adjacent tall fescue areas (Table 48). This difference may be due in part to the sampling method. Soil sampling for switchgrass was chosen to be about 10 cm from any observable stubble/crown, since the root mass under a crown can be very dense. We were able to avoid extreme variability in our sample (eliminate the need for many samples to get a representative sample) but may have an under-estimate of weight in the upper 10 cm. Tall fescue formed a dense sod, with the majority of the roots near the surface as compared with the deeper rooting nature of switchgrass. Organic matter in the 0- to 10-cm layer declined during the ten years after switchgrass was planted into a killed tall fescue sod. This trend might be expected, since roots of tall fescue concentrate more near the surface than does switchgrass. Organic matter turnover is dependent on average temperatures so that any buildup of OM may reach an equilibrium in the top soil layer, and continued build up would not be expected. In other testing, we found significant buildup of switchgrass root mass and OM at depths greater than 10 cm.

Table 48. Soil test values and yields for Alamo switchgrass when sampled in the spring of 1992 before planting at several locations and the fall of several different years

[Managements included one cut and two cuts per season. The productivity potentials are soil test values that are recommended to achieve low, medium, and high yields of agronomic crops. Values in parentheses are for tall fescue areas near the experimental plots (no harvesting and no fertilization).]

Location	Year	Cuts		Cuts		Cuts	
		Once	Twice	Once	Twice	Once	Twice
		--- Ca (ppm) —		----- OM (%) -----		---- Mg ha^{-1} ----	
Blacksburg, VA (Site A)	1992	651		.		.	
	1996	663	549	3.2 (3.2)	3.1	8.8	12.1
	1998	672	525	3.3 (3.6)	3.1	19.3	15.7
	2001	497	371	2.4 (3.1)	2.5	10.6	13.7
Blacksburg, VA (Site B)	1992	402		--		--	
	1996	285	345	2.6 (2.6)	2.5	13.6	16.5
	1998	330	405	2.8 (2.7)	2.5	14.1	22.0
	2001	241	212	2.0 (2.6)	2.0	27.4	19.7
Orange, VA	1992	798		--			
	1996	642	696	4.8 (5.0)	4.8	18.8	16.5
	1998	651	651	4.4 (4.1)	4.5	20.4	17.4
	2001	586	535	4.0 (5.6)	4.0	17.6	15.1
Knoxville, TN	1992	594		--		--	
	1996	468	486	3.0 (3.1)	2.9	24.3	25.4
	1998	513	513	3.2 (4.2)	3.1	20.4	21.8
	2001	369	342	2.3 (3.0)	2.3	24.8	18.1
Jackson, TN	1992	900		--		--	
	1996	759	768	2.1 (2.0)	2.2	11.7	13.2
	1998	738	816	2.0 (2.2)	2.1	16.4	13.3
	2001	674	692	2.0 (1.9)	1.7	11.6	16.6
Princeton, KY[1]	1992	1720		--		--	
	1996	1403	1132	2.0 (2.0)	1.9	16.4	14.5
	1998	1239	1300	2.0 (2.3)	2.0	11.6	16.0
	2001	1077	1123	1.8 (1.8)	1.9	13.6	15.2
Morgantown, WV	1992	801		--		--	
	1996	645	735	2.5 (2.6)	2.3	19.2	13.4
	1998	675	663	2.4 (2.7)	2.4	15.1	14.9
	2001	514	558	2.1 (2.3)	2.2	18.2	13.0
Raleigh, NC	1992	996		--		--	
	1996	675	612	2.9 (2.8)	2.8	15.3	20.1
	1998	795	946	2.8 (3.1)	2.7	19.5	20.4
	2001	587	610	2.1 (2.3)	2.0	7.4	9.7
Average[1]	1992	735		--		--	
	1996	591	599	3.0	2.8	16.0	16.5
	1998	702	727	2.8 (3.1)	2.8	17.1	17.7
	2001	495	474	2.3 (2.8)	2.3	16.4	15.1L

Table 48 (continued)

Location	Year	Cuts		Cuts		Cuts	
		Once	Twice	Once	Twice	Once	Twice
	Range	212 to 1403		1.7 to 4.8		7.4 to 27.4	
Productivity potential	Low	121 to 240 ppm		?		--	
	Medium	481 to 600 ppm		?		--	
	High	841 to 960 ppm		?		--	

*LSD values are for comparisons within locations.

[1]Ca from Princeton, KY, was not included in averages because of unusually high values.

?Indicates that potential productivity values are not known.

TASK TWO (SCREENING OF NEW GENETIC MATERIAL)

Table 49. Biomass yield of 12 switchgrass selections when harvested in late October at the Northern Piedmont Agricultural Research and Extension Center at Orange, VA [Planting was in June 1998. Nitrogen (50 kg/ha) was applied in May of each year.]

Rank	Selection	1999	2000	2001	Average
		---------------------- Mg ha^{-1}	----------------------		
1	SL93-3	16.3	18.7	18.8	17.9
2	SL93-1	14.0	14.7	21.3	16.7
3	SL94-1	12.9	16.5	20.0	16.5
4	SL92-1	12.8	16.0	18.0	15.6
5	SL93-2	10.4	16.8	18.2	15.1
6	NL92-1	11.2	15.4	16.4	14.3
7	Alamo	12.2	15.6	14.2	14.0
8	Kanlow	9.1	16.4	16.1	13.9
9	NL93-1	9.4	15.8	15.0	13.4
10	NL94-1	11.4	16.1	12.3	13.3
11	NL93-2	9.0	14.8	13.0	12.3
12	Cave-in-Rock	6.7	11.0	7.9	8.5

Switchgrass plots (nine experimental lines from the Oklahoma State breeding program and three commonly used varieties) were planted in mid-June 1998. Establishment was highly successful. The land area where this planting was located has a low productive potential for row crops. Nitrogen, P, and K were Applied at 50, 24, and 46 kg ha^{-1} yr^{-1}, respectively, in early May 1999, 2000, and 2001. Yields were taken in late October of each year. After four years of growth, all selections had excellent stands as judged by tiller numbers. Yields were measured using a one-cut management system. The experimental lines had less lodging than the traditional varieties, especially Cave-in-Rock which had considerable lodging. No disease was noted on any selection. The SL lines (from southern lowland sources) had higher yields than the NL lines (from northern lowland sources) (Table 49). The SL lines were superior to the commonly used varieties of Alamo, Kanlow, lowland types) and Cave-in-Rock (the only upland type). These data show that biomass increases can be achieved by plant breeding/selection.

TASK THREE (N, P, AND K REMOVAL/RECOMMENDATIONS)

Concentrations of whole-plant N, P, and K in the fall harvest (dead herbage) were about one-half the concentrations when harvested in late June (at an early heading stage) (Table 50). Whole-plant Ca was similar in the spring and fall harvests. The Raleigh, North Carolina, location had about a 50 to 100 fold greater soil-P test than other locations, yet the whole-plant P did not differ among locations for the June harvest. For the fall harvest, however, whole-plant P at Raleigh was low but about double that at other locations. The Princeton, Kentucky, location had very high soil Ca but no high concentrations in whole plant Ca. Whole-plant K was not related to yields even when location effects were statistically removed. These data indicate that soil P, K, and Ca (at the levels found in these soils) were not limiting biomass yields.

The quantity of nutrient elements removed depended largely on the biomass yield, in that high yields resulted in high removal. More element mass was remove from the two-cut management than the one-cut management because of the high concentrations in the first harvest of the two-cut management (Table 51). Only Ca had the same removal amounts with the two different managements. We discuss the removal amounts in relation to soil test levels in the discussion of the five-year data earlier in this report.

Table 50. Nitrogen, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations (2001 data)

Location	Concentrations, June				Concentrations, Nov.				Yield		
	N	P	K	Ca	N	P	K	Ca	June	Nov	Total
	---------------------------------- % ----------------------------------								------ Mg ha^{-1} ------		
					One-cut management						
Blacksburg, VA											
Site A	--	--	--	--	0.41	0.06	0.61	0.25	--	10.6	10.6
Site B	--	--	--	--	0.61	0.07	0.85	0.31	--	27.4	27.4
Orange, VA	--	--	--	--	0.48	0.08	0.82	0.39	--	17.6	17.6
Knoxville, TN	--	--	--	--	0.40	0.07	0.66	0.32	--	24.8	24.8
Jackson, TN	--	--	--	--	0.49	0.09	0.61	0.28	--	11.6	11.6
Princeton, KY	–				0.50	0.09	0.51	0.24	--	18.2	18.2
Morgantown,WV	–	--	–	–	0.33	0.09	0.53	0.20	--	13.6	13.6
Raleigh, NC	--	--	--	--	0.38	0.15	0.72	0.28	--	7.4	7.4
Average	--	--	--	--	0.45	0.09	0.66	0.28	--	16.4	16.4
					Two-cut management						
Blacksburg, VA											
Site A	1.53	0.21	1.18	0.39	0.87	0.09	0.45	0.40	7.0	6.7	13.7
Site B	1.67	0.20	1.76	0.35	0.74	0.07	0.64	0.35	8.5	11.2	19.7
Orange, VA	1.65	0.23	1.86	0.43	0.45	0.07	0.44	0.34	6.2	8.9	15.1
Knoxville, TN	0.90	0.11	0.71	0.32	0.67	0.08	0.30	0.45	10.0	8.1	18.1
Jackson, TN	0.93	0.14	1.06	0.33	0.57	0.08	0.44	0.28	9.9	6.8	16.7
Princeton, KY	0.90	0.17	0.95	0.32	0.48	0.08	0.13	0.29	7.4	5.6	13.0
Morgantown,WV	0.85	0.18	1.19	0.27	0.69	0.12	0.32	0.32	5.4	9.8	15.2
Raleigh, NC	0.77	0.19	1.19	0.33	0.57	0.21	0.69	0.42	6.6	3.2	9.8
Average	1.15	0.18	1.30	0.33	0.63	0.10	0.43	0.36	7.6	7.5	15.2
LSD 0.05	0.11	0.20	0.12	0.05	0.13	0.03	0.11	0.06	1.3	1.3	2.4

Table 51. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (2001 data)

Location	June removal				Nov. removal				Total removal			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	---- kg ha^{-1} removed ----											
					One-cut management							
Blacksburg, VA												
Site A	--	--	--	--	43	6	65	27	43	6	65	27
Site B	--	--	--	--	167	19	233	85	167	19	233	85
Orange, VA	--	--	--	--	84	14	144	69	84	14	144	69
Knoxville, TN	--	--	--	--	99	17	164	79	99	17	164	79
Jackson, TN	--	--	--	--	57	10	71	32	57	10	71	32
Princeton, KY	--				91	16	93	44	91	16	93	44
Morgantown,WV	--	--	--	--	45	12	72	27	45	12	72	27
Raleigh, NC	--	--	--	--	28	11	53	21	28	11	53	21
Average	--	--	--	--	74	15	108	46	74	15	108	46
					Two-cut management							
Blacksburg, VA												
Site A	107	15	83	27	58	6	30	27	165	21	113	54
Site B	142	17	150	30	83	8	72	39	225	25	222	69
Orange, VA	102	14	115	27	40	6	39	30	142	20	154	57
Knoxville, TN	90	11	71	32	54	6	24	36	144	17	95	68
Jackson, TN	92	14	105	33	39	5	30	19	131	19	135	52
Princeton, KY	67	13	70	24	47	8	13	28	114	21	83	52
Morgantown,WV	46	10	64	15	39	7	18	18	85	17	82	33
Raleigh, NC	51	13	79	22	18	7	22	13	69	20	101	35
Average	87	14	99	25	47	8	32	27	134	22	131	52

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APPENDIX

Table A-1. Observed and long-term normal rainfall and mean temperature data for June through September (June-Sept.) near sites cooperating with the Virginia Tech switchgrass biofuels project

(Departure from long-term normals is observed values minus long-term normal values.)

Location	Long-term	Observed (June-Sept.)					Departure from long-term (June-Sept.)				
	June-Sept.	1997	1998	1999	2000	2001	1997	1998	1999	2000	2001
	---------- Precipitation (cm) ----------										
VA (B)	34.8	44.5	17.7	35.1	50.2	39.1	9.7	-17.1	0.3	15.4	4.3
VA (O)	39.6	34.2	27.3	40.0	43.7	41.4	-5.4	-12.3	0.4	4.1	1.8
TN (K)	38.1	37.5	44.3	45.3	36.8	39.3	-0.6	6.2	7.2	-1.3	1.2
TN (J)	38.6	61.8	48.5	26.2	32.1	42.2	23.2	9.9	-12.4	-6.5	3.6
KY	39.4	32.8	52.8	27.6	34.7	45.0	-6.6	13.4	-11.8	-4.7	5.6
WV	39.7	32.6	33.9	27.2	33.8	45.4	-7.1	-5.8	-12.5	-5.9	5.7
NC	40.3	32.6	34.0	59.7	92.4	65.0	-7.7	-6.3	19.4	52.1	24.7
Average	38.6	39.4	36.9	37.3	46.2	45.3	0.8	-1.7	-1.3	7.6	6.7
	---------- Mean temperature (ºC) ----------										
VA (B)	20.1	23.1	20.7	20.2	20.3	19.6	3.0	0.6	0.1	0.2	-0.5
VA (O)	22.5	19.8	23.9	23.3	21.9	21.7	-2.7	1.4	0.8	-0.6	-0.8
TN (K)	23.3	22.6	23.1	23.3	23.6	23.1	-0.7	-0.2	0.0	0.3	-0.2
TN (J)	24.4	24.2	26.1	25.5	25.0	24.5	-0.2	1.7	1.1	0.6	0.1
KY	23.9	24.6	25.5	25.5	24.5	21.8	0.7	1.6	1.6	0.6	-2.1
WV	20.9	20.3	22.5	21.6	20.4	20.4	-0.6	1.6	0.7	-0.5	-0.5
NC	24.3	23.6	23.9	23.8	23.4	23.6	-0.7	-0.4	-0.5	-0.9	-0.7
Average	22.7	22.6	23.7	23.3	22.7	22.1	-0.1	1.0	0.6	0.0	-0.6

Table A-2. Rainfall and mean temperature (and departure from long-term normals) data during 1997 near sites cooperating with the Virginia Tech switchgrass biofuels project

(T/A is total rainfall or average temperature.)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	---------- Precipitation (cm) ----------												
VA (B)	6.6	5.4	10.8	5.4	2.3	6.9	25.2	3.9	8.5	7.7	14.3	5.0	102.0
VA (O)	6.2	4.9	10.4	5.4	5.4	8.4	12.2	4.8	8.7	3.1	6.6	5.6	81.7
TN (K)	13.1	10.7	16.5	12.9	15.5	14.1	14.2	2.7	6.5	18.2	6.0	7.5	137.9
TN (J)	10.9	15.0	33.8	14.2	8.2	24.9	11.9	17.0	8.0	5.7	7.1	8.9	165.6
KY	7.0	9.7	33.1	10.0	13.6	12.9	4.8	5.2	9.9	5.1	6.7	5.8	123.8
WV	4.1	3.4	13.6	4.7	11.1	6.5	5.0	12.2	8.5	3.0	12.5	6.3	90.9
NC	7.5	8.0	8.9	15.8	5.4	11.0	11.0	3.5	7.1	7.3	8.9	8.2	102.6
Average	7.9	8.2	18.2	9.8	8.8	12.1	12.0	7.0	8.2	7.2	8.9	6.8	115.1
	---------- Mean temperature (ºC) ----------												
VA (B)	1.1	4.7	8.0	15.6	15.6	21.1	24.3	27.6	19.4	13.4	6.7	3.4	13.4
VA (O)	0.8	4.4	8.3	8.8	13.1	18.4	22.0	20.8	17.8	12.1	4.4	1.8	11.1
TN (K)	3.5	7.2	12.1	11.8	16.2	21.9	25.5	23.3	21.0	14.1	6.1	3.5	13.9
TN (J)	2.8	7.5	12.3	12.5	18.0	22.8	26.7	25.0	22.1	15.3	7.8	4.7	14.8
KY	1.1	6.7	11.1	12.1	17.8	24.4	26.1	25.6	22.2	15.6	7.8	4.4	14.6
WV	-0.5	3.3	6.3	8.9	11.9	20.2	22.6	22.1	17.4	12.0	5.4	2.0	11.0
NC	5.9	9.1	13.4	13.6	18.3	22.0	26.4	23.8	22.1	15.8	7.0	6.0	15.3
Average	2.1	6.1	10.2	11.9	15.8	21.5	24.8	24.0	20.3	14.0	6.5	3.7	13.4
	---------- Departure from long-term normal precipitation (cm) ----------												
VA (B)	1.0	-1.5	3.2	-1.7	-7.4	-1.7	15.0	-4.5	0.9	-0.7	7.9	-1.9	8.6
VA (O)	-1.2	-2.0	1.8	-2.5	-5.8	-0.2	1.0	-6.1	-0.2	-7.1	-2.5	-2.0	-26.8
TN (K)	2.4	0.3	3.5	3.5	5.1	3.9	2.3	-5.4	-1.4	11.1	-3.4	-4.2	17.7
TN (J)	1.1	3.9	20.8	1.2	-5.8	14.5	1.0	9.6	-1.9	-2.7	-5.3	-5.1	31.3
KY	-2.7	-1.5	20.7	-2.2	0.9	3.2	-6.1	-5.0	1.3	-2.5	-5.0	-7.2	-6.1
WV	-2.3	-3.0	3.9	-4.2	1.2	-3.9	-5.7	2.0	0.1	-4.1	3.9	-1.8	-13.9
NC	-2.4	-1.9	-1.5	8.4	-5.5	1.1	-0.4	-7.4	-1.0	-1.3	1.0	-0.4	-11.3
Average	-0.6	-0.7	7.5	0.4	-2.4	2.4	1.0	-2.4	-0.3	-1.0	-0.5	-3.2	0.2
	---------- Departure from long-term normal mean temperature (ºC) ----------												
VA (B)	1.7	3.9	2.2	5.1	-0.1	1.3	2.5	6.4	1.8	1.7	0.2	1.6	2.3
VA (O)	0.6	2.7	1.3	-3.6	-4.4	-3.7	-2.3	-2.7	-2.1	-1.4	-3.9	-0.8	-1.7
TN (K)	1.3	2.7	2.7	-2.4	-2.3	-1.0	0.7	-1.1	-0.1	-0.6	-3.2	-1.0	-0.4
TN (J)	0.9	3.2	2.5	-2.8	-1.9	-1.3	0.6	-0.4	0.2	-0.3	-2.2	0.1	-0.1

