Upland Switchgrass Yield, Nutritive Value, and Soil Carbon Changes Under Grazing and Clipping

Matt A. Sanderson*

ABSTRACT

There have been few evaluations of switchgrass (Panicum virgatum L.) cultivars under multiple harvest managements in the northeastern United States. The objective of this study was to determine the yield, nutritive value, and soil C changes of switchgrass cultivars under grazing and clipping. In 1999, ‘Cave-in-Rock’, ‘Trailblazer’, and ‘Shawnee’ switchgrass were established in field plots at Rock Springs, PA, and in pastures in southeastern Pennsylvania. In 2000 and 2001, two- and three-cut treatments were imposed at Rock Springs. At the southeastern Pennsylvania site, pastures were grazed three or four times per year during 2000 to 2004. Forage yield, crude protein (CP), neutral detergent fiber (NDF), and neutral detergent fiber digestibility (NDFD) were determined at each harvest. Soil was analyzed for C and stable C isotopes before planting in 1999 and at the end of the experiments. Cultivars differed slightly in yield and nutritive value. Variation in forage yield was greater among years and management treatments (3300 to 8200 kg ha⁻¹) than among cultivars (5900 to 9400 kg ha⁻¹). Trailblazer suffered from leaf diseases and lodging during wet years. There were no differences among cultivars in soil C. Soil C accumulated in the surface 5 cm of soil after 7 yr at Rock Springs, but soil C did not change after 5 yr of grazing. By the end of the experiments, about 20% of soil C in the surface 5 cm was derived from switchgrass. Cave-in-Rock and Shawnee are equally suited and superior to Trailblazer for hay and grazing in Pennsylvania and similar areas in the northeast.

Warm season perennial grasses, such as switchgrass, can provide valuable forage during the summer and complement cool-season forages (Vogel, 2004). Cutting experiments in the northeastern United States and Canada have shown differences among switchgrass cultivars in forage production and persistence (Berg, 1971; Madakadze et al., 1999; Belesky and Fedders, 1995). There have been few evaluations of switchgrass cultivars under grazing in the northeastern United States. Several trials have evaluated switchgrass cultivars for biomass feedstock production (Sanderson et al., 2004); however, with one exception (Morgantown, WV) (Fike et al., 2006), there were no northeastern U.S. locations in those studies.

Cave-in-Rock, a commonly recommended switchgrass cultivar in the northeastern United States, was developed from plant material collected in Illinois and released in 1973 (Alderson and Sharp, 1995). Trailblazer, a cultivar selected for improved whole-plant in vitro dry matter digestibility, was released in 1984 (Vogel et al., 1991). Beef steers gained better on Trailblazer than other cultivars in Nebraska trials (Anderson et al., 1988). Shawnee, released in 1995, is a selection out of Cave-in-Rock and has improved dry matter digestibility (Vogel et al., 1996). There are no published data on the yield or nutritive value of Shawnee in the northeastern United States.

Rising atmospheric CO₂ levels and associated changes in climate have raised interest in managing agricultural lands to increase soil storage of C (Lal, 2006). Growing warm-season perennial grasses for soil conservation purposes, forage, or biomass feedstock has been recommended as a CO₂ mitigation practice (Schnabel et al., 2000; Intergovernmental Panel on Climate Change, 2007). Information is needed on how management of warm-season grasses affects soil C changes. Therefore, the objective was to determine forage yield and nutritive value of switchgrass cultivars along with soil C changes under clipping and grazing management.

MATERIALS AND METHODS

Clipping Experiment

The clipping experiment was conducted at the Russell E. Larson Agricultural Research Center at Rock Springs. Soil at the site is a Hagerstown silt loam (fine, mixed, semiactive, mesic, Typic Hapludalfs). Soil tests in 1999 indicated a pH of 6.4, 78 kg ha⁻¹ of available P, and 124 kg ha⁻¹ of available K to a 15-cm depth. No additional P fertilizer was applied during the experiment. The site was tilled to switchgrass in 1994, potato (Solanum tuberosum L.) in 1995, wheat (Triticum aestivum L.) in 1996, corn grain (Zea mays L.) in 1997, and soybean (Glycine max L. Merr.) in 1998.