Table A-2 (continued)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
KY	0.2	3.3	1.8	-2.6	-1.4	0.8	0.5	0.8	0.8	0.4	-1.6	0.8	0.3
WV	1.2	3.4	0.6	-2.1	-4.4	-0.4	-0.1	0.1	-0.9	0.0	-1.5	0.8	-0.2
NC	2.1	3.7	3.1	-1.7	-1.3	-1.8	0.5	-1.5	0.1	0.0	-4.3	0.1	0.0
Average	1.1	3.2	2.0	-1.4	-2.3	-0.9	0.4	0.2	0.0	-0.1	-2.3	0.3	0.0

Table A-3. Rainfall and mean temperature (and departure from long-term normals) data during 1998 near sites cooperating with the Virginia Tech switchgrass biofuels project

(T/A is total rainfall or average temperature.)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	Precipitation (cm)												
VA (B)	17.4	8.1	9.1	11.8	16.0	4.9	2.2	8.7	2.0	5.1	1.1	6.2	92.6
VA (O)	15.4	19.1	14.0	8.9	12.0	11.9	8.3	3.8	3.3	7.1	2.6	6.2	112.6
TN (K)	12.3	8.4	11.4	30.0	13.3	21.6	14.2	5.9	2.6	4.1	5.6	19.7	149.1
TN (J)	15.8	11.0	11.8	17.5	17.0	8.2	26.1	11.5	2.6	6.4	2.4	15.4	145.7
KY	7.5	8.7	5.8	15.5	9.7	32.1	16.5	3.6	0.7	15.7	5.9	11.3	133.0
WV	7.2	6.8	6.4	8.8	9.2	18.4	1.8	7.4	6.4	4.8	2.3	3.8	83.3
NC	7.6	7.6	8.6	14.3	6.1	12.1	14.3	2.3	5.3	10.7	8.7	8.2	105.8
Average	11.9	9.9	9.6	15.3	11.9	15.6	11.9	6.2	3.3	7.7	4.1	10.1	117.5
	Mean temperature (ºC)												
VA (B)	2.1	2.8	4.2	10.5	17.1	20.0	21.9	21.3	19.8	12.1	6.3	3.5	11.8
VA (O)	4.7	5.0	7.2	13.7	19.0	22.1	24.5	24.4	24.5	14.5	9.0	6.3	14.6
TN (K)	4.8	6.5	8.0	13.0	19.9	22.2	24.2	23.4	22.8	15.4	9.2	5.5	14.6
TN (J)	6.3	7.8	9.8	15.3	22.4	26.4	27.1	25.9	25.0	17.8	11.8	6.3	16.8
KY	6.5	7.1	10.1	14.7	22.1	25.1	26.6	25.5	24.8	17.5	11.4	5.9	16.4
WV	4.6	4.8	6.7	11.7	18.0	20.1	24.4	23.3	22.2	13.3	8.0	2.2	13.3
NC	5.0	8.3	12.8	13.3	18.3	22.4	26.4	25.0	21.8	16.0	9.2	6.0	15.4
Average	4.9	6.0	8.4	13.2	19.6	22.7	25.1	24.2	23.0	15.3	9.4	5.2	14.8
	Departure from long-term normal precipitation (cm)												
VA (B)	11.8	1.2	1.5	4.7	6.3	-3.7	-8.0	0.3	-5.6	-3.3	-5.3	-0.7	-0.8
VA (O)	8.0	12.2	5.4	1.0	0.8	3.3	-2.9	-7.1	-5.6	-3.1	-6.5	-1.4	4.1
TN (K)	1.6	-2.0	-1.6	20.6	2.9	11.4	2.3	-2.2	-5.3	-3.0	-3.8	8.0	28.9
TN (J)	6.0	-0.1	-1.2	4.5	3.0	-2.2	15.2	4.1	-7.3	-2.0	-10.0	1.4	11.4
KY	-2.2	-2.5	-6.6	3.3	-3.0	22.4	5.6	-6.6	-7.9	8.1	-5.8	-1.7	3.1
WV	0.8	0.4	-3.3	-0.1	-0.7	8.0	-8.9	-2.8	-2.0	-2.3	-6.3	-4.3	-21.5
NC	-2.3	-2.3	-1.8	6.9	-4.8	2.2	2.9	-8.6	-2.8	2.1	0.8	-0.4	-8.1
Average	3.4	1.0	-1.1	5.9	0.7	5.9	0.9	-3.2	-5.2	-0.5	-5.3	0.1	2.6

Table A-3 (continued)

Location	Month												
	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**T/A**
	------------------------ Departure from long-term normal mean temperature (ºC) ------------------------												
VA (B)	2.7	2.0	-1.6	0.0	1.4	0.2	0.1	0.1	2.2	0.4	-0.2	1.7	0.7
VA (O)	4.5	3.3	0.2	1.3	1.5	0.0	0.2	0.9	4.6	1.0	0.7	3.7	1.8
TN (K)	2.6	2.0	-1.4	-1.2	1.4	-0.7	-0.6	-1.0	1.7	0.7	-0.1	1.0	0.4
TN (J)	4.4	3.5	0.0	0.0	2.5	2.3	1.0	0.5	3.1	2.2	1.8	1.7	1.9
KY	5.6	3.7	0.8	0.0	2.9	1.5	1.0	0.7	3.4	2.3	2.0	2.3	2.1
WV	6.3	4.9	1.0	0.7	1.7	-0.5	1.7	1.3	3.9	1.3	1.1	1.0	2.1
NC	1.2	2.9	2.5	-2.0	-1.3	-1.4	0.5	-0.3	-0.2	0.2	-2.1	0.1	0.1
Average	3.9	3.1	0.2	-0.1	1.5	0.3	0.7	0.4	2.7	1.2	0.6	1.8	1.4

Table A-4. Rainfall and mean temperature (and departure from long-term normals) data during 1999 near sites cooperating with the Virginia Tech switchgrass biofuels project

(T/A is total rainfall or average temperature.)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	Precipitation (cm)												
VA (B)	8.8	5.9	7.5	8.1	6.1	3.3	12.1	8.1	11.7	4.3	5.3	4.6	85.8
VA (O)	13.4	4.9	9.4	3.8	4.2	1.9	6.8	7.5	23.7	5.2	7.1	6.8	94.7
TN (K)	17.9	11.3	12.5	8.9	14.7	15.1	25.9	2.4	2.0	5.3	7.4	5.0	128.4
TN (J)	21.8	4.3	10.1	11.7	10.8	13.3	10.4	1.4	1.2	10.4	7.6	12.1	115.1
KY	22.4	5.6	10.3	14.9	8.5	11.5	11.7	2.5	1.8	8.8	8.2	10.3	116.5
WV	15.6	4.3	7.8	10.9	7.2	7.3	6.2	4.1	9.7	5.8	9.9	6.6	95.4
NC	14.0	4.8	10.8	6.2	5.2	3.0	7.8	12.3	41.2	8.4	2.5	4.2	120.4
Average	16.3	5.9	9.8	9.2	8.1	7.9	11.6	5.5	13.0	6.9	6.9	7.1	108.2
	Mean temperature (ºC)												
VA (B)	1.7	2.3	3.0	11.5	14.5	19.4	22.9	21.1	17.3	10.8	9.7	2.7	11.4
VA (O)	3.1	4.2	5.7	13.2	18.1	22.3	26.4	24.8	19.9	12.5	11.1	4.3	13.8
TN (K)	4.4	5.4	5.9	14.7	16.2	20.6	25.1	25.4	21.0	14.9	11.8	4.9	14.2
TN (J)	6.1	8.8	8.3	17.7	19.9	25.1	27.9	26.3	22.6	15.7	12.9	5.8	16.4
KY	4.3	7.9	7.6	17.0	20.0	24.7	27.9	26.0	23.3	16.7	13.8	6.7	16.3
WV	1.4	2.5	2.3	12.3	17.0	21.3	25.0	21.6	18.5	12.0	9.8	2.9	12.2
NC	6.9	6.9	8.0	15.4	18.6	22.4	26.0	26.1	20.5	15.0	12.7	6.9	15.5
Average	4.0	5.4	5.8	14.5	17.8	22.3	25.9	24.5	20.4	13.9	11.7	4.9	14.3
	Departure from long-term normal precipitation (cm)												
VA (B)	3.2	-1.0	-0.1	1.0	-3.6	-5.3	1.9	-0.3	4.1	-4.1	-1.1	-2.3	-7.6
VA (O)	6.0	-2.0	0.8	-4.1	-7.0	-6.7	-4.4	-3.4	14.8	-5.0	-2.0	-0.8	-13.8
TN (K)	7.2	0.9	-0.5	-0.5	4.3	4.9	14.0	-5.7	-5.9	-1.8	-2.0	-6.7	8.2
TN (J)	12.0	-6.8	-2.9	-1.3	-3.2	2.9	-0.5	-6.0	-8.7	2.0	-4.8	-1.9	-19.2
KY	12.7	-5.6	-2.1	2.7	-4.2	1.8	0.8	-7.7	-6.8	1.2	-3.5	-2.7	-13.4
WV	9.2	-2.1	-1.9	2.0	-2.7	-3.1	-4.5	-6.1	1.3	-1.3	1.3	-1.5	-9.4
NC	4.1	-5.1	0.4	-1.2	-5.7	-6.9	-3.6	1.4	33.1	-0.2	-5.4	-4.4	6.5
Average	7.8	-3.0	-0.9	-0.2	-3.1	-1.8	0.6	-3.9	4.5	-1.3	-2.5	-2.9	-6.7

Table A-4 (continued)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	---------------------- Departure from long-term normal mean temperature (ºC) ----------------------												
VA (B)	2.3	1.5	-2.8	1.0	-1.2	-0.4	1.1	-0.1	-0.3	-0.9	3.2	0.9	0.3
VA (O)	2.9	2.5	-1.3	0.8	0.6	0.2	2.1	1.3	0.0	-1.0	2.8	1.7	1.0
TN (K)	2.2	0.9	-3.5	0.5	-2.3	-2.3	0.3	1.0	-0.1	0.2	2.5	0.4	0.0
TN (J)	4.2	4.5	-1.5	2.4	0.0	1.0	1.8	0.9	0.7	0.1	2.9	1.2	1.5
KY	3.4	4.5	-1.7	2.3	0.8	1.1	2.3	1.2	1.9	1.5	4.4	3.1	2.0
WV	3.1	2.6	-3.4	1.3	0.7	0.7	2.3	-0.4	0.2	0.0	2.9	1.7	1.0
NC	3.1	1.5	-2.3	0.1	-1.0	-1.4	0.1	0.8	-1.5	-0.8	1.4	1.0	0.2
Average	3.0	2.5	-2.4	1.2	-0.3	-0.1	1.5	0.7	0.1	-0.2	2.9	1.5	0.9

Table A-5. Rainfall and mean temperature (and departure from long-term normals) data during 2000 near sites cooperating with the Virginia Tech switchgrass biofuels project

(T/A is total rainfall or average temperature.)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	---------- Precipitation (cm) ----------												
VA (B)	6.3	5.9	5.5	11.6	4.4	14.3	15.3	9.5	11.1	0.2	2.4	6.2	92.7
VA (O)	6.3	4.5	5.9	13.1	5.5	15.1	8.7	6.9	13.0	0.2	4.2	6.4	89.8
TN (K)	13.5	9.7	10.6	17.1	20.1	12.1	9.8	5.0	9.9	0.2	11.7	7.6	127.3
TN (J)	4.5	10.1	10.0	13.2	8.9	10.1	6.3	7.4	8.3	2.2	10.9	7.6	99.5
KY	14.9	13.6	10.7	14.6	12.8	7.8	11.4	5.0	10.5	2.9	10.2	9.8	124.2
WV	3.4	13.2	8.0	12.1	16.7	11.1	8.8	8.3	5.6	4.0	3.7	5.0	99.9
NC	11.4	4.8	7.6	7.0	1.9	34.9	9.4	25.8	22.3	0.0	5.6	2.9	133.6
Average	7.5	7.7	7.3	11.1	8.8	13.2	8.7	8.5	10.1	1.2	6.1	5.7	95.9
	---------- Mean temperature (ºC) ----------												
VA (B)	0.1	4.0	8.2	10.4	16.4	21.3	21.2	20.7	17.8	14.6	4.4	-2.9	11.4
VA (O)	0.6	4.6	10.1	12.7	19.1	23.0	22.7	23.0	18.9	14.8	6.9	-1.5	12.9
TN (K)	3.1	6.9	11.2	12.7	20.4	23.7	24.8	24.2	21.5	15.7	8.3	0.6	14.4
TN (J)	4.4	8.0	12.7	14.0	21.9	24.4	26.1	27.2	22.3	17.9	9.0	-0.3	15.6
KY	3.5	9.2	11.9	14.6	21.4	24.2	25.3	26.7	21.7	20.3	8.0	-2.0	15.4
WV	-1.1	4.5	7.9	10.8	17.5	21.5	21.0	21.0	17.9	12.7	4.2	-3.9	11.2
NC	4.0	8.0	12.5	14.3	21.6	24.9	24.0	23.8	20.8	15.7	9.1	2.2	15.1
Average	1.8	5.7	9.3	11.2	17.3	20.4	20.6	20.8	17.6	14.0	6.2	-1.0	12.0
	---------- Departure from long-term normal precipitation (cm) ----------												
VA (B)	0.7	-1.0	-2.1	4.5	-5.3	5.7	5.1	1.1	3.5	-8.2	-4.0	-0.7	-0.7
VA (O)	-1.1	-2.4	-2.7	5.2	-5.7	6.5	-2.5	-4.0	4.1	-10.0	-4.9	-1.2	-18.7
TN (K)	2.8	-0.7	-2.4	7.7	9.7	1.9	-2.1	-3.1	2.0	-6.9	2.3	-4.1	7.1
TN (J)	-5.3	-1.0	-3.0	0.2	-5.1	-0.3	-4.6	0.0	-1.6	-6.2	-1.5	-6.4	-34.8
KY	5.2	2.4	-1.7	2.4	0.1	-1.9	0.5	-5.2	1.9	-4.7	-1.5	-3.2	-5.7
WV	-3.0	6.8	-1.7	3.2	6.8	0.7	-1.9	-1.9	-2.8	-3.1	-4.9	-3.1	-4.9
NC	1.5	-5.1	-2.8	-0.4	-9.0	25.0	-2.0	14.9	14.2	-8.6	-2.3	-5.7	19.7
Average	-1.0	-1.2	-3.4	1.7	-2.4	3.5	-2.3	-0.9	1.6	-7.0	-3.3	-4.3	-19.0

Table A-5 (continued)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	---------------------- Departure from long-term normal mean temperature (°C) ----------------------												
VA (B)	0.7	3.2	2.4	-0.1	0.7	1.5	-0.6	-0.5	0.2	2.9	-2.1	-4.7	0.3
VA (O)	0.4	2.9	3.1	0.3	1.6	0.9	-1.6	-0.5	-1.0	1.3	-1.4	-4.1	0.1
TN (K)	0.9	2.4	1.8	-1.5	1.9	0.8	0.0	-0.2	0.4	1.0	-1.0	-3.9	0.2
TN (J)	2.5	3.7	2.9	-1.3	2.0	0.3	0.0	1.8	0.4	2.3	-1.0	-4.9	0.7
KY	2.6	5.8	2.6	-0.1	2.2	0.6	-0.3	1.9	0.3	5.1	-1.4	-5.6	1.1
WV	0.6	4.6	2.2	-0.2	1.2	0.9	-1.7	-1.0	-0.4	0.7	-2.7	-5.1	0.0
NC	0.2	2.6	2.2	-1.0	2.0	1.1	-1.9	-1.5	-1.2	-0.1	-2.2	-3.7	-0.2
Average	0.8	2.8	1.1	-2.1	-0.8	-2.0	-3.8	-3.0	-2.7	-0.1	-2.6	-4.4	-1.4

Table A-6. Rainfall and mean temperature (and departure from long-term normals) during 2001 near sites cooperating with the Virginia Tech switchgrass biofuels project