The plot site was moldboard plowed, disked, and cultivated before planting. The upland switchgrass cultivars Cave-in-Rock, Shawnee, and Trailblazer were planted at 11 kg pure live seed ha⁻¹ with a plot drill (18-cm row spacing) in 9- by 15-m plots on 29 April 1999. Each cultivar was planted in six randomized complete blocks. The plot area

Abbreviations: CP, crude protein; DM, dry matter; MSW, mean stage by weight; NDF, neutral detergent fiber; NDFD, neutral detergent fiber digestibility.

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Grazing Defoliation Experiment

Defoliation under grazing was conducted on a private farm in Chester County, southeastern Pennsylvania. Soil at the site is a Glenelg silt loam (fine-loamy, mixed, semiaquic, Mesic Typic Hapludults) with a 3 to 8% slope and moderate erosion. Soil tests in 1999 indicated a pH of 5.9, 29 kg ha⁻¹ of available P, and 131 kg ha⁻¹ of available K. According to the producer, the pasture site had been a hayfield from 1970 to 1981. It was converted to cool-season grass-legume pasture in 1982. In 1984, the site was no-till planted to switchgrass. The initial stand was fair but it deteriorated rapidly and was essentially eliminated by 1996. In 1997, the producer planted the pasture to chicory (Cichorium intybus L.); however, the stand failed in 1998.

In March 1999, existing vegetation at the site was killed with glyphosate herbicide. In April 1999, two 0.4-ha pastures each of Cave-in-Rock, Shawnee, and Trailblazer were no-till planted in a randomized complete block design with two replicates. Seeding rate was 11 kg pure live seed ha⁻¹. Pastures were not harvested in 1999. Nitrogen fertilizer was applied at 90 kg ha⁻¹ in May and 48 kg ha⁻¹ in June 2000 and 2001. Potassium was applied at 50 kg ha⁻¹ in April 2001. Glyphosate [N-(phosphonomonomethyl) glycine] herbicide was applied at 1 kg ha⁻¹ in early April 2001 (when switchgrass was dormant) to control cool-season weeds.

Plots were split in 2000 and 2001 with one-half randomly assigned to a two-cut or three-cut harvest schedule. The first harvest of the two-cut schedule occurred at about early boot stage and the second harvest at 60 cm of regrowth. The first harvest of the three-cut schedule occurred when the canopy was 45 cm and at 60 to 70 cm of regrowth in the second and third harvests. Harvest dates for the two-cut schedule were 21 June and 9 August 2000 and 19 June and 7 August 2001. Harvest dates for the three-cut schedule were 8 June, 12 July, and 6 September 2000 and 19 June, 23 July, and 2 October 2001. At each harvest, a 1-m by 5-m strip was cut to a 15-cm stubble height with a sickle-bar mower. The fresh weight of herbage was recorded and a 400-g subsample of herbage was dried at 55°C for 48 h to determine dry matter (DM) yield.

The switchgrass pastures were grazed by 25 Angus cow-calf pairs on four dates in 2000 and three dates in 2001 to 2004 (Table 1). The producer grazed the 2.4-ha area in rotation with cool-season grass pastures. The 2.4-ha area of switchgrass was subdivided across the cultivar pastures into five 0.48-ha paddocks for grazing so that the cattle grazed all cultivars at once. Grazing time in each paddock ranged from 1 to 3 d depending on herbage mass and weather. The grazing, fertilizer, and herbicide management decisions were made by the producer.

In 2000, N fertilizer was applied at 25 kg of N ha⁻¹ in late May. During 2001 to 2004, N fertilizer was applied at 112 kg N ha⁻¹ in two split applications of 56 kg each. The first application occurred in late May before the first grazing and the second application in mid-June after the first grazing in 2001 and 2002. In 2003, the second application of N was delayed until August because frequent rain and flooding precluded machine access to the pastures. In 2004, the N applications were delayed until mid-June and mid-July because of heavy rains. Urea was the source of fertilizer N at each application except in May 2003 when 26–5–21 fertilizer was applied to supply 56 kg N, 12 kg P, and 48 kg K ha⁻¹. Lime was applied in April 2002 at 2.5 Mg ha⁻¹.

Dicamba (3,6-dichloro-2-methoxybenzoic acid; 0.28 kg ha⁻¹) and 2,4-D (2,4-dichlorophenoxy acetic acid; 0.84 kg ha⁻¹) were applied in June 2001 to control broadleaf weeds. Glyphosate was applied at 1 kg ha⁻¹ in late March 2003 and early April 2004 (when switchgrass was dormant) to control cool-season weeds. Pastures were clipped once with a rotary mower to a 20-cm stubble after the first grazing in 2002, 2003, and 2004. Weather data were collected with a portable meteorological station (Table 2).

Dry matter yield was determined in September 1999 by cutting three 0.6- by 1-m strips in each pasture to ground level. The herbage was hand sorted into switchgrass and weeds. In 2000 to 2004, three 1-m by 6.3-m strips were cut from each pasture before each grazing to estimate DM yield. Strips were cut to a stubble height of 15 cm and the fresh weight of herbage measured. A 400-g subsample of herbage was dried at 55°C for 48 h to determine DM yield.

Table 1. Dates grazing began on three switchgrass cultivars during 5 yr in southeastern Pennsylvania.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>25</td>
<td>30</td>
<td>12</td>
<td>13</td>
<td>27</td>
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<tr>
<td>June</td>
<td>20</td>
<td>3</td>
<td>27</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>July</td>
<td>13</td>
<td>16</td>
<td>1</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Aug</td>
<td>17</td>
<td>18</td>
<td>1</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

The switchgrass pastures were grazed by 25 Angus cow-calf pairs on four dates in 2000 and three dates in 2001 to 2004 (Table 1). The producer grazed the 2.4-ha area in rotation with cool-season grass pastures. The 2.4-ha area of switchgrass was subdivided across the cultivar pastures into five 0.48-ha paddocks for grazing so that the cattle grazed all cultivars at once. Grazing time in each paddock ranged from 1 to 3 d depending on herbage mass and weather. The grazing, fertilizer, and herbicide management decisions were made by the producer.

Table 2. Monthly total rainfall during the switchgrass growing seasons at the clipping site in Rock Springs, PA, and the grazing site in southeastern Pennsylvania.

<table>
<thead>
<tr>
<th>Month</th>
<th>Rock Springs</th>
<th>Southeastern PA farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>74</td>
<td>62</td>
</tr>
<tr>
<td>May</td>
<td>62</td>
<td>35</td>
</tr>
<tr>
<td>June</td>
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<tr>
<td>July</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>Aug</td>
<td>74</td>
<td>91</td>
</tr>
<tr>
<td>Sept.</td>
<td>48</td>
<td>80</td>
</tr>
</tbody>
</table>
Tillers were separated into individual stage categories, counted, dried at 55°C for 48 h, and weighed. Tillers from individual stage categories were combined to provide one sample per plot at each harvest. Composite samples were ground to pass a 1-mm screen in a shear mill for nutritive value analysis. Only samples from the years 2001, 2002, and 2003 were analyzed for nutritive value in the grazing experiment.

The dried and ground samples from both experiments were analyzed for CP, NDF, and NDFD (48 h fermentation) by a commercial laboratory (DairyOne, Ithaca, NY). Detergent fiber and NDFD procedures were according to van Soest and Robertson (1980). Nitrogen was determined by the Dumas combustion method (Association of Official Analytical Chemists, 1990) and CP calculated as N × 6.25. In both experiments, a weighted seasonal average was calculated for NDF, CP, and NDFD using individual harvest yields as the weighting factor (Cherney and Volenec, 1992).