(T/A is total rainfall or average temperature.)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	---------- Precipitation (cm) ----------												
VA (B)	4.5	2.0	8.7	1.6	21.2	9.3	17.9	6.6	5.3	1.8	3.0	6.0	88
VA (O)	4.7	2.8	11.0	1.8	11.9	21.3	10.4	7.6	2.1	3.0	1.2	5.0	83
TN (K)	12.7	18.0	6.8	5.7	10.8	7.5	21.2	7.2	10.9	2.7	3.7	12.6	124
TN (J)	6.8	18.3	7.1	6.3	12.4	12.2	12.0	11.8	5.8	18.7	27.7	19.6	159
KY	3.9	12.9	7.1	11.0	6.2	12.2	13.9	10.0	8.9	18.9	10.2	9.8	125
WV	-1.4	4.4	6.4	7.9	8.7	11.6	14.0	10.7	9.1	3.6	5.4	6.7	87
NC	3.6	6.0	16.7	6.9	6.5	24.7	25.6	10.7	4.0	5.6	2.5	8.0	121
Average	5.0	9.2	9.1	5.9	11.1	14.1	16.4	9.2	6.6	7.8	8.6	9.3	112
	---------- Mean temperature (ºC) ----------												
VA (B)	-0.9	2.8	3.1	11.7	15.4	19.7	20.1	22.0	16.5	10.0	7.0	3.0	10.9
VA (O)	1	4.4	5.7	13.4	17.3	22.5	22.7	22.3	19.4	13.9	9.0	8.0	13.3
TN (K)	1.2	7.0	7.5	15.3	19.7	22.5	25.0	25.0	20.0	13.2	9.3	4.5	14.2
TN (J)	1.7	7.5	7.8	18.3	20.8	23.5	27.0	26.5	21.1	14.9	11.7	7.2	15.8
KY	1.7	7.0	6.7	18.0	20.9	23.0	26.7	26.7	20.9	16.4	9.0	5.5	15.2
WV	4.9	3.3	2.8	12.8	16.0	20.5	21.3	23.0	16.9	12.9	9.6	4.4	12.4
NC	4	9.3	9.7	16.1	19.9	24.0	24.4	25.3	20.6	15.6	14.1	6.5	15.8
Average	1.9	5.9	6.2	15.1	18.5	22.2	23.9	24.4	19.3	13.8	10.1	5.6	13.9
	---------- Departure from long-term normal precipitation (cm) ----------												
VA (B)	-1.1	-4.9	1.1	-5.5	11.5	0.7	7.7	-1.8	-2.3	-6.6	-3.4	-0.9	-5.5
VA (O)	-2.7	-4.1	2.4	-6.1	0.7	12.7	-0.8	-3.3	-6.8	-7.2	-7.9	-2.6	-25.7
TN (K)	2.0	7.6	-6.2	-3.7	0.4	-2.7	9.3	-0.9	3.0	-4.4	0.6	-1.7	3.3
TN (J)	-3.0	7.2	-5.9	-6.7	-1.6	1.8	1.1	4.4	-4.1	10.3	15.3	5.6	24.4
KY	-5.8	1.7	-5.3	-1.2	-6.5	2.5	3.0	-0.2	0.3	11.3	-1.5	-3.2	-4.9
WV	-7.8	-2.0	-3.3	-1.0	-1.2	1.2	3.3	0.5	0.7	-3.5	-3.2	-1.4	-17.7
NC	-6.3	-3.9	6.3	-0.5	-4.4	14.8	14.2	-0.2	-4.1	-3.0	-5.4	-0.6	6.9
Average	-3.5	0.3	-1.6	-3.5	-0.1	4.4	5.4	-0.2	-1.9	-0.4	-0.8	-0.7	-2.6

Table A-6 (continued)

Location	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	T/A
	------------------ Departure from long-term normal mean temperature (ºC) -----------------												
VA (B)	-0.3	2.0	-2.7	1.2	-0.3	-0.1	-1.7	0.8	-1.1	-1.7	0.5	1.2	-0.2
VA (O)	0.8	2.7	-1.3	1.0	-0.2	0.4	-1.6	-1.2	-0.5	0.4	0.7	5.4	0.5
TN (K)	-1.0	2.5	-1.9	1.1	1.2	-0.4	0.2	0.6	-1.1	-1.5	0.0	0.0	0.0
TN (J)	-0.2	3.2	-2.0	3.0	0.9	-0.6	0.9	1.1	-0.8	-0.7	2.5	3.0	0.9
KY	0.8	3.6	-2.6	3.3	1.7	-0.6	1.1	1.9	-0.5	1.2	-0.4	1.9	0.9
WV	6.6	3.4	-2.9	1.8	-0.3	-0.1	-1.4	1.0	-1.4	0.9	2.7	3.2	1.2
NC	0.2	3.9	-0.6	0.8	0.3	0.2	-1.5	0.0	-1.4	-0.2	2.8	0.6	0.5
Average	0.9	3.0	-2.0	1.8	0.5	-0.2	-0.5	0.6	-1.0	-0.3	1.3	2.2	0.5

Table A-7. Mean rainfall and mean temperature long-term normal data near sites cooperating with the Virginia Tech switchgrass biofuels project

(T/A is total rainfall or average temperature.)

Location	Month												
	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**T/A**
	---------- Precipitation (cm) ----------												
VA (B)	5.6	6.9	7.6	7.1	9.7	8.6	10.2	8.4	7.6	8.4	6.4	6.9	93.4
VA (O)	7.4	6.9	8.6	7.9	11.2	8.6	11.2	10.9	8.9	10.2	9.1	7.6	108.5
TN (K)	10.7	10.4	13.0	9.4	10.4	10.2	11.9	8.1	7.9	7.1	9.4	11.7	120.2
TN (J)	9.8	11.1	13.0	13.0	14.0	10.4	10.9	7.4	9.9	8.4	12.4	14.0	134.3
KY	9.7	11.2	12.4	12.2	12.7	9.7	10.9	10.2	8.6	7.6	11.7	13.0	129.9
WV	6.4	6.4	9.7	8.9	9.9	10.4	10.7	10.2	8.4	7.1	8.6	8.1	104.8
NC	9.9	9.9	10.4	7.4	10.9	9.9	11.4	10.9	8.1	8.6	7.9	8.6	113.9
Average	8.5	8.9	10.7	9.4	11.2	9.7	11.0	9.4	8.5	8.2	9.4	10.0	114.9
	---------- Mean temperature (ºC) ----------												
VA (B)	-0.6	0.8	5.8	10.5	15.7	19.8	21.8	21.2	17.6	11.7	6.5	1.8	11.1
VA (O)	0.2	1.7	7.0	12.4	17.5	22.1	24.3	23.5	19.9	13.5	8.3	2.6	12.8
TN (K)	2.2	4.5	9.4	14.2	18.5	22.9	24.8	24.4	21.1	14.7	9.3	4.5	14.2
TN (J)	1.9	4.3	9.8	15.3	19.9	24.1	26.1	25.4	21.9	15.6	10.0	4.6	14.9
KY	0.9	3.4	9.3	14.7	19.2	23.6	25.6	24.8	21.4	15.2	9.4	3.6	14.3
WV	-1.7	-0.1	5.7	11.0	16.3	20.6	22.7	22.0	18.3	12.0	6.9	1.2	11.2
NC	3.8	5.4	10.3	15.3	19.6	23.8	25.9	25.3	22.0	15.8	11.3	5.9	15.3
Average	1.0	2.9	8.2	13.3	18.1	22.4	24.4	23.8	20.3	14.1	8.8	3.4	13.4

Table A-8. Average corn grain yields from county agricultural statistics for locations where switchgrass is being studied as a biofuels crop

[Also average corn yields estimated by soil capability class as used by Soil Conservation Service (based on soil productivity factors).]

Location	1993	1994	1995	1996	1997	1998	1999	2000	2001	Av	By class
	----------	----------	----------	----------	----------	Mg ha^{-1}	----------	----------	----------	----------	----------
Blacksburg, VA											
Site A	5.9	7.4	6.8	7.1	4.9	4.5	2.2	6.9	7.1	5.9	7.0
Site B	5.9	7.4	6.8	7.1	4.9	4.5	2.2	6.9	7.1	5.9	8.1
Orange, VA	4.3	6.2	7.3	7.9	6.8	5.3	4.1	8.4	7.3	6.4	7.0
Knoxville, TN	4.7	7.2	4.6	6.2	5.5	9.3	5.8	6.3	6.3	6.2	6.7
Jackson, TN	4.1	6.5	5.7	6.1	6.7	5.1	5.5	6.0	7.1	5.9	5.7
Princeton, KY	6.3	7.9	7.4	6.8	6.5	6.5	5.8	7.2	7.9	6.9	8.1
Morgantown, WV	--	6.2	8.3	7.1	7.4	6.3	2.2	5.1	7.8	5.6	6.7
Raleigh, NC	--	4.7	4.7	5.3	5.2	3.4	2.7	5.6	5.3	4.1	5.7
Average	5.2	6.6	6.4	6.6	6.2	5.8	4.1	6.5	7.0	6.0	6.9

Table A-9. Fertilization history during ten years (1992 to 2001) of switchgrass growth at eight locations

[All applications were made before growth began in any year. No limestone was applied at any location. Nitrogen was applied at 100 kg ha^{-1} for the first 10 years. No N was applied in 1997. In 1998, no N was applied to two replications, and two replications received the full yearly amount (100 kg ha^{-1} N in a split application for the two-cut management and 50 kg ha^{-1} N in the spring for the one-cut management). The full amount was applied the last three years.]

Location	Amount received (year)	
	P	K
	-------------------- kg ha^{-1}	--------------------
Blacksburg, VA (Site A)	63 (1993)	200 (1998)
	82 (1998)	
	145 Total	200 Total
Blacksburg, VA (Site B)	63 (1993)	200 (1998)
	82 (1998)	
	145 Total	200 Total
Orange, VA	35 (1993)	34 (1993)
	19 (1994)	140 (1994)
	19 (1995)	140 (1995)
	22 (1998)	30 (1998)
	22 (1999)	30 (1999)
	22 (2000)	30 (2000)
	22 (2001)	30 (2001)
	161 Total	434 Total
Knoxville, TN	33 (1992)	50 (1994)
	50 (1994)	135 (1997)
	45 (1997)	
	128 Total	185 Total
Jackson, TN	40 (1992)	116 (1999)
	18 (1999)	
	58 Total	116 Total
Morgantown, WV	44 (1993)	76 (1993)
	53 (1994)	52 (1994)
	50 (1997)	50 (1997)
	147 Total	178 Total
Princeton, KY	44 (1993)	60 (1993)
	48 (1994)	72 (1994)
	92 Total	132 Total
Raleigh, NC	60 (1993)	82 (1993)
	50 (1997)	50 (1997)
	110 Total	132 Total

Table A-10. Seasonal yields (averaged over six varieties of switchgrass) and rainfall in several different years at eight locations

[Harvested management included one cut (in November) or two cuts (first cut in early heading stage and second cut in November).]

Cutting mgt	Year	Virginia			Tennessee		WV	KY	NC	Av
		Blacksburg		Orange						
		Site A	Site B		Knox	Jack				
		Mg ha^{-1}								
Once	1994-1996	11.0	11.8	12.7	19.4	11.6	15.1	15.6	12.9	13.8
	1997	11.0	13.9	13.2	17.7	--	12.2	10.5	13.0	13.0
	1998	16.5	15.1	17.6	18.2	14.0	16.2	13.3	18.0	16.1
	1999	13.5	19.1	11.1	16.2	8.0	14.4	18.1	11.6	14.0
	2000	11.2	15.6	16.0	16.4	9.1	15.6	12.9	13.1	13.7
	2001	11.2	21.5	15.9	18.2	10.3	17.5	13.9	6.7	14.4
	1997-2001	12.7	17.0	14.8	17.3	10.4	15.2	13.7	12.5	14.2
Twice	1994-1996	13.7	17.0	14.6	21.2	14.0	13.4	14.3	17.6	15.7
	1997	11.9	13.7	10.6	14.9	--	8.8	11.6	11.1	11.8
	1998	18.5	20.2	17.8	20.6	14.3	15.2	15.0	20.6	17.8
	1999	18.5	23.7	11.0	14.0	8.0	12.5	13.3	13.5	15.1
	2000	16.2	21.1	19.0	15.1	11.7	15.2	14.6	16.2	16.1
	2001	14.6	18.9	15.2	16.6	15.5	14.0	13.6	9.8	14.8
	1997-2001	15.9	19.5	14.7	16.2	12.4	13.1	13.6	14.2	15.1
		Rainfall June through September (cm)								
	1994-1996	35.9	35.9	58.1	35.0	43.6	46.8	37.5	47.3	43.5
	1997	44.5	44.5	34.2	37.5	61.8	32.6	32.8	32.6	39.4
	1998	17.7	17.7	27.3	44.3	48.5	33.9	52.8	34.0	36.9
	1999	35.1	35.1	40.0	45.3	26.2	27.2	27.6	59.7	37.3
	2000	50.2	50.2	41.7	36.8	32.1	33.8	34.7	92.4	46.0
	2001	39.1	39.1	41.4	39.3	42.2	45.4	45.0	65.0	45.3
	1997-2001	37.3	37.3	36.9	40.6	42.2	34.6	38.6	56.7	31.9
		Long-term normal rainfall June through September (cm)								
		34.8	34.8	39.6	38.1	38.6	39.7	39.4	40.3	38.6

Table A-10 (continued)

Cutting Mgt	Year	Virginia			Tennessee		WV	KY	NC	Av
		Blacksburg		Orange						
		Site A	Site B		Knox	Jack				
		---------- Deviation from long-term rainfall June through September (cm) ----------								
Twice	1994-1996	1.1	1.1	23.3	0.2	8.8	12.0	2.7	12.5	4.8
	1997	9.7	9.7	-5.4	-0.6	23.2	-7.1	-6.6	-7.7	0.8
	1998	-17.1	-17.1	-12.3	6.2	9.9	-5.8	13.4	-6.3	-1.7
	1999	0.3	0.3	0.4	7.2	-12.4	-12.5	-11.8	19.4	-1.3
	2000	15.4	15.4	2.1	-1.3	-6.5	-5.9	-4.7	52.1	7.3
	2001	4.3	4.3	1.8	-0.3	2.6	5.8	5.4	25.4	6.7
	1997-2001	2.5	2.5	-2.7	2.2	4.7	-3.9	-0.9	16.4	2.3

Table A-11. Seasonal yields averaged over five years (1997 to 2001) from six varieties of switchgrass at eight locations when harvested once (in November) or twice (first cut in early heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the two-cut management yields.)

Treatment		Virginia			Tennessee		WV[1]	KY	NC	Av
		Blacksburg		Orange						
Cuts	Variety	Site A	Site B		Knox	Jack				
		Mg ha^{-1}								
Once	Alamo	12.3	17.8	17.6	21.0	11.1	14.9	13.7	13.6	15.3
	Kanlow	14.0	19.5	16.1	18.9	11.8	17.9	15.5	13.4	15.9
	Cave-in-Rock	13.0	14.9	12.6	15.0	9.3	13.9	13.0	9.5	12.7
	Shelter	10.8	13.2	10.8	12.3	8.7	12.9	10.8	8.7	11.0
	NC1	13.8	19.5	16.1	18.2	11.1	15.9	14.2	13.9	15.3
	NC2	12.3	17.3	15.4	18.6	10.1	15.7	15.1	15.6	15.0
	Average	12.7	17.0	14.8	17.3	10.4	15.2	13.7	12.5	14.2
Twice	Alamo	15.0	21.1	15.4	16.8	12.6	13.0	15.3	14.5	15.5
	Kanlow	17.0	19.2	14.8	15.3	12.5	13.1	14.3	14.8	15.1
	Cave-in-Rock	16.7	19.3	15.2	17.5	13.3	13.9	13.0	13.9	15.4
	Shelter	15.2	17.2	12.2	16.7	11.4	12.3	11.1	12.1	13.5
	NC1	15.8	20.5	15.6	15.5	11.0	13.3	14.1	15.6	15.2
	NC2	15.9	19.8	14.9	15.6	13.0	13.2	13.9	14.6	15.1
	Average	15.9	19.5	14.7	16.2	12.3	13.1	13.6	14.3	15.0
	LSD 0.05*	1.1	1.6	1.2	1.2	1.1	1.0	1.1	1.2	0.4
		Difference between one- and two-cut managements								
Difference	Alamo	2.7	3.3	-2.2	-4.2	1.5	-1.9	1.6	0.9	0.2
	Kanlow	3.0	-0.3	-1.3	-3.6	0.7	-4.8	-1.2	1.4	-0.8
(Two minus one)	Cave-in-Rock	3.7	4.4	2.6	2.5	4.0	0.0	0.0	4.4	2.7
	Shelter	4.4	4.0	1.4	4.4	2.7	-0.6	0.3	3.4	2.5
	NC1	2.0	1.0	-0.5	-2.7	-0.1	-2.6	-0.1	1.7	-0.2
	NC2	3.6	2.5	-0.5	-3.0	2.9	-2.5	-1.2	-1.0	0.1
	Average	3.2	2.5	-0.1	-1.1	1.9	-2.1	-0.1	1.8	0.8

Table A-11 (continued)

Treatment		Virginia			Tennessee		WV[1]	KY	NC	Av
		Blacksburg		Orange						
Cuts	Variety	Site A	Site B		Knox	Jack				
		Percentage difference								
% Difference (Diff/one)	Alamo	22	19	-13	-20	14	-13	12	7	1
	Kanlow	21	-2	-8	-19	6	-27	-8	10	-5
	Cave-in-Rock	28	30	21	17	43	0	0	46	21
	Shelter	41	30	13	36	31	-5	3	39	23
	NC1	14	5	-3	-15	-1	-16	-1	12	-1
	NC2	29	14	-3	-16	29	-16	-8	-6	1
	Average	25	15	-1	-6	18	-14	-1	14	5

*LSD values are for comparison of means for varieties within and between cutting managements.

[1]Varieties NC1 and NC2 were not present in the WV planting; therefore their estimated values were calculated as missing plots in order to compare across varieties. The one-cut management received only 50 kg of N per ha in the spring and the two-cut management received 50 kg in spring and again after the first harvest.

Table A-12. Seasonal yields from six varieties of switchgrass (averaged over eight locations) when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		------------------------------------- $Mg\ ha^{-1}$ -------------------------------------						
Once	Alamo	13.8	17.1	14.2	15.1	16.4	74.9	15.3
	Kanlow	14.1	17.8	15.8	15.3	16.7	78.0	15.9
	Cave-in-Rock	12.0	14.0	13.0	12.2	12.2	62.0	12.7
	Shelter	9.9	12.5	11.4	10.3	11.2	54.1	11.0
	NC1	13.7	17.6	15.2	15.1	15.4	75.3	15.3
	NC2	14.8	17.6	14.2	14.4	14.6	73.8	15.0
	Average	13.1	16.1	14.0	13.7	14.4	69.7	14.2
Twice	Alamo	12.2	17.7	15.1	17.1	15.1	75.7	15.5
	Kanlow	12.1	18.4	14.2	16.1	14.9	74.1	15.1
	Cave-in-Rock	12.2	17.8	14.8	16.8	15.0	75.1	15.4
	Shelter	10.6	16.0	12.6	14.2	14.2	66.2	13.5
	NC1	12.0	18.3	14.7	16.2	14.8	74.5	15.2
	NC2	11.7	18.5	14.5	16.2	14.7	74.0	15.1
	Average	11.8	17.8	14.3	16.1	14.8	73.3	15.0
	LSD 0.05*	0.9	0.9	0.9	0.9	1.0		0.4
		------------ Difference between one- and two-cut managements ------------						
(Two minus one)	Alamo	-1.6	0.6	0.9	2.1	-1.3	0.9	0.2
	Kanlow	-2.0	0.6	-1.7	0.8	-1.8	-3.8	-0.8
	Cave-in-Rock	0.2	3.8	1.8	4.6	2.8	13.1	2.7
	Shelter	0.7	3.5	1.2	3.8	3.0	12.1	2.5
	NC1	-1.7	0.7	-0.5	1.1	-0.6	-0.8	-0.2
	NC2	-3.2	0.8	0.2	1.8	0.1	0.2	0.1
	Average	-1.3	1.7	0.3	2.4	0.4	3.6	0.8
		--------------------------------- % Difference ---------------------------------						
% Difference (Diff/one)	Alamo	-12	3	6	14	-8	--	1
	Kanlow	-14	3	-11	5	-11	--	-5
	Cave-in-Rock	1	27	14	38	23	--	21
	Shelter	7	28	10	37	26	--	23
	NC1	-12	4	-4	7	-4	--	-1
	NC2	-21	5	2	13	1	--	1
	Average	-10	10	2	17	3	--	5

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-13. Seasonal yields from six varieties of switchgrass at Blacksburg, VA (Site A), when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997-2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		---------- Mg ha^{-1} ----------						
Once	Alamo	10.3	19.3	11.6	9.5	10.6	61.3	12.3
	Kanlow	11.7	18.3	15.2	11.1	13.7	70.0	14.0
	Cave-in-Rock	11.9	14.5	14.8	14.2	9.6	65.0	13.0
	Shelter	10.1	11.0	13.0	10.3	9.6	54.0	10.8
	NC1	10.7	19.3	15.4	10.7	13.1	69.2	13.8
	NC2	11.4	16.8	11.0	11.1	11.1	61.4	12.3
	Average	11.0	16.5	13.5	11.2	11.3	63.5	12.7
Twice	Alamo	12.2	15.7	17.7	15.7	13.7	75.0	15.0
	Kanlow	12.5	21.0	19.0	16.1	16.5	85.1	17.0
	Cave-in-Rock	12.6	17.8	21.1	17.2	14.6	83.3	16.7
	Shelter	11.2	17.9	15.4	16.8	14.8	76.1	15.2
	NC1	11.1	20.5	16.6	17.0	13.7	78.9	15.8
	NC2	11.6	18.3	20.9	14.1	14.4	79.3	15.9
	Average	11.9	18.5	18.5	16.2	14.6	79.6	15.9
	LSD 0.05*	1.8	3.5	2.2	2.3	2.2	--	1.1
		---------- Difference between one- and two-cut managements ----------						
Difference (Two minus one)	Alamo	1.9	-3.6	6.1	6.2	3.1	13.7	2.7
	Kanlow	0.8	2.7	3.8	5.0	2.8	15.1	3.0
	Cave-in-Rock	0.7	3.3	6.3	3.0	5.0	18.3	3.7
	Shelter	1.1	6.9	2.4	6.5	5.2	22.1	4.4
	NC1	0.4	1.2	1.2	6.3	0.6	9.7	1.9
	NC2	0.2	1.5	9.9	3.0	3.3	17.9	3.6
	Average	0.9	2.0	5.0	5.0	3.3	16.2	3.2

Table A-13 (continued)

Treatment		Year of harvest					1997-2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		% Difference						
% Difference (Diff/one)	Alamo	18	-19	53	65	29	--	29
	Kanlow	7	15	25	45	20	--	22
	Cave-in-Rock	6	23	43	21	52	--	29
	Shelter	11	63	18	63	54	--	42
	NC1	4	6	8	59	5	--	16
	NC2	2	9	90	27	30	--	31
	Average	8	12	37	45	29	--	26

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-14. Seasonal yields from six varieties of switchgrass at Blacksburg, VA (Site B), when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut managements and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		------------------------------------ Mg ha^{-1} ------------------------------------						
Once	Alamo	15.6	14.1	14.7	17.1	27.4	88.9	17.8
	Kanlow	15.4	16.9	23.9	18.9	22.2	97.3	19.5
	Cave-in-Rock	12.1	14.0	18.1	11.8	18.4	74.4	14.9
	Shelter	10.0	13.0	15.2	12.0	15.7	65.9	13.2
	NC1	15.0	18.6	22.5	17.2	24.0	97.3	19.5
	NC2	15.0	13.9	20.0	16.4	21.2	86.5	17.3
	Average	13.9	15.1	19.1	15.6	21.5	85.1	17.0
Twice	Alamo	15.9	22.0	25.3	22.4	19.7	105.3	21.1
	Kanlow	13.5	20.0	21.0	21.4	19.9	95.8	19.2
	Cave-in-Rock	13.5	19.3	26.3	20.5	16.7	96.3	19.3
	Shelter	11.2	16.5	22.3	17.4	18.7	86.1	17.2
	NC1	13.8	21.3	26.2	21.5	19.7	102.5	20.5
	NC2	14.1	21.7	21.2	23.3	18.8	99.1	19.8
	Average	13.7	20.2	23.7	21.1	18.9	97.5	19.5
	LSD 0.05*	2.4	3.0	4.4	3.6	4.7	18.1	1.6
		------------- Difference between one- and two-cut managements -------------						
Difference (Two minus one)	Alamo	0.3	7.9	10.6	5.3	-7.7	16.4	3.3
	Kanlow	-1.9	3.1	-2.9	2.5	-2.3	-1.5	-0.3
	Cave-in-Rock	1.4	5.3	8.2	8.7	-1.7	21.9	4.4
	Shelter	1.2	3.5	7.1	5.4	3.0	20.2	4.0
	NC1	-1.2	2.7	3.7	4.3	-4.3	5.2	1.0
	NC2	-0.9	7.8	1.2	6.9	-2.4	12.6	2.5
	Average	-0.2	5.1	4.7	5.5	-2.6	12.5	2.5

Table A-14 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		% Difference						
% Difference	Alamo	2	56	72	31	-28	--	27
	Kanlow	-12	18	-12	13	-10	--	-1
(Diff/one)	Cave-in-Rock	12	38	45	74	-9	--	32
	Shelter	12	27	47	45	19	--	30
	NC1	-8	15	16	25	-18	--	6
	NC2	-6	56	6	42	-11	--	17
	Average	-1	34	24	35	-12	--	16

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-15. Seasonal yields from six varieties of switchgrass at Orange, VA, when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		------------------------------------ Mg ha^{-1} ------------------------------------						
Once	Alamo	15.4	20.4	15.0	19.8	17.6	88.2	17.6
	Kanlow	13.6	18.4	11.9	16.5	20.0	80.4	16.1
	Cave-in-Rock	11.7	15.2	8.3	15.0	12.6	62.8	12.6
	Shelter	9.7	12.8	8.3	11.2	12.2	54.2	10.8
	NC1	14.3	19.7	11.4	18.3	16.7	80.4	16.1
	NC2	14.6	19.0	11.6	15.4	16.2	76.8	15.4
	Average	13.2	17.6	11.1	16.0	15.9	73.8	14.8
Twice	Alamo	10.8	17.4	13.5	20.4	15.1	77.2	15.4
	Kanlow	10.7	17.8	12.0	19.3	14.3	74.1	14.8
	Cave-in-Rock	11.6	19.8	9.6	19.6	15.5	76.1	15.2
	Shelter	8.6	15.0	7.4	15.7	14.2	60.9	12.2
	NC1	11.0	18.5	12.0	19.4	17.0	77.9	15.6
	NC2	11.0	18.0	11.3	19.3	15.0	74.6	14.9
	Average	10.6	17.8	11.0	19.0	15.2	73.5	14.7
	LSD 0.05*	2.6	2.2	2.1	2.4	3.6	12.9	1.2
		------------- Difference between one- and two-cut managements -------------						
Difference	Alamo	-4.6	-3.0	-1.5	0.6	-2.5	-11.0	-2.2
	Kanlow	-2.9	-0.6	0.1	2.8	-5.7	-6.3	-1.3
(Two minus one)	Cave-in-Rock	-0.1	4.6	1.3	4.6	2.9	13.3	2.7
	Shelter	-1.1	2.2	-0.9	4.5	2.0	6.7	1.3
	NC1	-3.3	-1.2	0.6	1.1	0.3	-2.5	-0.5
	NC2	-3.6	-1.0	-0.3	3.9	-1.2	-2.2	-0.4
	Average	-2.6	0.2	-0.1	2.9	-0.7	-0.3	-0.1

Table A-15 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		---------------------------------- % Difference ----------------------------------						
% Difference	Alamo	-30	-15	-10	3	-14	--	-13
	Kanlow	-21	-3	1	17	-28	--	-7
(Diff/one)	Cave-in-Rock	-1	30	16	31	23	--	20
	Shelter	-11	17	-11	40	16	--	10
	NC1	-23	-6	5	6	2	--	-3
	NC2	-25	-5	-3	25	-7	--	-3
	Average	-20	1	-1	18	-4	--	-1

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-16. Seasonal yields from six varieties of switchgrass at Knoxville, TN, when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut managements and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		------------------------------------ $Mg\ ha^{-1}$ ------------------------------------						
Once	Alamo	19.2	20.4	20.0	20.8	24.8	105.2	21.0
	Kanlow	19.3	20.2	16.9	15.5	22.5	94.4	18.9
	Cave-in-Rock	17.7	15.6	13.5	14.4	13.8	75.0	15.0
	Shelter	12.0	13.9	12.7	11.8	11.2	61.6	12.3
	NC1	18.7	18.3	17.3	18.0	18.6	90.9	18.2
	NC2	19.0	20.8	16.7	18.0	18.4	92.9	18.6
	Average	17.7	18.2	16.2	16.4	18.2	86.7	17.3
Twice	Alamo	14.7	21.8	12.5	17.0	18.1	84.1	16.8
	Kanlow	13.8	20.6	13.2	14.1	15.0	76.7	15.3
	Cave-in-Rock	15.9	21.4	16.4	16.7	17.1	87.5	17.5
	Shelter	16.9	19.2	16.6	14.2	16.6	83.5	16.7
	NC1	14.1	20.3	12.6	14.2	16.3	77.5	15.5
	NC2	14.2	20.5	12.6	14.2	16.4	77.9	15.6
	Average	14.9	20.6	14.0	15.1	16.6	81.2	16.2
	LSD 0.05*	2.9	2.6	2.6	2.3	3.0	12.5	1.1
		------------- Difference between one- and two-cut managements -------------						
Difference	Alamo	-4.5	1.4	-7.5	-3.8	-6.7	-21.1	-4.2
	Kanlow	-5.5	0.4	-3.7	-1.4	-7.5	-17.7	-3.5
(Two minus one)	Cave-in-Rock	-1.8	5.8	2.9	2.3	3.3	12.5	2.5
	Shelter	4.9	5.3	3.9	2.4	5.4	21.9	4.4
	NC1	-4.6	2.0	-4.7	-3.8	-2.3	-13.4	-2.7
	NC2	-4.8	-0.3	-4.1	-3.8	-2.0	-15.0	-3.0
	Average	-2.7	2.4	-2.2	-1.4	-1.6	-5.5	-1.1

Table A-16 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		% Difference						
% Difference (Diff/one)	Alamo	-23	7	-38	-18	-27	--	-20
	Kanlow	-28	2	-22	-9	-33	--	-18
	Cave-in-Rock	-10	37	21	16	24	--	18
	Shelter	41	38	31	20	48	--	36
	NC1	-25	11	-27	-21	-12	--	-15
	NC2	-25	-1	-25	-21	-11	--	-17
	Average	-15	13	-14	-8	-9	--	-7

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-17. Seasonal yields from six varieties of switchgrass at Jackson, TN, when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		------ Mg ha^{-1} ------						
Once	Alamo	--	16.4	8.7	7.8	11.6	44.5	11.1
	Kanlow	--	14.7	9.0	11.0	12.7	47.4	11.8
	Cave-in-Rock	--	12.9	7.7	8.3	8.2	37.1	9.3
	Shelter	--	10.9	7.2	7.9	8.7	34.7	8.7
	NC1	--	15.6	8.4	9.9	10.6	44.5	11.1
	NC2	--	13.8	6.8	9.7	10.2	40.5	10.1
	Average	--	14.0	8.0	9.1	10.3	41.4	10.4
Twice	Alamo	--	13.3	8.3	12.0	16.6	50.2	12.6
	Kanlow	--	14.8	8.1	11.7	15.5	50.1	12.5
	Cave-in-Rock	--	14.2	7.9	14.2	16.9	53.2	13.3
	Shelter	--	14.7	7.1	10.0	13.9	45.7	11.4
	NC1	--	12.3	7.4	9.3	15.1	44.1	11.0
	NC2	--	16.5	8.9	11.6	15.1	52.1	13.0
	Average	--	14.3	8.0	11.5	15.5	49.2	12.3
	LSD 0.05*	--	1.7	2.1	3.3	2.8	9.9	1.1
		------ Difference between one- and two-cut managements ------						
Difference	Alamo	--	-3.1	-0.4	4.2	5.0	5.7	1.4
	Kanlow	–	0.1	-0.9	0.7	2.8	2.7	0.7
(Two minus one)	Cave-in-Rock	--	1.3	0.2	5.9	8.7	16.1	4.0
	Shelter	--	3.8	-0.1	2.1	5.2	11.0	2.7
	NC1	--	-3.3	-1.0	-0.6	4.5	-0.4	-0.1
	NC2	--	2.7	2.1	1.9	4.9	11.6	2.9
	Average	--	0.3	0.0	2.4	5.2	7.8	1.9

Table A-17 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		% Difference						
% Difference (Diff/one)	Alamo	--	-19	-5	54	43	--	18
	Kanlow	–	1	-10	6	22	--	5
	Cave-in-Rock	--	10	3	71	106	--	48
	Shelter	--	35	-1	27	60	--	30
	NC1	--	-21	-12	-6	42	--	1
	NC2	--	20	31	20	48	--	30
	Average	--	2	0	26	50	--	19

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-18. Seasonal yields from six varieties of switchgrass at Morgantown, WV, when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		Mg ha^{-1}						
Once	Alamo	10.8	15.1	14.8	15.5	18.2	74.4	14.9
	Kanlow	15.1	19.8	15.8	18.3	20.5	89.5	17.9
	Cave-in-Rock	11.3	14.3	14.7	13.6	15.7	69.6	13.9
	Shelter	10.1	13.8	11.4	12.8	16.6	64.7	12.9
	NC1	13.0	16.7	15.6	17.0	17.0	79.3	15.9
	NC2	13.0	17.6	14.5	16.5	17.0	78.6	15.7
	Average	12.2	16.2	14.5	15.6	17.5	76.0	15.2
Twice	Alamo	8.4	14.9	13.0	15.9	13.0	65.2	13.0
	Kanlow	9.7	14.9	12.6	14.7	13.8	65.7	13.1
	Cave-in-Rock	9.0	15.6	13.1	16.4	15.6	69.7	13.9
	Shelter	8.1	14.7	11.3	14.0	13.3	61.4	12.3
	NC1	8.8	15.8	12.6	15.3	13.8	66.3	13.3
	NC2	8.8	15.5	12.4	14.9	14.3	65.9	13.2
	Average	8.8	15.2	12.5	15.2	14.0	65.7	13.1
	LSD 0.05*	2.6	2.0	1.5	2.4	2.3	10.8	1.1
		Difference between one- and two-cut managements						
Difference (Two minus one)	Alamo	-2.4	-0.2	-1.8	0.4	-5.2	-9.2	-1.8
	Kanlow	-5.4	-4.9	-3.2	-3.6	-6.7	-23.8	-4.8
	Cave-in-Rock	-2.3	1.3	-1.6	2.8	-0.1	0.1	0.0
	Shelter	-2.0	0.9	-0.1	1.2	-3.3	-3.3	-0.7
	NC1[1]	-4.2	-0.9	-3.0	-1.7	-3.2	-13.0	-2.6
	NC2[1]	-4.2	-2.1	-2.1	-1.6	-2.7	-12.7	-2.5
	Average	-3.4	-1.0	-2.0	-0.4	-3.5	-10.3	-2.1

Table A-18 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		------------------------------------ % Difference ------------------------------------						
% Difference (Diff/one)	Alamo	-22	-1	-12	3	-29	--	-12
	Kanlow	-36	-25	-20	-20	-33	--	-27
	Cave-in-Rock	-20	9	-11	21	-1	--	0
	Shelter	-20	6	-1	9	-20	--	-5
	NC1	-32	-5	-19	-10	-19	--	-17
	NC2	-32	-12	-14	-10	-16	--	-17
	Average	-28	-6	-14	-3	-20	--	-14

*LSD values are for comparison of means between varieties within and between cutting managements.
[1]NC1 and NC2 lines were calculated as missing plots for all dates.