### Soil C and Root Mass Determination

In the clipping experiment, soil samples for C and root mass determination were collected to a depth of 30 cm from each whole plot in April 1999 and again in December 2006. About 70 to 90% of switchgrass root mass occurs in the upper 30 to 40 cm of soil (Jung et al., 1988; Garten and Wullsclager, 1999; Ma et al., 2000a). In 1999, three soil cores (4.7 cm diameter) were taken in each plot. In 2006, one soil core (4.1 cm diameter) was taken in the four quadrants of each plot. Surface debris was removed before sampling. In 1999 and 2006, individual cores were divided into 0- to 5-, 5- to 15-, and 15- to 30-cm segments, air dried, crushed, and passed through a 2-mm sieve to remove stones and coarse roots. The sieved soil was then ground with a mortar and pestle. The processed soil from the individual cores was combined by depth segment within a plot, resulting in one sample per depth segment for each plot. For the 2006 soil samples, the coarse roots (roots remaining on the 2-mm screen; Garten and Wullsclager, 1999) were gently washed with deionized water, dried at 55°C, and weighed to determine root mass in each depth segment. Coarse roots from all segments and cores within a plot were then combined into one sample per plot and ground to pass a 1-mm screen for C, N, and stable C isotope analysis. Segments and cores were combined to provide enough root material for analysis.

In the grazing experiment, soil samples for C and root mass determination were collected in April 1999 and October 2004. Ten soil cores (4.7 cm diameter) were taken to a 1-m depth at 25-m intervals on a line transect in each pasture. Surface debris was removed before sampling. Individual cores were divided into 0- to 5-, 5- to 15-, 15- to 30-, 30- to 60-, 60- to 90-, and > 90-cm segments. Soil and roots were processed and combined as in the clipping experiment. Only soil (1999 and 2004) and roots (2004 only) from the 0- to 5-, 5- to 15-, and 15- to 30-cm segments in each pasture were analyzed for C, N, and stable C isotopes.

A total of 36 soil samples (three cultivars, two replicates, three soil depths, and 2 yr) from the grazing experiment and 108 soil samples (three cultivars, six replicates, three soil depths, and 2 yr) for the clipping experiment were analyzed for total N, C, and stable C isotopes. Six composite root samples (one from each cultivar pasture in 2004) from the grazing experiment and 18 composite root samples (one from each plot in 2006) from the clipping experiment were analyzed for total N, C, and stable C isotopes.

The differences in stable C isotope ratios between C₃ and C₄ plants can be used to estimate C₄-derived soil organic C (Balesdent et al., 1987). Changing the vegetation from C₃ to C₄ plants changes the isotopic signature of the soil organic C. Stable C isotopes in soil, roots, and herbage (eight herbage samples of each cultivar) were measured with a continuous-flow stable isotope mass spectrometer (Europa Scientific Integra) by the Stable Isotope Facility at the University of California-Davis. Carbon isotope ratios (δ¹³C) were expressed relative to the Pee Dee belemnite standard as a delta-value (δ) with units of parts per thousand (%). The proportion of total soil C derived from C₄ plants was calculated as: 

\[ \frac{(δ¹³C_{soil\ end}) - (δ¹³C_{soil\ start})}{(δ¹³C_{switchgrass}) - (δ¹³C_{soil\ start})} \times 100 \]

Where: δ¹³C_{soil\ start} was the isotope ratio of soil before planting the experiments in 1999; δ¹³C_{soil\ end} was the isotope ratio of soil in September 2004 for the grazing defoliation experiment and December 2006 for the clipping experiment; and δ¹³C_{switchgrass} was the average isotope ratio of switchgrass roots and herbage (Balesdent et al., 1987; Corre et al., 1999).

### Statistical Analyses

A combined analysis of variance across years was conducted for herbage yield and nutritive value data in both studies. The clipping experiment was analyzed as a randomized complete block with a split-plot arrangement of treatments. Cultivars were the whole plots and cutting schedule was the subplot. Years were treated as a repeated measure. The grazing experiment was analyzed as a randomized complete block with years as a repeated measure. Herbage yield data from the grazing site in 1999 were analyzed separately. Soil C and N data from both experiments were analyzed by year as a randomized complete block design. In both experiments, blocks were considered random and treatments (cultivars, cutting dates) were fixed effects. A linear mixed models procedure (PROC MIXED; with the variance components option for covariance structure and the Kenward-Rogers option for denominator degrees of freedom) in SAS (Littell et al., 1996) was used to conduct the analyses. Means were separated with the PDIF option.

### RESULTS AND DISCUSSION

#### Herbage Yields

Switchgrass cultivars did not differ in DM yield (P > 0.35) under clipping at Rock Springs (Table 3). Dry matter yield differed (P < 0.01) among years, cutting schedules, and there was a year × cutting schedule interaction. The interaction was caused by a change in magnitude of the cutting schedule means and not a change in the direction of response. Averaged for cultivars, the three-cut schedule yielded 24% more forage than the 2-cut schedule in 2000 and 11% more forage in 2001.

Yield distribution between harvests in the two-cut schedule changed dramatically from year to year (data not shown). In 2000, 60% of the season total forage yield occurred in the first harvest, whereas in 2001, the first harvest accounted for only
In the grazing experiment, cultivars did not differ in DM yield in September 1999 (Table 4). Weeds (primarily annual *Panicum* species) were prevalent and averaged 600 kg DM ha\(^{-1}\). Switchgrass can be slow to establish and obtaining enough forage for grazing or cutting in the first year would be valuable to the producer. Vogel et al. (2006) recommended a goal of obtaining 50% of the first production year yield in the establishment year for switchgrass grown for biomass. In this experiment, switchgrass yield in the establishment year (1999) was only 27% of that in the first production year (2000).

There was a year × cultivar interaction (*P < 0.01*) for DM yield in the grazing experiment caused by differences among cultivars in 2000, 2003, and 2004 (Table 4). Cultivars did not differ in DM yield in 2001 and 2002. Trailblazer yielded 40% more forage than Shawnee in 2000 but did not differ in yield from Cave-in-Rock. By 2003 and 2004, however, Trailblazer yielded 19 to 44% less forage than Cave-in-Rock or Shawnee.

Variation in herbage yield among years (3300–8200 kg ha\(^{-1}\)) was greater than variation among cultivars within years (5900–9400 kg ha\(^{-1}\)). Yields were highly variable among years due to differences in grazing dates (Table 1), weather (Table 2), and perhaps leaf diseases (see discussion below). Grazing started and ended later in 2002 and 2003, which may have allowed for greater DM accumulation compared with other years.

Grazing and leaf disease, which may have reduced herbage yields, were observed in the Trailblazer pastures in 2003 and 2004 but damage was not quantified. Significant leaf disease and lodging were noted in Trailblazer during 2000 and 2001 at Rock Springs; however, yields were not affected (Table 3). The leaf disease at Rock Springs was identified as anthracnose (caused by *Colletotrichum graminicola*) by the Plant Diagnostic Laboratory at Penn State University. Leaf disease or lodging problems were not observed in Cave-in-Rock or Shawnee; however, damage was not quantified in the clipping experiment. Trailblazer had poor persistence after the first production year at four sites in WV (Belesky and Fedders, 1995). In the WV study, leaf diseases (presumably helminthosporium leaf blotch caused by *Bipolaris sorokiniana* [Sacc.] Shoemaker [Zeiders, 1984]) damaged Trailblazer in late summer. Poor agronomic performance and greater weed invasion was noted for N-fertilized Trailblazer switchgrass at Rock Springs in earlier research (Reid et al., 1992).

Trailblazer traces its lineage to switchgrass collections from natural grasslands in Nebraska and its primary area of adaptation is the central Great Plains and western Corn Belt (Vogel et al., 1991). Cave-in-Rock originated from collections in southern Illinois (Alderson and Sharp, 1995) and formed the base population from which Shawnee was selected (Vogel et al., 1996). Therefore, both Cave-in-Rock and Shawnee are more adapted to humid eastern environments than is Trailblazer.