Table A-19. Seasonal yields from six varieties of switchgrass at Princeton, KY, when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		-- Mg ha^{-1} --						
Once	Alamo	11.3	11.6	16.5	15.5	13.6	68.5	13.7
	Kanlow	11.0	14.6	20.9	16.4	14.8	77.7	15.5
	Cave-in-Rock	10.0	12.1	19.4	10.1	13.2	64.8	13.0
	Shelter	8.0	11.8	15.4	8.4	10.6	54.2	10.8
	NC1	11.2	13.4	17.2	13.8	15.5	71.1	14.2
	NC2	11.7	16.1	18.9	13.4	15.5	75.6	15.1
	Average	10.5	13.3	18.1	12.9	13.9	68.7	13.7
Twice	Alamo	13.4	16.0	14.9	17.0	15.2	76.5	15.3
	Kanlow	12.5	15.8	12.6	15.8	14.7	71.4	14.3
	Cave-in-Rock	10.9	14.8	12.5	13.4	13.6	65.2	13.0
	Shelter	8.2	12.9	10.0	11.4	13.1	55.6	11.1
	NC1	13.0	15.3	14.8	15.5	11.9	70.5	14.1
	NC2	11.7	15.3	15.0	14.5	13.2	69.7	13.9
	Average	11.6	15.0	13.3	14.6	13.6	68.2	13.6
	LSD 0.05*	2.2	2.1	3.4	2.4	2.3	12.4	1.1
		--------------- Difference between one- and two-cut managements ---------------						
Difference (Two minus one)	Alamo	2.1	4.4	-1.6	1.5	1.6	8.0	1.6
	Kanlow	1.5	1.2	-8.3	-0.6	-0.1	-6.3	-1.3
	Cave-in-Rock	0.9	2.7	-6.9	3.3	0.4	0.4	0.1
	Shelter	0.2	1.1	-5.4	3.0	2.5	1.4	0.3
	NC1	1.8	1.9	-2.4	1.7	-3.6	-0.6	-0.1
	NC2	0.0	-0.8	-3.9	1.1	-2.3	-5.9	-1.2
	Average	1.1	1.8	-4.8	1.7	-0.3	-0.5	-0.1

Table A-19 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		------------------------------------ % Difference ------------------------------------						
% Difference (Diff/one)	Alamo	19	38	-10	10	12	--	14
	Kanlow	14	8	-40	-4	-1	--	-4
	Cave-in-Rock	9	22	-36	33	3	--	6
	Shelter	2	9	-35	36	24	--	7
	NC1	16	14	-14	12	-23	--	1
	NC2	0	-5	-21	8	-15	--	-6
	Average	10	13	-26	13	-2	--	2

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-20. Seasonal yields from six varieties of switchgrass at Raleigh, NC, when harvested once (in November) or twice (first cut in heading stage and second cut in November)

(Differences are calculated between one-cut and two-cut management and expressed as percentages of the one-cut management yields.)

Treatment		Year of harvest					1997 to 2001	
Cuts	Variety	1997	1998	1999	2000	2001	Total	Av
		----- Mg ha^{-1} -----						
Once	Alamo	14.0	19.5	12.4	14.6	7.4	67.9	13.6
	Kanlow	12.7	19.5	13.0	14.8	6.9	66.9	13.4
	Cave-in-Rock	9.4	13.5	7.8	10.5	6.2	47.4	9.5
	Shelter	9.6	12.7	8.0	8.3	5.1	43.7	8.7
	NC1	13.1	19.5	13.8	15.8	7.5	69.7	13.9
	NC2	19.2	23.1	14.3	14.5	7.1	78.2	15.6
	Average	13.0	18.0	11.6	13.1	6.7	62.3	12.5
Twice	Alamo	9.9	20.4	15.7	16.7	9.7	72.4	14.5
	Kanlow	12.2	22.3	14.8	15.8	9.1	74.2	14.8
	Cave-in-Rock	11.8	19.3	11.7	16.7	10.2	69.7	13.9
	Shelter	10.1	17.0	10.5	13.9	8.8	60.3	12.1
	NC1	12.4	22.6	15.1	17.1	10.9	78.1	15.6
	NC2	10.3	21.8	13.3	17.6	10.2	73.2	14.6
	Average	11.1	20.6	13.5	16.3	9.8	71.3	14.3
	LSD 0.05*	3.0	3.7	2.3	2.9	1.6	13.5	1.2
		----- Difference between one- and two-cut managements -----						
Difference	Alamo	-4.1	0.9	3.3	2.1	2.3	4.5	0.9
	Kanlow	-0.5	2.8	1.8	1.0	2.2	7.3	1.5
(Two minus one)	Cave-in-Rock	2.4	5.8	3.9	6.2	4.0	22.3	4.5
	Shelter	0.5	4.3	2.5	5.6	3.7	16.6	3.3
	NC1	-0.7	3.1	1.3	1.3	3.4	8.4	1.7
	NC2	-8.9	-1.3	-1.0	3.1	3.1	-5.0	-1.0
	Average	-1.9	2.6	2.0	3.2	3.1	9.0	1.8

Table A-20 (continued)

Treatment		Year of harvest					1997 to 2001	
Cuts	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		---------------------------------- % Difference ----------------------------------						
% Difference (Diff/one)	Alamo	-29	5	27	14	31	--	9
	Kanlow	-4	14	14	7	32	--	13
	Cave-in-Rock	26	43	50	59	65	--	48
	Shelter	5	34	31	67	73	--	42
	NC1	-5	16	9	8	45	--	15
	NC2	-46	-6	-7	21	44	--	1
	Average	-14	14	17	25	47	--	18

*LSD values are for comparison of means between varieties within and between cutting managements.

Table A-21. First harvest, second harvest, and total yields from six varieties of switchgrass at Blacksburg, VA (Site A), when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		------------------------------------ Mg ha^{-1} ------------------------------------						
First	Alamo	3.4	7.2	8.1	6.7	7.0	32.4	6.5
	Kanlow	5.3	9.8	10.4	7.8	9.2	42.5	8.5
	Cave-in-Rock	6.2	10.0	13.0	9.8	8.8	47.8	9.6
	Shelter	5.2	10.2	9.9	9.3	8.4	43.0	8.6
	NC1	4.1	9.2	9.0	8.9	7.6	38.8	7.8
	NC2	4.9	9.0	8.8	6.6	6.9	36.2	7.2
	Average	4.9	9.2	9.9	8.2	8.0	40.1	8.0
2nd	Alamo	8.8	8.5	9.6	9.0	6.7	42.6	8.5
	Kanlow	7.2	11.2	8.7	8.3	7.4	42.8	8.6
	Cave-in-Rock	6.4	7.8	8.1	7.4	5.9	35.6	7.1
	Shelter	6.0	7.7	5.6	7.5	4.7	31.5	6.3
	NC1	6.9	11.2	7.6	8.1	7.2	41.0	8.2
	NC2	6.8	9.3	12.1	7.5	6.7	42.4	8.5
	Average	7.0	9.3	8.6	8.0	6.4	39.3	7.9
Total	Alamo	12.2	15.7	17.7	15.7	13.7	75.0	15.0
	Kanlow	12.5	21.0	19.1	16.1	16.6	85.3	17.1
	Cave-in-Rock	12.6	17.8	21.1	17.2	14.7	83.4	16.7
	Shelter	11.2	17.9	15.5	16.8	13.1	74.5	14.9
	NC1	11.0	20.5	16.6	17.0	14.8	79.9	16.0
	NC2	11.7	18.3	20.9	14.1	13.6	78.6	15.7
	Average	11.9	18.5	18.5	16.2	14.4	79.4	15.9
	LSD 0.05*	1.8	3.5	2.2	2.3	1.8	11.6	1.1
		------------------------- % of total yield in the first cut -------------------------						
% of total in first cut	Alamo	28	46	46	43	51	--	43
	Kanlow	42	47	54	48	55	--	49
	Cave-in-Rock	49	56	62	57	60	--	57
	Shelter	46	57	64	55	64	--	57
	NC1	37	45	54	52	51	--	48
	NC2	42	49	42	47	51	--	46
	Average	41	50	53	51	56	--	50

*LSD values are for comparison of variety means (for totals).

Table A-22. First harvest, second harvest, and total yields from six varieties of switchgrass at Blacksburg, VA (Site B), when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		Mg ha^{-1}						
First	Alamo	4.7	10.1	11.8	10.1	8.5	45.2	9.0
	Kanlow	5.9	11.3	10.8	11.1	9.6	48.7	9.7
	Cave-in-Rock	7.4	11.6	15.4	12.5	8.9	55.8	11.2
	Shelter	6.1	11.0	12.4	10.4	9.7	49.6	9.9
	NC1	5.4	12.2	13.8	11.0	8.2	50.6	10.1
	NC2	5.9	11.3	11.0	11.4	9.8	49.4	9.9
	Average	5.9	11.2	12.5	11.1	9.1	49.9	10.0
2nd	Alamo	11.2	11.8	13.6	12.3	11.2	60.1	12.0
	Kanlow	7.6	8.8	10.0	10.3	10.3	47.0	9.4
	Cave-in-Rock	6.2	7.7	10.8	8.0	7.8	40.5	8.1
	Shelter	5.1	5.5	9.9	7.0	8.3	35.8	7.2
	NC1	8.4	9.1	12.4	10.5	10.4	50.8	10.2
	NC2	8.1	10.4	10.2	11.9	9.9	50.5	10.1
	Average	7.8	8.9	11.2	10.0	9.7	47.5	9.5
Total	Alamo	15.9	22.0	25.4	22.4	19.7	105.4	21.1
	Kanlow	13.5	20.0	20.8	21.4	19.9	95.6	19.1
	Cave-in-Rock	13.6	19.3	26.2	20.5	16.7	96.3	19.3
	Shelter	11.2	16.5	22.3	17.4	18.0	85.4	17.1
	NC1	13.8	21.3	26.2	21.5	18.6	101.4	20.3
	NC2	14.0	21.7	21.2	23.3	19.7	99.9	20.0
	Average	13.7	20.1	23.7	21.1	18.8	97.4	19.5
	LSD 0.05*	2.0	3.0	4.4	3.6	4.5	17.5	1.6
		% of total yield in the first cut						
% of total in first cut	Alamo	30	46	46	45	43	--	42
	Kanlow	44	56	52	52	48	--	50
	Cave-in-Rock	54	60	59	61	53	--	58
	Shelter	54	67	56	60	54	--	58
	NC1	39	57	53	51	44	--	49
	NC2	42	52	52	49	50	--	49
	Average	43	56	53	53	48	--	51

*LSD values are for comparison of variety means (for totals).

Table A-23. First harvest, second harvest, and total yields from six varieties of switchgrass at Orange, VA, when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		Mg ha^{-1}						
First	Alamo	4.2	9.4	3.3	9.4	6.2	32.5	6.5
	Kanlow	5.6	11.3	3.8	10.0	8.2	38.9	7.8
	Cave-in-Rock	5.9	13.2	4.7	11.0	8.3	43.1	8.6
	Shelter	4.4	10.5	3.5	8.8	8.4	35.6	7.1
	NC1	5.4	11.3	4.1	9.5	7.0	37.3	7.5
	NC2	4.8	11.0	3.7	9.6	7.5	36.6	7.3
	Average	5.1	11.1	3.9	9.7	7.6	37.3	7.5
2nd	Alamo	6.7	8.0	10.2	11.0	8.9	44.8	9.0
	Kanlow	5.1	6.5	8.2	9.4	6.1	35.3	7.1
	Cave-in-Rock	5.7	6.6	4.9	8.6	7.2	33.0	6.6
	Shelter	4.3	4.5	3.8	6.9	5.2	24.7	4.9
	NC1	5.6	7.1	7.8	10.0	7.2	37.7	7.5
	NC2	6.2	7.0	7.6	9.7	9.6	40.1	8.0
	Average	5.6	6.6	7.1	9.3	7.3	35.9	7.2
Total	Alamo	10.9	17.4	13.5	20.4	15.1	77.3	15.5
	Kanlow	10.7	17.8	12.0	19.4	14.3	74.2	14.8
	Cave-in-Rock	11.6	19.8	9.6	19.6	15.5	76.1	15.2
	Shelter	8.7	15.0	7.3	15.7	13.6	60.3	12.1
	NC1	11.0	18.5	11.9	19.5	14.2	75.1	15.0
	NC2	11.0	18.0	11.3	19.3	17.1	76.7	15.3
	Average	10.7	17.7	10.9	19.0	14.9	73.2	14.6
	LSD 0.05*	2.6	2.2	2.1	2.4	3.1	12.4	1.1
		% of total yield in the first cut						
% of total in first cut	Alamo	39	54	24	46	41	--	41
	Kanlow	52	64	32	52	57	--	51
	Cave-in-Rock	51	67	49	56	54	--	55
	Shelter	51	70	48	56	62	--	57
	NC1	49	61	34	49	49	--	49
	NC2	44	61	33	50	44	--	46
	Average	47	63	35	51	51	--	49

*LSD values are for comparison of variety means (for totals).

Table A-24. First harvest, second harvest, and total yields from six varieties of switchgrass at Knoxville, TN, when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		------------------------------------ Mg ha^{-1} ------------------------------------						
First	Alamo	8.8	14.1	8.5	10.9	10.0	52.3	10.5
	Kanlow	9.3	15.7	9.8	10.5	9.0	54.3	10.9
	Cave-in-Rock	11.5	16.2	12.5	12.1	11.3	63.6	12.7
	Shelter	12.8	15.0	12.9	10.5	10.4	61.6	12.3
	NC1	9.1	15.4	9.1	9.6	9.6	52.8	10.6
	NC2	9.4	15.1	9.1	9.8	9.2	52.6	10.5
	Average	10.2	15.3	10.3	10.6	9.9	56.2	11.2
2nd	Alamo	5.8	7.6	4.0	6.1	8.1	31.6	6.3
	Kanlow	4.4	4.9	3.4	3.5	6.0	22.2	4.4
	Cave-in-Rock	4.4	5.3	3.8	4.6	5.8	23.9	4.8
	Shelter	4.1	4.2	3.7	3.7	4.9	20.6	4.1
	NC1	5.0	5.0	3.5	4.6	7.1	25.2	5.0
	NC2	4.8	5.6	3.5	4.4	7.1	25.4	5.1
	Average	4.8	5.4	3.7	4.5	6.5	24.8	5.0
Total	Alamo	14.6	21.8	12.5	17.0	18.1	84.0	16.8
	Kanlow	13.7	20.6	13.2	14.0	15.0	76.5	15.3
	Cave-in-Rock	15.9	21.4	16.3	16.7	17.1	87.4	17.5
	Shelter	16.9	19.2	16.6	14.2	15.3	82.2	16.4
	NC1	14.1	20.4	12.6	14.2	16.7	78.0	15.6
	NC2	14.2	20.7	12.6	14.2	16.3	78.0	15.6
	Average	14.9	20.7	14.0	15.1	16.4	81.0	16.2
	LSD 0.05*	2.9	2.4	2.6	2.3	2.8	13.0	1.2
		------------------------- % of total yield in the first cut -------------------------						
% of total in first cut	Alamo	60	65	68	64	55	--	63
	Kanlow	68	76	74	75	60	--	71
	Cave-in-Rock	72	75	77	72	66	--	73
	Shelter	76	78	78	74	68	--	75
	NC1	65	75	72	68	57	--	67
	NC2	66	73	72	69	56	--	67
	Average	68	74	74	70	60	--	69

*LSD values are for comparison of variety means (for totals).

Table A-25. First harvest, second harvest, and total yields from six varieties of switchgrass at Jackson, TN, when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		---------- Mg ha^{-1} ----------						
First	Alamo	--	6.8	7.0	7.4	9.9	31.1	7.8
	Kanlow	--	9.4	7.2	7.6	10.4	34.6	8.7
	Cave-in-Rock	--	9.3	7.1	9.9	11.5	37.8	9.5
	Shelter	--	9.6	6.4	7.4	8.6	32.0	8.0
	NC1	--	7.7	6.2	6.8	8.4	29.1	7.3
	NC2	--	10.3	8.1	7.9	8.6	34.9	8.7
	Average	--	8.9	7.0	7.8	9.6	33.3	8.3
2nd	Alamo	--	6.5	1.3	4.6	6.8	19.2	4.8
	Kanlow	--	5.3	0.9	4.1	5.1	15.4	3.9
	Cave-in-Rock	--	4.9	0.8	4.3	5.5	15.5	3.9
	Shelter	--	5.2	0.7	2.6	4.2	12.7	3.2
	NC1	--	4.6	1.2	4.2	5.5	15.5	3.9
	NC2	--	6.2	0.8	3.6	6.5	17.1	4.3
	Average	--	5.4	1.0	3.9	5.6	15.9	4.0
Total	Alamo	--	13.3	8.3	12.0	16.7	50.3	12.6
	Kanlow	--	14.8	8.1	11.7	15.5	50.1	12.5
	Cave-in-Rock	--	14.2	7.9	14.2	17.0	53.3	13.3
	Shelter	--	14.7	7.1	10.0	12.8	44.6	11.2
	NC1	--	12.3	7.4	11.0	13.9	44.6	11.2
	NC2	--	16.5	8.9	11.5	15.1	52.0	13.0
	Average	--	14.3	8.0	11.7	15.2	49.2	12.3
	LSD 0.05*	--	1.7	2.1	3.3	2.0	9.1	1.1
		---------- % of total yield in the first cut ----------						
% of total in first cut	Alamo	--	51	84	62	59	--	64
	Kanlow	–	64	89	65	67	--	71
	Cave-in-Rock	--	66	90	70	68	--	73
	Shelter	--	65	90	74	67	--	74
	NC1	--	63	84	62	60	--	67
	NC2	--	62	91	69	57	--	70
	Average	--	62	88	67	63	--	70

*LSD values are for comparison of variety means (for totals).

Table A-26. First harvest, second harvest, and total yields from six varieties of switchgrass at Morgantown, WV, when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		---------- Mg ha^{-1} ----------						
First	Alamo	2.1	7.7	7.6	8.8	7.4	33.6	6.7
	Kanlow	4.1	10.1	9.0	9.0	9.1	41.3	8.3
	Cave-in-Rock	5.0	10.7	9.5	10.6	11.0	46.8	9.4
	Shelter	5.2	10.9	8.8	9.5	10.2	44.6	8.9
	NC1	4.0	9.8	8.4	9.0	8.3	39.5	7.9
	NC2	4.0	9.8	8.2	8.9	8.8	39.7	7.9
	Average	4.1	9.8	8.6	9.3	9.4	41.2	8.2
2nd	Alamo	6.3	7.3	5.4	7.1	5.6	31.7	6.3
	Kanlow	5.6	4.8	3.7	5.7	4.7	24.5	4.9
	Cave-in-Rock	4.1	5.0	3.6	5.9	4.7	23.3	4.7
	Shelter	2.9	3.8	2.6	4.5	4.6	18.4	3.7
	NC1	5.5	5.7	4.2	6.3	5.0	26.7	5.3
	NC2	5.4	5.7	4.2	6.0	5.0	26.3	5.3
	Average	5.0	5.4	5.9	8.9	4.9	30.1	6.0
Total	Alamo	8.4	14.9	13.0	15.9	13.0	65.2	13.0
	Kanlow	9.7	14.9	12.7	14.7	13.8	65.8	13.2
	Cave-in-Rock	9.1	15.6	13.1	16.5	15.7	70.0	14.0
	Shelter	8.1	14.7	11.4	14.0	14.8	63.0	12.6
	NC1	9.5	15.5	12.6	15.3	13.3	66.2	13.2
	NC2	9.4	15.5	12.4	14.9	13.8	66.0	13.2
	Average	9.0	15.2	14.5	18.2	14.3	71.2	14.2
	LSD 0.05*	1.6	2.0	1.5	2.3	2.2	9.6	0.9
		---------- % of total yield in the first cut ----------						
% of total in first cut	Alamo	25	51	58	55	57	--	49
	Kanlow	42	68	71	61	66	--	62
	Cave-in-Rock	55	68	73	64	70	--	66
	Shelter	64	74	77	68	69	--	70
	NC1	42	63	67	59	62	--	59
	NC2	43	63	66	60	64	--	59
	Average	45	65	59	51	66	--	57

*LSD values are for comparison of variety means (for totals).

Table A-27. First harvest, second harvest, and total yields from six varieties of switchgrass at Princeton, KY, when harvested twice (first cut in heading stage and second cut in November)

[The first cut yields are expressed as a percentage of total yields. The total and average yields for five years of data (1997 to 2001) were calculated.]

Treatment		Year of harvest					1997 to 2001	
Cut	Variety	1997	1998	1999	2000	2001	Total	Av
		Mg ha^{-1}						
First	Alamo	3.9	7.3	7.8	8.8	5.4	33.2	6.6
	Kanlow	5.8	8.7	8.4	9.8	6.9	39.6	7.9
	Cave-in-Rock	5.5	9.4	7.9	8.5	7.9	39.2	7.8
	Shelter	4.4	8.0	7.9	6.9	5.8	33.0	6.6
	NC1	5.1	7.3	7.9	8.8	5.2	34.3	6.9
	NC2	4.5	7.1	7.5	8.2	5.2	32.5	6.5
	Average	4.9	8.0	7.9	8.5	6.0	35.2	7.0
2nd	Alamo	9.5	8.7	7.1	8.2	9.8	43.3	8.7
	Kanlow	6.7	7.1	4.2	6.0	7.8	31.8	6.4
	Cave-in-Rock	5.4	5.4	4.6	4.8	5.8	26.0	5.2
	Shelter	3.8	4.8	2.1	4.5	4.9	20.1	4.0
	NC1	8.0	8.0	6.9	6.7	7.9	37.5	7.5
	NC2	7.0	8.2	7.5	6.3	6.7	35.7	7.1
	Average	6.7	7.0	5.4	6.1	7.2	32.5	6.5
Total	Alamo	13.4	16.0	14.9	17.0	15.2	76.5	15.3
	Kanlow	12.5	15.8	12.6	15.8	14.7	71.4	14.3
	Cave-in-Rock	10.9	14.8	12.5	13.3	13.7	65.2	13.0
	Shelter	8.2	12.8	10.0	11.4	10.7	53.1	10.6
	NC1	13.1	15.3	14.8	15.5	13.1	71.8	14.4
	NC2	11.5	15.3	15.0	14.5	11.9	68.2	13.6
	Average	11.6	15.0	13.3	14.6	13.2	67.7	13.5
	LSD 0.05*	2.2	2.1	3.4	2.4	1.4	11.5	1.1
		% of total yield in the first cut						
% of total in first cut	Alamo	29	46	52	52	36	--	43
	Kanlow	46	55	67	62	47	--	55
	Cave-in-Rock	50	64	63	64	58	--	60
	Shelter	54	63	79	61	54	--	62
	NC1	39	48	53	57	40	--	47
	NC2	39	46	50	57	44	--	47
	Average	42	53	59	58	45	--	52

*LSD values are for comparison of variety means (for totals).

Table A-28. First harvest, second harvest, and total yields from six varieties of switchgrass at Raleigh, NC, when harvested twice (first cut in heading stage and second cut in November)

(The first cut yields are expressed as a percentage of total yields.)

Treatment		**Year of harvest**					**1997 to 2001**	
Cut	**Variety**	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**	**Av**
		------------------------------------ Mg ha^{-1} ------------------------------------						
First	Alamo	5.2	12.6	10.2	11.2	6.6	45.8	9.2
	Kanlow	8.3	15.3	10.2	10.9	6.5	51.2	10.2
	Cave-in-Rock	8.4	13.2	8.4	10.5	7.3	47.8	9.6
	Shelter	7.9	11.6	7.8	8.7	6.6	42.6	8.5
	NC1	7.4	14.6	11.0	10.8	7.2	51.0	10.2
	NC2	6.0	13.2	9.2	11.3	7.2	46.9	9.4
	Average	7.2	13.4	9.5	10.6	6.9	47.5	9.5
2nd	Alamo	4.7	7.7	5.6	5.5	3.2	26.7	5.3
	Kanlow	3.9	7.1	3.7	4.6	2.6	21.9	4.4
	Cave-in-Rock	3.4	6.1	3.3	6.2	3.0	22.0	4.4
	Shelter	2.2	5.5	2.8	5.2	2.2	17.9	3.6
	NC1	5.0	8.0	4.1	6.2	3.6	26.9	5.4
	NC2	4.2	8.3	4.1	6.3	3.1	26.0	5.2
	Average	3.9	7.1	3.9	5.7	3.0	23.6	4.7
Total	Alamo	9.9	20.4	15.8	16.7	9.8	72.6	14.5
	Kanlow	12.2	22.3	13.9	15.5	9.1	73.0	14.6
	Cave-in-Rock	11.8	19.3	11.7	16.7	10.3	69.8	14.0
	Shelter	10.1	17.0	10.6	13.9	8.8	60.4	12.1
	NC1	12.4	22.6	15.1	17.0	10.8	77.9	15.6
	NC2	10.2	21.4	13.3	17.6	10.3	72.8	14.6
	Average	11.1	20.5	13.4	16.2	9.9	71.1	14.2
	LSD 0.05*	3.2	3.7	2.3	2.9	1.4	13.5	1.2
		---------------------- % of total yield in the first cut ----------------------						
% of total in first cut	Alamo	53	62	65	67	67	--	63
	Kanlow	68	68	73	70	71	--	70
	Cave-in-Rock	71	68	72	63	71	--	69
	Shelter	78	68	74	63	75	--	71
	NC1	60	65	73	64	67	--	65
	NC2	59	61	69	64	70	--	65
	Average	65	65	71	65	70	--	67

*LSD values are for comparison of variety means (for totals).

Table A-29. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations (1997 data)

Location	June				Nov.				Yield (1997)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	%								Mg ha^{-1}		
	One-cut management										
Blacksburg, VA											
Site A	--	--	--	--	0.58	0.07	0.18	0.43	--	10.3	10.3
Site B	--	--	--	--	0.66	0.05	0.38	0.44	--	16.6	16.6
Orange, VA	--	--	--	--	0.34	0.06	0.38	0.50	--	15.4	15.4
Knoxville, TN	--	--	--	--	0.33	0.09	0.34	0.40	--	19.2	19.2
Jackson, TN	--	--	--	--	0.24	0.13	0.64	0.32	--	--	--
Princeton, KY	--	--	--	--	0.26	0.10	0.34	0.28	--	11.3	11.3
Morgantown, WV	--	--	--	--	0.27	0.08	0.32	0.24	--	10.8	10.8
Raleigh, NC	--	--	--	--	0.45	0.21	0.80	0.51	--	14.0	14.0
Average	--	--	--	--	0.39	0.10	0.42	0.39	--	12.2	12.2
	Two-cut management										
Blacksburg, VA											
Site A	1.41	0.12	0.82	0.18	0.68	0.06	0.10	0.54	3.4	8.8	12.2
Site B	1.66	0.12	1.10	0.17	0.74	0.05	0.16	0.46	4.7	11.2	15.9
Orange, VA	1.37	0.21	1.72	0.39	0.51	0.06	0.44	0.33	4.2	6.7	10.9
Knoxville, TN	0.74	0.08	0.45	0.34	0.42	0.13	0.52	0.45	8.8	5.8	14.6
Jackson, TN	0.50	0.21	1.28	0.30	0.55	0.10	0.22	0.30	--	--	--
Princeton, KY	0.89	0.25	0.82	0.40	0.40	0.10	0.25	0.33	5.2	4.7	9.9
Morgantown, WV	0.82	0.16	1.20	0.28	0.77	0.09	0.27	0.33	2.1	6.3	8.4
Raleigh, NC	0.78	0.13	1.07	0.21	0.68	0.22	0.42	0.37	3.9	9.5	13.4
Average	1.02	0.16	1.06	0.28	0.59	0.10	0.30	0.39	4.6	7.6	12.2

Table A-30. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations (1998 data)

Location	June				Nov.				Yield (1998)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	%								Mg ha^{-1}		
	One-cut management										
Blacksburg, VA											
Site A	--	--	--	--	0.61	0.10	0.97	0.36	--	19.3	19.3
Site B	--	--	--	--	0.78	0.07	0.95	0.40	--	14.1	14.1
Orange, VA	--	--	--	--	0.72	0.07	0.75	0.38	--	20.4	20.4
Knoxville, TN	-	--	--	--	0.29	0.06	0.49	0.19	--	20.4	20.4
Jackson, TN	--	--	--	--	0.31	0.07	0.70	0.18	--	16.4	16.4
Princeton, KY	--				0.25	0.12	0.25	0.31		11.6	11.6
Morgantown, WV	--	--	--	--	0.29	0.06	0.41	0.22	--	15.1	15.1
Raleigh, NC	--	--	--	--	0.34	0.12	0.72	0.23	--	19.5	19.5
Average					0.45	0.08	0.66	0.28		17.1	17.1
	Two-cut management										
Blacksburg, VA											
Site A	1.21	0.23	1.80	0.29	0.80	0.08	0.90	0.38	7.2	9.3	16.5
Site B	1.26	0.21	1.94	0.30	0.87	0.13	1.14	0.42	10.1	8.9	19.0
Orange, VA	1.23	0.17	1.37	0.35	0.87	0.09	0.71	0.43	9.4	6.6	16.0
Knoxville, TN	0.92	0.11	0.73	0.23	0.29	0.10	0.60	0.32	14.1	5.4	19.5
Jackson, TN	0.80	0.10	0.94	0.28	0.30	0.13	0.74	0.28	6.8	5.4	12.2
Princeton, KY	0.74	0.21	1.22	0.29	0.40	0.10	0.17	0.41	7.3	7.0	14.3
Morgantown, WV	1.00	0.23	0.80	0.20	0.49	0.12	0.55	0.34	7.7	5.4	13.1
Raleigh, NC	0.89	0.24	0.99	0.22	0.71	0.14	0.65	0.40	12.6	7.1	19.7
Average	1.01	0.19	1.22	0.27	0.51	0.11	0.68	0.37	9.4	6.9	16.3

Table A-31. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations (1999 data)

Location	June				Nov.				Yield (1999)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	%								Mg ha^{-1}		
	One-cut management										
Blacksburg, VA											
Site A	--	--	--	--	0.93	0.17	0.67	0.34	--	11.6	11.6
Site B	--	--	--	--	0.80	0.11	1.33	0.46	--	14.7	14.7
Orange, VA	--	--	--	--	0.84	0.10	0.98	0.34	--	15.0	15.0
Knoxville, TN	--	--	--	--	0.36	0.06	0.20	0.22	--	20.0	20.0
Jackson, TN	--	--	--	--	0.38	0.09	0.48	0.18	--	8.7	8.7
Princeton, KY	--				0.31	0.08	0.22	0.31		16.5	16.5
Morgantown, WV	--	--	--	--	0.30	0.09	0.70	0.21	--	14.8	14.8
Raleigh, NC	--	--	--	--	0.67	0.10	0.47	0.27	--	12.4	12.4
Average					0.57	0.10	0.63	0.29		14.2	14.2
	Two-cut management										
Blacksburg, VA											
Site A	1.20	0.20	1.54	0.40	1.00	0.16	1.12	0.38	8.1	9.6	17.7
Site B	1.22	0.18	1.83	0.33	0.96	0.13	1.42	0.40	11.8	13.6	25.4
Orange, VA	1.03	0.16	1.52	0.33	0.95	0.14	1.28	0.47	3.3	10.2	13.5
Knoxville, TN	1.21	0.13	0.91	0.26	0.58	0.08	0.30	0.38	8.5	4.0	12.5
Jackson, TN	0.80	0.15	1.54	0.20	0.60	0.14	0.85	0.35	7.0	1.3	8.3
Princeton, KY	0.77	0.22	1.37	0.26	0.47	0.10	0.22	0.39	7.8	7.1	14.9
Morgantown, WV	0.74	0.20	1.72	0.24	0.47	0.13	0.81	0.34	7.6	5.4	13.0
Raleigh, NC	0.93	0.23	1.38	0.42	0.73	0.20	0.82	0.45	10.2	5.6	15.8
Average	0.99	0.18	1.48	0.31	0.72	0.14	0.85	0.40	8.0	7.1	15.1

Table A-32. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations (2000 data)

Location	June				Nov.				Yield (2000)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	%								Mg ha^{-1}		
	One-cut management										
Blacksburg, VA											
Site A	--	--	--	--	0.51	0.12	0.90	0.40	--	9.5	9.5
Site B	--	--	--	--	0.58	0.09	1.20	0.38	--	17.1	17.1
Orange, VA	--	--	--	--	0.42	0.09	0.65	0.38	--	19.8	19.8
Knoxville, TN	--	--	--	--	0.27	0.07	0.50	0.25	--	20.8	20.8
Jackson, TN	--	--	--	--	0.48	0.12	0.60	0.28	--	7.8	7.8
Princeton, KY	--				0.47	0.11	0.70	0.35	--	15.5	15.5
Morgantown, WV	--	--	--	.	0.21	0.08	0.53	0.20	--	15.5	15.5
Raleigh, NC	--	--	--	--	0.36	0.13	0.65	0.25	--	14.6	14.6
Average	--	--	--	--	0.41	0.10	0.72	0.31		15.1	15.1
	Two-cut management										
Blacksburg, VA											
Site A	1.38	0.21	1.33	0.40	0.74	0.13	0.75	0.40	6.7	9.0	15.7
Site B	1.51	0.20	1.80	0.40	0.96	0.11	0.93	0.45	10.1	12.3	22.4
Orange, VA	1.13	0.16	1.33	0.38	0.79	0.10	0.50	0.65	9.4	11.0	20.4
Knoxville, TN	0.67	0.13	0.85	0.25	0.53	0.08	0.33	0.30	10.9	6.1	17.0
Jackson, TN	0.87	0.15	1.35	0.18	0.70	0.11	0.63	0.25	7.4	4.6	12.0
Princeton, KY	1.08	0.21	1.35	0.33	0.51	0.11	0.35	0.30	8.8	7.1	15.9
Morgantown, WV	0.54	0.18	1.30	0.25	0.25	0.13	0.60	0.30	8.8	8.2	17.0
Raleigh, NC	0.83	0.21	1.05	0.38	0.69	0.16	0.68	0.40	11.2	5.5	16.7
Average	1.00	0.18	1.30	0.33	0.65	0.11	0.6	0.4	9.2	8.0	17.1

Table A-33. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations (2001 data)

Location	June				Nov.				Yield (2001)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	---------------------------------- % ------------------------------------								------ $Mg\ ha^{-1}$ ------		
					One-cut management						
Blacksburg, VA											
Site A	--	--	--	--	0.41	0.06	0.61	0.25	--	10.6	10.6
Site B	--	--	--	--	0.61	0.07	0.85	0.31	--	27.4	27.4
Orange, VA	--	--	--	--	0.48	0.08	0.82	0.39	--	17.6	17.6
Knoxville, TN	--	--	--	--	0.40	0.07	0.66	0.32	--	24.8	24.8
Jackson, TN	--	--	--	--	0.49	0.09	0.61	0.28	--	11.6	11.6
Princeton, KY	--				0.50	0.09	0.51	0.24	--	18.2	18.2
Morgantown, WV	--	--	--	--	0.33	0.09	0.53	0.20	--	13.6	13.6
Raleigh, NC	--	--	--	--	0.38	0.15	0.72	0.28	--	7.4	7.4
Average	--	--	--	--	0.45	0.09	0.66	0.28	--	16.4	16.4
					Two-cut management						
Blacksburg, VA											
Site A	1.53	0.21	1.18	0.39	0.87	0.09	0.45	0.40	7.0	6.7	13.7
Site B	1.67	0.20	1.76	0.35	0.74	0.07	0.64	0.35	8.5	11.2	19.7
Orange, VA	1.65	0.23	1.86	0.43	0.45	0.07	0.44	0.34	6.2	8.9	15.1
Knoxville, TN	0.90	0.11	0.71	0.32	0.67	0.08	0.30	0.45	10.0	8.1	18.1
Jackson, TN	0.93	0.14	1.06	0.33	0.57	0.08	0.44	0.28	9.9	6.8	16.7
Princeton, KY	0.90	0.17	0.95	0.32	0.48	0.08	0.13	0.29	7.4	5.6	13.0
Morgantown, WV	0.85	0.18	1.19	0.27	0.69	0.12	0.32	0.32	5.4	9.8	15.2
Raleigh, NC	0.77	0.19	1.19	0.33	0.57	0.21	0.69	0.42	6.6	3.2	9.8
Average	1.15	0.18	1.30	0.33	0.63	0.10	0.43	0.36	7.6	7.5	15.2
LSD 0.05	0.11	0.02	0.12	0.05	0.13	0.03	0.11	0.06	1.3	1.3	2.4