### Nutritive Value

There was a year × cultivar interaction (*P < 0.05*) for nutritive value of switchgrass in the clipping experiment at Rock Springs (Table 5). Crude protein was similar among cultivars in 2000, whereas Trailblazer had the least CP compared with Shawnee or Cave-in-Rock in 2001. Trailblazer had greater NDF than the other cultivars in both years. In 2000, Trailblazer had greater NDFD than Shawnee but similar to Cave-in-Rock, whereas in 2001 it was least and all cultivars were similar in 2003. There was a year × cutting schedule interaction (*P < 0.05*) caused by changes in magnitude of the means and not by changes in the direction of response in each year. Concentrations of CP were least, whereas NDF and NDFD were greater in herbage from the two-cut schedule compared with the three-cut schedule except for NDFD in 2001 (data not shown). Differences between cutting schedules were a result of differences in MSW with forage being more mature in the two-cut than the three-cut schedule. The year × cultivar × cutting schedule interaction was not significant (*P = 0.48*).
In the grazing defoliation experiment, only the main effects of cultivar and year were significant for nutritive value. Cultivars did not differ in CP (P > 0.08) or NDFD (P > 0.35) averaged for 3 yr (Table 6). Trailblazer had a greater (P < 0.03) NDF concentration than the other cultivars, similar to the results for the clipping experiment. Morphological developmental stage was similar among the cultivars in each year (data not shown). Crude protein was lower (P < 0.05) in 2002 than the other years and NDFD decreased each year.

Feeding and grazing trials in Nebraska demonstrated that a 6% improvement of Trailblazer in vitro digestibility resulted in a 23% greater beef production per hectare compared with ‘Pathfinder’ switchgrass (Vogel et al., 1991). Feeding trials with hay of four switchgrass cultivars (Trailblazer, Pathfinder, NJ50 [now Carthage] and KY1625) grown at Rock Springs indicated no difference among cultivars in N or NDF concentrations (Reid et al., 1992). In vivo DM digestibility by sheep, however, was slightly greater for Trailblazer (579 g kg−1) compared with the average of the other cultivars (560 g kg−1; Reid et al., 1992). It is possible that forage quality differences among cultivars may be more apparent with animal feeding trials than with laboratory assays of chemical composition and fiber digestibility.

Shawnee was released based on its greater in vitro digestibility compared with Cave-in-Rock and greater herbage yields (Vogel et al., 1996). In trials conducted in Nebraska, Iowa, and Indiana, Shawnee averaged 16 g kg−1 greater in vitro digestibility than Cave-in-Rock when vegetative and 13 g kg−1 greater when reproductive (Hopkins et al., 1995). In the current clipping and grazing experiments, however, Shawnee did not differ from Cave-in-Rock in CP, NDF, or NDFD.

### Root Mass and Soil Carbon

Coarse root distribution was relatively uniform among soil depths in Shawnee. Greater root mass at shallow soil depths (0 to 15 cm) for Cave-in-Rock (14 Mg ha−1) compared with ‘Alamo’ (8.3 Mg ha−1) and ‘Kanlow’ (7.4 Mg ha−1) switchgrass was observed in Alabama (Ma et al., 2000a). Root mass to a 3.3-m depth, however, did not differ between Cave-in-Rock and Alamo (17.6 and 18.1 Mg ha−1) but was lower in Kanlow (14.7 Mg ha−1; Ma et al., 2000a). They did not speculate on the causes of differences among cultivars. Coarse root mass of Alamo switchgrass ranged from 880 to 1050 kg ha−1 in the upper 40 cm of soil at four southeastern U.S. locations (Garten and Wullschleger, 1999; 2000). In the current study, frequent grazing at the southeastern Pennsylvania site may have accounted for differences in root mass between locations. Frequent defoliation of native warm-season perennial grasses often reduces root mass (Sanderson, 2000).

The average δ13C value for roots was −12.5‰ for Rock Springs and −13.0‰ for the grazed site. Corresponding δ13C values for herbage were −11.4 and −11.2‰, respectively. Cultivars were similar in δ13C values, root C, and N concentrations. The average root C concentration was 441 g kg−1 DM at Rock Springs and 429 g kg−1 at the southeastern Pennsylvania site. Corresponding root N concentrations were 9.4 and 7.7 g kg−1, respectively.