Table A-34. N, P, K, and Ca concentrations in whole-plant tissue collected at harvest of one- and two-cut managements for Alamo switchgrass grown at eight locations averaged over 1997 to 2001

Location	June				Nov.				Yield (2001)		
	N	P	K	Ca	N	P	K	Ca	June	Nov.	Total
	------ % ------								------ Mg ha^{-1} ------		
One-cut management											
Blacksburg, VA											
Site A	--	--	--	--	0.61	0.10	0.67	0.36	--	12.3	12.3
Site B	--	--	--	--	0.69	0.08	0.94	0.40	--	18.0	18.0
Orange, VA	--	--	--	--	0.56	0.08	0.72	0.40	--	17.6	17.6
Knoxville, TN	--	--	--	--	0.33	0.07	0.44	0.28	--	21.0	21.0
Jackson, TN	--	--	--	--	0.38	0.10	0.61	0.25	--	11.1	11.1
Princeton, KY	--				0.36	0.10	0.40	0.30	--	14.6	14.6
Morgantown, WV	--	--	--	--	0.28	0.08	0.50	0.21	--	14.0	14.0
Raleigh, NC	--	--	--	--	0.44	0.14	0.67	0.31	--	13.6	13.6
Average[1]					0.45b	0.09b	0.62a	0.31b	--	15.0a	15.0a
Two-cut management											
Blacksburg, VA											
Site A	1.35	0.19	1.33	0.33	0.82	0.10	0.66	0.42	6.5	8.5	15.0
Site B	1.46	0.18	1.69	0.31	0.85	0.10	0.86	0.42	9.0	12.0	21.0
Orange, VA	1.28	0.19	1.56	0.38	0.71	0.09	0.67	0.44	6.5	9.0	15.5
Knoxville, TN	0.89	0.11	0.73	0.28	0.50	0.09	0.41	0.38	10.5	6.3	16.8
Jackson, TN	0.78	0.15	1.23	0.26	0.54	0.11	0.58	0.29	7.8	4.8	12.6
Princeton, KY	0.88	0.21	1.14	0.32	0.45	0.10	0.22	0.34	6.6	8.7	15.3
Morgantown, WV	0.79	0.19	1.24	0.25	0.53	0.12	0.51	0.33	6.7	6.3	13.0
Raleigh, NC	0.84	0.20	1.14	0.31	0.55	0.19	0.65	0.41	9.2	5.3	14.5
Average[1]	1.03	0.18	1.27	0.30	0.62a	0.11a	0.57a	0.38a	7.9	7.6b	15.5a
LSD 0.05*	0.09	0.02	0.12	0.03	0.07	0.01	0.11	0.03	0.8	1.4	1.9

*LSD values are for comparison of means for locations across managements.

[1]Averages within columns (between cutting managements) followed by similar letters do not differ at the

Table A-35. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (1997 data)

Location	June harvest				Nov. harvest				Total season			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	---------- kg ha^{-1} removed ----------											
	One-cut management											
Blacksburg, VA												
Site A	--	--	--	--	60	7	19	44	60	7	19	44
Site B	--	--	--	--	110	8	63	73	110	8	63	73
Orange, VA	--	--	--	--	52	9	59	77	52	9	59	77
Knoxville, TN	--	--	--	--	63	17	65	77	63	17	65	77
Jackson, TN	--	--	--	--	--	--	--	--	--	--	--	--
Princeton, KY	–				29	11	38	32	29	11	38	32
Morgantown, WV	--	--	--	--	29	9	35	26	29	9	35	26
Raleigh, NC	--	--	--	--	63	29	112	71	63	29	112	71
Average	--	--	--	--	48	12	51	48	48	12	51	48
	Two-cut management											
Blacksburg, VA												
Site A	48	4	28	6	60	5	9	48	108	9	37	54
Site B	78	6	52	8	83	6	18	52	161	11	70	60
Orange, VA	58	9	72	16	34	4	29	22	92	13	102	38
Knoxville, TN	65	7	40	30	24	8	30	26	89	15	70	56
Jackson, TN	--	--	--	--	--	--	--	--	--	--	--	--
Princeton, KY	46	13	43	21	19	5	12	16	65	18	54	36
Morgantown, WV	17	3	25	6	49	6	17	21	66	9	42	27
Raleigh, NC	30	5	42	8	65	21	40	35	95	26	82	43
Average	49	7	43	14	48	8	22	31	97	14	65	45

Table A-36. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (1998 data)

Location	June harvest				Nov. harvest				Total season			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	kg ha^{-1} removed											
	One-cut management											
Blacksburg, VA												
Site A	--	--	--	--	118	19	187	69	118	19	187	69
Site B	--	--	--	--	110	10	134	56	110	10	134	56
Orange, VA	--	--	--	--	147	14	153	78	147	14	153	78
Knoxville, TN	--	--	--	--	59	12	100	39	59	12	100	39
Jackson, TN	--	--	--	--	51	11	115	30	51	11	115	30
Princeton, KY	--				29	14	29	36	29	14	29	36
Morgantown, WV	--	--	--	--	44	9	62	33	44	9	62	33
Raleigh, NC	--	--	--	--	66	23	140	45	66	23	140	45
Average	--	--	--	--	77	14	113	48	77	14	113	48
	Two-cut management											
Blacksburg, VA												
Site A	87	17	130	21	74	7	84	35	162	24	213	56
Site B	127	21	196	30	77	12	101	37	205	33	297	68
Orange, VA	116	16	129	33	57	6	47	28	173	22	176	61
Knoxville, TN	130	16	103	32	16	5	32	17	145	21	135	50
Jackson, TN	54	7	64	19	16	7	40	15	71	14	104	34
Princeton, KY	54	15	89	21	28	7	12	29	82	22	101	50
Morgantown, WV	77	18	62	15	26	6	30	18	103	24	91	34
Raleigh, NC	112	30	125	28	50	10	46	28	117	40	171	56
Average	95	18	112	25	37	8	49	26	132	25	161	51

Table A-37. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for switchgrass grown at eight locations (1999 data)

Location	June harvest				Nov. harvest				Total season			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	kg ha^{-1} removed											
	One-cut management											
Blacksburg, VA												
Site A	--	--	--	--	108	20	78	39	108	20	78	39
Site B	--	--	--	--	118	16	196	68	118	16	196	68
Orange, VA	--	--	--	--	126	15	147	51	126	15	147	51
Knoxville, TN	--	--	--	--	72	12	40	44	72	12	40	44
Jackson, TN	--	--	--	--	33	8	42	16	33	8	42	16
Princeton, KY	--				51	13	36	51	51	13	36	51
Morgantown, WV	--	--	--	--	44	13	104	31	44	13	104	31
Raleigh, NC	--	--	--	--	83	12	58	33	83	12	58	33
Average	--	--	--	--	81	14	89	41	81	14	89	41
	Two-cut management											
Blacksburg, VA												
Site A	97	16	125	32	96	15	108	36	193	32	232	69
Site B	144	21	216	39	131	18	193	54	275	39	409	93
Orange, VA	34	5	50	11	97	14	131	48	131	20	181	59
Knoxville, TN	103	11	77	22	23	3	12	15	126	14	89	37
Jackson, TN	56	11	108	14	8	2	11	5	64	12	119	19
Princeton, KY	60	17	107	20	33	7	16	28	93	24	122	48
Morgantown, WV	56	15	131	18	25	7	44	18	82	22	174	37
Raleigh, NC	95	23	141	43	41	11	46	25	136	35	187	68
Average	81	15	119	25	57	10	70	29	138	25	189	54

Table A-38. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (2000 data)

Location	June harvest				Nov. harvest				Total season			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	---kg ha^{-1} removed ---											
	One-cut management											
Blacksburg, VA												
Site A	--	--	--	--	48	12	86	38	48	12	86	38
Site B	--	--	--	--	99	14	205	65	99	14	205	65
Orange, VA	--	--	--	--	83	17	129	75	83	17	129	75
Knoxville, TN	--	--	--	--	58	14	104	52	58	14	104	52
Jackson, TN	--	--	--	--	37	9	47	22	37	9	47	22
Princeton, KY	--				73	17	108	54	73	17	108	54
Morgantown, WV	--	--	--	--	32	12	82	31	32	12	82	31
Raleigh, NC	--	--	--	--	52	19	95	36	52	19	95	36
Average	--	--	--	--	60	14	107	47	60	14	107	47
	Two-cut management											
Blacksburg, VA												
Site A	92	14	89	27	67	11	68	36	159	25	157	63
Site B	152	20	182	40	118	13	114	55	270	33	296	95
Orange, VA	106	15	125	36	87	10	55	72	193	25	180	108
Knoxville, TN	73	14	93	27	32	5	20	18	105	19	113	45
Jackson, TN	64	13	100	13	33	5	29	12	97	18	129	25
Princeton, KY	95	18	119	29	36	8	25	21	131	26	144	50
Morgantown, WV	48	16	114	22	20	11	49	25	68	27	163	47
Raleigh, NC	93	24	118	42	38	9	37	22	131	33	155	64
Average	90	17	118	30	54	9	50	33	144	26	167	62

Table A-39. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (2001 data)

Location	June harvest				Nov. harvest				Total season			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	---------- kg ha^{-1} removed ----------											
	One-cut management											
Blacksburg, VA												
Site A	--	--	--	--	43	6	65	27	43	6	65	27
Site B	--	--	--	--	167	19	233	85	167	19	233	85
Orange, VA	--	--	--	--	84	14	144	69	84	14	144	69
Knoxville, TN	--	--	--	--	99	17	164	79	99	17	164	79
Jackson, TN	--	--	--	--	57	10	71	32	57	10	71	32
Princeton, KY	--				91	16	93	44	91	16	93	44
Morgantown, WV	--	--	--	--	45	12	72	27	45	12	72	27
Raleigh, NC	--	--	--	--	28	11	53	21	28	11	53	21
Average	--	--	--	--	74	15	108	46	74	15	108	46
	Two-cut management											
Blacksburg, VA												
Site A	107	15	83	27	58	6	30	27	165	21	113	54
Site B	142	17	150	30	83	8	72	39	225	25	222	69
Orange, VA	102	14	115	27	40	6	39	30	142	20	154	57
Knoxville, TN	90	11	71	32	54	6	24	36	144	17	95	68
Jackson, TN	92	14	105	33	39	5	30	19	131	19	135	52
Princeton, KY	67	13	70	24	47	8	13	28	114	21	83	52
Morgantown, WV	46	10	64	15	39	7	18	18	85	17	82	33
Raleigh, NC	51	13	79	22	18	7	22	13	69	20	101	35
Average	87	14	99	25	47	8	32	27	134	22	131	52

Table A-40. N, P, K, and Ca removal (kg ha^{-1}) in whole-plant tissue harvested from the one- and two-cut managements for Alamo switchgrass grown at eight locations (1997 to 2001 data)

Location	June harvest				Nov. harvest				Total season			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	---------- kg ha^{-1} removed ----------											
	One-cut management											
Blacksburg, VA												
Site A	--	--	--	–	75	13	87	43	75	13	87	43
Site B	--	--	--	--	121	13	166	69	121	13	166	69
Orange, VA	--	--	--	--	98	14	126	70	98	14	126	70
Knoxville, TN	--	--	--	--	70	14	95	58	70	14	95	58
Jackson, TN	--	--	--	--	45	10	69	25	45	10	69	25
Princeton, KY	--				55	14	61	43	55	14	61	43
Morgantown, WV	--	--	--	--	39	11	71	30	39	11	71	30
Raleigh, NC	--	--	--	--	58	19	92	41	58	19	92	41
Average[1]	--	--	--	--	68a	14a	94a	46a	68b	14b	94b	46b
	Two-cut management											
Blacksburg, VA												
Site A	86	13	91	23	71	9	60	36	157	22	150	59
Site B	129	17	159	29	98	11	100	48	227	28	259	77
Orange, VA	83	12	98	25	63	8	60	40	146	20	159	65
Knoxville, TN	92	12	77	29	30	5	24	23	122	17	101	51
Jackson, TN	67	11	94	20	24	5	27	13	90	15	122	32
Princeton, KY	64	15	86	23	29	6	14	22	93	21	100	45
Morgantown, WV	49	12	79	15	38	8	34	23	86	21	113	38
Raleigh, NC	76	19	101	29	33	12	38	25	110	31	139	53
Average	81	14	98	24	48b	8b	45b	29b	129a	22	143a	53a
LSD 0.05*	10	2	15	4	1	2	18	6	14	3	24	7

*LSD values are for comparison of means for locations across managements.

[1]Averages within columns (between managements) followed by similar letters do not differ at the 0.05

Table A-41. Soil pH with depth under Alamo switchgrass (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

(1998 data)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	---------- Soil pH ----------								
	---------- Switchgrass (One-cut management) ----------								
0 to 10	6.3	5.1	5.0	5.2	5.2	6.4	5.5	5.5	5.5
10 to 20	5.9	5.9	5.6	5.6	5.4	6.8	6.1	6.1	5.9
20 to 30	5.8	6.1	5.5	5.7	5.5	6.1	6.1	6.1	5.9
0 to 30	6.0	5.7	5.4	5.5	5.4	6.4	5.9	5.9	5.8
30 to 60	5.6	6.1	5.1	5.6	5.2	5.4	5.1	6.2	5.5
60 to 90	5.0	5.2	5.1	5.1	5.2	5.7	4.7	5.6	5.2
	---------- Switchgrass (Two-cut management) ----------								
0 to 10	5.7	5.2	5.0	5.2	5.4	6.4	5.5	5.8	5.5
10 to 20	5.8	5.9	5.6	5.6	5.5	6.7	6.2	6.2	5.9
20 to 30	5.8	6.2	5.4	5.9	5.5	5.9	6.2	6.3	5.9
0 to 30	5.8	5.8	5.3	5.6	5.5	6.3	6.0	6.1	5.8
30 to 60	4.9	5.8	5.3	5.7	5.1	4.8	5.1	6.4	5.4
60 to 90	5.0	5.4	5.2	5.2	5.1	5.1	4.8	6.0	5.2
	---------- Tall fescue ----------								
0 to 10	6.4	6.1	5.8	5.5	5.5	6.2	5.8	5.9	5.9
10 to 20	6.2	6.1	5.8	5.6	5.7	6.7	6.4	6.3	6.1
20 to 30	6.2	6.2	5.7	5.8	5.8	5.7	6.4	6.5	6.0
0 to 30	6.3	6.1	5.8	5.6	5.7	6.2	6.2	6.2	6.0
30 to 60	5.6	5.9	5.6	5.5	5.3	4.8	5.3	6.5	5.6
60 to 90	4.9	5.1	5.5	5.1	5.3	5.3	5.3	5.7	5.3
LSD 0.05	0.4	0.4	0.4	0.2	0.4	0.7	0.5	0.5	0.2

Table A-42. Soil P for several layers of soil under Alamo switchgrass (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

(1998 data)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC[1]	
cm	Soil P (ppm)								
	Switchgrass (One-cut management)								
0 to 10	29	33	5	6	8	8	12	133	14
10 to 20	4	4	2	1	7	7	5	150	4
20 to 30	5	6	1	1	7	2	6	72	4
0 to 30	13	14	3	3	7	6	8	118	8
30 to 60	1	2	2	1	8	1	0	4	2
60 to 90	1	1	1	1	7	1	0	8	2
	Switchgrass (Two-cut management)								
0 to 10	30	30	6	6	7	6	8	207	13
10 to 20	3	4	1	1	8	6	5	259	4
20 to 30	5	2	2	2	8	2	6	75	4
0 to 30	13	12	3	3	8	5	6	180	7
30 to 60	0	0	2	1	8	1	0	2	2
60 to 90	1	1	2	1	8	2	0	2	2
	Tall fescue								
0 to 10	2	4	4	4	10	6	7	216	5
10 to 20	1	2	2	2	7	6	6	296	4
20 to 30	1	3	2	1	6	3	4	176	3
0 to 30	1	3	3	2	8	5	6	229	4
30 to 60	0	2	3	1	7	1	0	16	2
60 to 90	0	0	3	1	6	2	0	2	2
LSD 0.05	5	8	2	1	3	3	3	121	

[1]Data from North Carolina were not included in the averages due to extremely high values.

Table A-43. Soil K for several layers of soil under Alamo switchgrass (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

(1998 data)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Soil K (ppm)								
	Switchgrass (One-cut management)								
0 to 10	101	146	50	46	74	40	54	66	72
10 to 20	60	121	25	22	53	29	28	32	46
20 to 30	50	70	17	21	48	30	25	29	36
0 to 30	70	112	31	30	58	33	36	42	52
30 to 60	31	80	20	18	40	33	29	30	35
60 to 90	31	83	20	25	31	43	36	24	37
	Switchgrass (Two -cut management)								
0 to 10	73	68	45	40	64	34	31	50	51
10 to 20	49	46	21	21	54	30	24	40	36
20 to 30	31	35	24	20	49	30	24	17	29
0 to 30	51	50	30	27	56	31	26	36	38
30 to 60	27	44	18	18	40	28	31	23	29
60 to 90	31	39	19	26	25	40	34	37	31
	Tall fescue								
0 to 10	91	153	157	114	105	43	58	89	101
10 to 20	36	141	123	42	58	29	32	40	63
20 to 30	24	111	80	27	50	31	30	38	49
0 to 30	50	135	120	61	71	34	40	56	71
30 to 60	37	78	50	23	41	28	32	54	43
60 to 90	40	62	25	44	26	45	34	41	40
LSD 0.05	30	28	22	14	16	8	9	15	3

Table A-44. Soil Ca with depth under Alamo switchgrass (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

(1998 data)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Soil Ca (ppm)								
	Switchgrass (One-cut management)								
0 to 10	672	330	651	513	738	1239	675	795	702
10 to 20	333	480	672	522	867	1312	774	815	722
20 to 30	330	432	495	486	756	1118	780	597	624
0 to 30	445	414	606	507	787	1223	743	736	683
30 to 60	382	414	345	405	408	814	561	417	468
60 to 90	315	375	168	186	222	994	399	402	383
	Switchgrass (Two-cut management)								
0 to 10	525	405	651	513	816	1300	663	946	727
10 to 20	333	510	621	561	864	1400	810	1279	797
20 to 30	339	420	495	549	768	1142	801	630	643
0 to 30	399	445	589	541	816	1281	758	952	723
30 to 60	315	396	264	429	392	723	594	471	448
60 to 90	248	345	270	189	212	934	513	441	394
	Tall fescue								
0 to 10	693	495	880	612	906	1269	750	972	822
10 to 20	384	456	724	486	936	1390	861	1280	815
20 to 30	330	336	560	531	834	1108	810	791	663
0 to 30	469	429	721	543	892	1256	807	1014	766
30 to 60	306	324	412	396	345	693	675	402	444
60 to 90	267	306	380	174	228	1048	633	444	435
LSD 0.05	90	100	172	58	199	346	206	423	35

Table A-45. Soil organic matter with depth under Alamo switchgrass (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

(1998 data)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Soil Organic matter (%)								
	Switchgrass (One-cut management)								
0 to 10	3.3	2.6	4.4	3.2	2.0	2.0	2.4	2.8	2.8
10 to 20	1.9	2.3	2.2	1.8	1.4	1.8	2.0	2.2	1.9
20 to 30	1.5	1.4	1.0	1.0	0.8	1.2	1.8	1.7	1.3
0 to 30	2.2	2.1	2.5	2.0	1.4	1.7	2.1	2.2	2.0
30 to 60	0.8	0.7	0.8	0.8	0.6	0.8	1.3	0.9	0.8
60 to 90	0.7	0.6	0.7	0.6	0.6	0.8	2.2	0.8	0.9
	Switchgrass (Two-cut management)								
0 to 10	3.1	2.5	4.5	3.1	2.1	2.0	2.4	2.7	2.8
10 to 20	1.7	2.0	2.1	1.8	1.6	1.6	1.9	1.9	1.8
20 to 30	1.0	1.1	1.0	1.1	0.8	1.2	1.8	1.5	1.2
0 to 30	1.9	1.9	2.5	2.0	1.5	1.6	2.0	2.0	1.9
30 to 60	0.7	0.8	0.8	0.7	0.6	0.8	1.3	0.9	0.8
60 to 90	0.7	0.7	0.7	0.7	0.6	0.7	2.0	0.7	0.8
	Tall fescue								
0 to 10	3.6	2.7	4.1	4.2	2.2	2.3	2.7	3.1	3.1
10 to 20	1.8	2.2	2.3	1.7	1.2	1.6	2.1	2.1	1.9
20 to 30	1.0	1.2	1.3	1.0	0.8	1.0	1.6	1.6	1.2
0 to 30	2.1	2.0	2.6	2.3	1.4	1.6	2.1	2.3	2.1
30 to 60	0.8	0.8	0.9	0.7	0.6	0.9	1.3	0.9	0.8
60 to 90	0.7	0.8	0.7	0.7	0.5	0.8	1.7	0.7	0.8
LSD 0.05	0.3	0	0.5	0.3	0.3	3.0	0.7	0.5	0.1

Table A-46. Soil chemical properties with depth under Alamo switchgrass averaged over eight locations after seven years of growth (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

[(1998 samples) The productivity potentials are soil test values that are recommended to achieve low, medium, and high yields of agronomic crops.]

Depth	Soil analyses (routine soil test at Virginia Tech)				
	pH	P	K	Ca	Soil-OM[1]
cm		ppm			%
	Switchgrass (One-cut management)				
0 to 10	5.5	14	72	702	2.8
10 to 20	5.9	4	46	722	1.9
20 to 30	5.9	4	36	624	1.3
0 to 30	5.8	7	51	683	2.0
30 to 60	5.5	2	35	468	0.8
60 to 90	5.2	2	37	383	0.9
	Switchgrass (Two-cut management)				
0 to 10	5.5	13	51	727	2.8
10 to 20	5.9	4	36	797	1.8
20 to 30	5.9	4	29	643	1.2
0 to 30	5.8	7	39	722	1.9
30 to 60	5.4	2	29	448	0.8
60 to 90	5.2	2	31	394	0.8
	Tall fescue				
0 to 10	5.9	5	101	822	3.1
10 to 20	6.1	4	63	815	1.9
20 to 30	6.0	3	49	663	1.2
0 to 30	6.0	4	71	767	2.1
30 to 60	5.6	2	43	444	0.8
60 to 90	5.3	2	40	435	0.8
LSD 0.05	0.2	2.0	6	63	0.2
	Productivity potential based on field crops				
Low	?	2 to 4 ppm	8 to 28 ppm	121 to 240 ppm	?
Medium	?	11 to 15 ppm	51 to 75 ppm	481 to 600 ppm	?
High	?	28 to 34 ppm	1.6 to 140 ppm	841 to 960 ppm	?

Table A-47. Root mass distribution (percentage of total) and total root mass (Mg ha^{-1})[1] with depth of soil under Alamo switchgrass (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

(1998 data)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Percentage of roots ha^{-1} per 10 cm								
	Switchgrass (One-cut management)								
0 to 10	34	32	30	47	44	28	29	32	35
10 to 20	29	36	29	26	26	35	35	23	30
20 to 30	25	31	27	16	16	18	21	23	21
0 to 30	88	99	86	89	86	81	85	78	86
30 to 60	12	1	12	9	10	11	12	14	10
60 to 90	0	0	2	1	4	8.0	4	8	4
Mg ha^{-1}	8.6[2]	15.7	13.0	18.4	19.3	22.3	10.2	13.6	15.2
	Switchgrass (Two-cut management)								
0 to 10	42	28	47	51	52	33	28	40	41
10 to 20	35	38	24	18	23	38	35	25	29
20 to 30	21	21	19	16	15	15	20	16	18
0 to 30	98	87	90	85	89	86	83	81	87
30 to 60	2	9	6	11	7	10	12	11	9
60 to 90	0	4	3	4	4	4.0	5	8	4
Mg ha^{-1}	12.8[2]	18.7	12.0	22.5	16.8	17.3	17.1	17.4	16.8
	Tall fescue								
0 to 10	72	73	70	76	47	66	75	78	72
10 to 20	17	12	18	12	24	15	10	7	14
20 to 30	11	8	7	7	12	10	8	6	8
0 to 30	100	93	94	95	83	90	93	90	94
30 to 60	0	5	4	4	14	5.0	4	7	4
60 to 90	0	2	2	1	3	4.0	3	3	2
Mg ha^{-1}	10.6[2]	12.1	11.7	16.9	3.0	8.8	9.1	6.3	9.8

[1]Root mass was determined by screening dry soil. Vigorous handling to pulverize soil to pass a 10-mesh screen may have removed small branch rootlets.

[2]Total root mass in the profile. Weights were adjusted using a factor of 2.2 for switchgrass and a factor of 5 for tall fescue to account for the estimated loss during a dry soil collection method.

Table A-48. Soil C with depth under Alamo switchgrass (two cutting managements) and tall fescue grown at eight sites (fall 1998)

(Data from Oak Ridge National Laboratory)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Soil -C (%)								
	Switchgrass (One-cut management)								
0 to 10	1.73	1.35	2.67	1.64	1.04	1.01	1.31	1.42	1.52
10 to 20	0.84	1.08	1.19	0.77	0.76	0.75	1.10	1.00	0.94
20 to 30	0.59	0.65	0.48	0.44	0.31	0.46	1.01	0.78	0.59
0 to 30	1.05	1.03	1.45	0.95	0.70	0.7	1.14	1.07	1.02
30 to 60	0.18	0.25	0.25	0.25	0.16	0.24	0.06	0.29	0.23
60 to 90	0.15	0.17	0.14	0.18	0.09	0.19	1.20	0.25	0.17
	Switchgrass (Two-cut management)								
0 to 10	1.59	1.39	2.89	1.46	1.02	0.94	1.24	1.36	1.50
10 to 20	0.76	1.16	1.22	0.78	0.86	0.70	1.08	0.93	0.92
20 to 30	0.36	0.56	0.44	0.43	0.33	0.46	1.01	0.63	0.53
0 to 30	0.90	1.04	1.52	0.89	0.74	0.70	1.11	0.97	0.98
30 to 60	0.16	0.19	0.21	0.22	0.19	0.22	0.69	0.33	0.22
60 to 90	0.15	0.18	0.14	0.16	0.09	0.19	1.01	0.16	0.15
	Tall fescue								
0 to 10	1.73	1.39	2.85	2.20	1.25	1.14	1.48	1.60	0.67
10 to 20	0.76	1.15	1.48	0.86	0.75	0.77	0.99	0.91	0.94
20 to 30	0.43	0.57	0.77	0.49	0.40	0.49	0.78	0.63	0.65
0 to 30	0.97	1.04	1.70	1.18	0.80	0.80	1.08	1.05	0.75
30 to 60	0.22	0.22	0.37	0.27	0.22	0.22	0.52	0.30	0.23
60 to 90	0.23	0.14	0.23	0.23	0.16	0.20	0.73	0.15	0.19

Table A-49. Soil N with depth under Alamo switchgrass (two cutting managements) and tall fescue grown at eight sites (fall 1998)

(Data from Oak Ridge National Laboratory)

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Soil N (%)								
	Switchgrass (One-cut management)								
0 to 10	0.18	0.16	0.24	0.13	0.10	0.90	0.10	0.10	0.14
10 to 20	0.85	0.13	0.12	0.07	0.09	0.06	0.11	0.06	0.09
20 to 30	0.05	0.09	0.04	0.05	0.05	0.04	0.07	0.05	0.06
0 to 30	0.36	0.13	0.13	0.08	0.08	0.33	0.09	0.07	0.10
30 to 60	0.02	0.06	0.03	0.00	0.03	0.03	0.04	0.03	0.03
60 to 90	0.01	0.03	0.02	0.03	0.02	0.03	0.04	0.05	0.03
	Switchgrass (Two-cut management)								
0 to 10	0.16	0.18	0.25	0.13	0.10	0.10	0.10	0.08	0.14
10 to 20	0.08	0.14	0.11	0.07	0.08	0.08	0.10	0.06	0.09
20 to 30	0.05	0.09	0.04	0.05	0.05	0.06	0.07	0.04	0.06
0 to 30	0.10	0.14	0.13	0.08	0.08	0.08	0.09	0.06	0.10
30 to 60	0.04	0.05	0.02	0.04	0.04	0.04	0.06	0.04	0.04
60 to 90	0.03	0.04	0.02	0.03	0.01	0.03	0.04	0.02	0.02
	Tall fescue								
0 to 10	0.13	0.16	0.22	0.18	0.12	0.11	0.13	0.14	0.15
10 to 20	0.06	0.13	0.10	0.06	0.08	0.09	0.09	0.08	0.09
20 to 30	0.03	0.08	0.05	0.04	0.04	0.05	0.07	0.07	0.05
0 to 30	0.07	0.12	0.12	0.09	0.08	0.08	0.10	0.10	0.10
30 to 60	0.04	0.05	0.01	0.02	0.02	0.03	0.05	0.05	0.03
60 to 90	0.01	0.04	0.01	0.02	0.01	0.03	0.05	0.04	0.02

Table A-50. Stock soil C[1] with depth under switchgrass (two cutting managements) and tall fescue grown at eight sites (fall 1998)

[(mg cm^{-2} x 0.1 = Mg ha^{-1}) Data from Oak Ridge National Laboratory]

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	------ Stock soil C (mg cm^{-2}) ------								
	------ Switchgrass (One-cut management) ------								
0 to 10	238	210	297	230	162	148	191	192	209
10 to 20	128	161	149	128	129	127	171	170	145
20 to 30	102	106	63	71	52	86	165	142	98
0 to 30	468	477	509	429	343	361	527	504	452
30 to 60	92	121	96	120	81	120	285	155	112
60 to 90	78	87	56	85	48	96	595	138	84
0 to 90	638	685	661	634	472	577	1407	797	648
	------ Switchgrass (Two-cut management) ------								
0 to 10	220	216	320	205	159	138	181	183	203
10 to 20	118	175	153	131	145	116	167	140	143
20 to 30	64	92	58	70	54	86	165	114	88
0 to 30	402	483	531	406	358	340	513	437	434
30 to 60	84	92	83	107	96	108	641	182	107
60 to 90	76	92	54	77	44	94	500	86	75
0 to 90	562	667	668	590	498	542	1654	705	616
	------ Tall fescue ------								
0 to 10	239	216	316	309	195	168	216	217	235
10 to 20	116	172	184	144	126	125	153	145	147
20 to 30	75	94	102	78	67	90	129	114	94
0 to 30	430	482	602	531	388	383	498	476	476
30 to 60	117	107	143	129	113	114	257	166	127
60 to 90	121	67	85	109	80	101	361	81	92
0 to 90	668	656	830	769	581	598	1116	723	695

[1]Stock soil C was calculated from the percentage of soil C and bulk density values.

Table A-51. Stock soil N[1] with depth under switchgrass (two cutting managements) and tall fescue grown at eight sites (fall 1998)

[(mg cm^{-2} x 0.1 = Mg ha^{-1}) Data from Oak Ridge National Laboratory]

Depth	Location								Av
	Site A	Site B	Orange	Knox	Jack	Princeton	WV	NC	
cm	Stock soil N (mg cm^{-2})								
	Switchgrass (One-cut management)								
0 to 10	24	25	27	19	15	13	15	14	19
10 to 20	13	20	14	12	15	10	17	10	14
20 to 30	8	15	6	8	8	7	11	9	9
0 to 30	45	60	47	39	38	30	43	33	42
30 to 60	11	3	11	14	14	16	19	15	16
60 to 90	7	17	9	14	8	13	21	16	12
0 to 90	63	80	67	67	60	59	83	64	70
	Switchgrass (Two-cut management)								
0 to 10	22	27	28	18	16	15	14	11	19
10 to 20	13	21	13	12	14	13	15	9	14
20 to 30	8	15	6	8	8	9	11	8	9
0 to 30	43	63	47	38	38	37	40	28	42
30 to 60	18	24	8	19	19	18	28	20	18
60 to 90	15	18	8	13	5	14	31	12	12
0 to 90	76	105	63	70	62	69	99	60	72
	Tall fescue								
0 to 10	18	25	24	25	18	16	18	19	20
10 to 20	9	20	13	10	13	14	14	14	13
20 to 30	5	12	7	6	6	10	11	13	9
0 to 30	32	57	44	41	37	40	43	46	42
30 to 60	25	23	14	11	11	17	25	26	18
60 to 90	5	18	4	8	6	16	25	23	12
0 to 90	62	98	62	60	54	73	93	95	72

[1]Stock soil N was calculated from the percentage of soil N and bulk density values.

Table A-52. Soil C and soil N percentage and stock (mg cm^{-2} for each soil layer) averaged over eight locations for several layers under Alamo switchgrass after seven years of growth (cut once or twice during the previous seven seasons) and tall fescue (tall fescue samples were taken from large center alleys and did not receive the same fertility or cutting management as the switchgrass)

[Root mass in the 0 to 90-cm profile is in brackets. (Fall 1998 samples)]

Depth	Soil C[1]	Soil N[1]	C:N ratio	Stock soil C[1]	Stock soil N[1]	Root mass
cm	%			------------ mg cm^{-2}	------------	%
	------------------------------ Switchgrass (One-cut management) -----------------------------					
0 to 10	1.52	0.14	10.9	209	19	35
10 to 20	0.94	0.09	10.4	145	14	30
20 to 30	0.59	0.06	9.8	98	9	21
0 to 30	1.02	0.10	10.2	452	42	86
30 to 60	0.23	0.03	7.7	112	16	10
60 to 90	0.17	0.03	5.7	84	12	4
0 to 90				648	70	[15.2 Mg ha^{-1}]
	------------------------------ Switchgrass (Two-cut management) -----------------------------					
0 to 10	1.50	0.14	10.7	203	19	41
10 to 20	0.92	0.09	10.2	143	14	29
20 to 30	0.53	0.06	8.8	88	9	18
0 to 30	0.98	0.10	9.8	434	42	87
30 to 60	0.22	0.04	5.5	107	18	9
60 to 90	0.15	0.02	7.5	75	12	4
0 to 90				616	72	[16.8 Mg ha^{-1}]
	-- Tall fescue --					
0 to 10	0.67	0.15	4.5	235	20	72
10 to 20	0.94	0.09	10.4	147	13	14
20 to 30	0.65	0.05	13.0	94	9	8
0 to 30	0.75	0.10	7.5	476	42	94
30 to 60	0.23	0.03	7.7	127	18	4
60 to 90	0.19	0.02	9.5	92	12	2
0 to 90				695	72	[9.8 Mg ha^{-1}]

[1]Soil C and soil N were determined by a combustion method (Leco) by a lab at Oak Ridge, TN.

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