Soil C in the 0- to 5-cm layer at Rock Springs was 33% greater and N was 26% greater in December 2006 than before sampling.
planting switchgrass in April 1999 (Table 8). At the 5- to 15- and 15- to 30-cm soil depths, however, soil C and N were slightly but not significantly lower. There were no differences in soil C and N levels among cultivars and between the different sampling years in the grazing experiment. Soil C and N decreased with depth in the soil at both locations. In Alabama, soil C in the surface 15 cm was 45% greater under a 10-yr-old Alamo switchgrass sod managed for biomass production compared with an adjacent fallow area (Ma et al., 2000b). At the 15- to 30-cm depth, soil C was 28% greater under switchgrass.

The proportion of soil C derived from switchgrass increased during the 5 yr under grazing and 7 yr under clipping as indicated by changes in the δ13C values (Table 8). By 2004, 21 to 23% of the soil C in the 0- to 5-cm soil layer came from C4 plants at both sites. Much smaller changes occurred at the 5- to 15- and 15- to 30-cm depths. The grazing site in southeastern Pennsylvania had been in hay or pasture for more than 30 yr and was renovated by no-till methods three times during those years. Thus, with a permanent vegetative cover and minimal soil disturbance, soil C probably had reached a stable level at those sites. The Rock Springs site had a history of switchgrass (1994) and corn (1997) cropping, which is reflected in the less negative δ13C values (−21.75‰) compared with the grazed site (−24.87‰).

Differences in initial soil C levels, age of the switchgrass stand, harvest management, and cropping history probably accounted for differences in soil C levels and soil C derived from switchgrass at each site. The increased soil C in the surface 5 cm of soil at Rock Springs probably resulted mostly from roots because aboveground biomass was removed one or more times each year. Under grazing, however, much of the C in switchgrass herbage was recycled in dung and litter that probably accumulated on the surface because pastures were clipped after grazing and the residue left on the surface. In the southeastern United States, switchgrass grown for biomass accumulated more soil C than row crops (Bransby et al., 1998). In the midsouth, soil organic C beneath switchgrass grown as a biomass feedstock was no different than beneath tall fescue (Lolium arundinaceum [Schreb.] S.J. Darbyshire) or pasture (Garten and Wullschleger, 1999).

The proportion of soil C derived from C4 plants in the current study is consistent with other research. About 22 to 43% of soil C in the surface 10 cm originated from switchgrass after 5 yr of growth at four southeastern U.S. locations (Garten and Wullschleger, 2000), with highest levels occurring at the more southern sites with higher mean average air temperature. Soil C in the surface 5 cm derived from switchgrass ranged from 25% for a 9-yr-old sod to 37% for an 18-yr-old sod in the northeastern United States (Corre et al., 1999).

CONCLUSIONS

Under both clipping and grazing management, annual variation in weather and harvest management had larger effects on yield and nutritive value of switchgrass than did genetics of the switchgrass cultivars. Trailblazer suffered from leaf disease and lodging during wet years. The three-cut schedule distributed some forage in each season and resulted in an 11 to 24% greater yield, and slightly greater forage quality, than the two-cut schedule. Other long-term studies under forage and biomass harvests have shown that frequent cutting of switchgrass can reduce stand density. Thus, producers must consider the tradeoff between slightly greater forage yields and quality and stand decline with more frequent harvests. Cave-in-Rock had a greater mass of coarse roots than either Trailblazer or Shawnee, but soil C levels did not differ among cultivars. Soil C levels to a 30-cm depth under switchgrass did not change after 5 yr of grazing on site with a long history of hay and pasture. At a site with a history of row crops, however, soil C in the 0- to 5-cm layer was 33% greater after 7 yr under clipping management. Cave-in-Rock and Shawnee switchgrass are equally suited and are superior to Trailblazer for hay and growing in the northeastern United States.

REFERENCES


