Progress Report AR-33 – January 31, 2011

Title

Biomass and macronutrient accumulation and losses in switchgrass during and after the growing season

Investigator

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Objectives

1. Describe growing-season biomass accumulation, NPK uptake, and moisture, ash, and total energy for switchgrass grown for biomass. (Experiment 1)

2. Characterize post-growing-season losses in biomass and macronutrients in delayed-harvested stands of switchgrass for biomass. (Experiment 1)

3. Determine nitrogen response curves for biomass yield for second- and third-year switchgrass stands. (Experiment 2)

Progress:

Two trials were conducted in 2009 and 2010, using cv. Alamo switchgrass, 1) a growth and composition trial and 2) a nitrogen fertilizer response trial. Results from the first trial were used to calibrate the ALMANAC crop simulation model. That was not a stated objective in this project, but is part of a Masters thesis superimposed on this trial. This progress report describes the current status of those studies, but does not include all data analysis because of delays in tissue analyses.

Experiment 1. This trial consisted of 12 sampling dates from early May to mid-February of 2009-2010 and 2010-2011. All plots received 67 kg/ha of N as urea on or about April 1 of each year, but no P or K fertilizer. The 12 dates comprised the active growing season followed by the post-season senescent period, the latter tracking fall and winter weathering losses. The 12 sampling dates were separated into two periods for regression analysis; 7 in-season dates describing the in-season growth curve (May 1 through September 30, to the seed-filling stage) and 6 end-of-season plus post-season dates, i.e. the last date of in-season served as the starting point of post-season. The latter timespan corresponds to changes in standing biomass yield and quality occurring during an extended harvest window in late fall to mid-winter.

For the 2009-10 growing season, the fitted regression showed that growth followed a typical S-shaped (logistic) curve (Fig. 1, page 2). Observed peak yield (14 Mg/ha, 6.25 tons/acre) occurred at the August 28 sampling date (Day 240; Fig. 1). Yields were essentially level from September 30 to October 27 (Day 300), and then followed a gradual decline to February 17, 2010 (Day 413), the last date of sampling (Fig. 2, page 2). Moisture content declined linearly in-season and curvilinearly post-season, attaining levels safe for storage of direct-chopped biomass in December onward (<20%). Cutting the stand crop at dates through November would require field curing before packaging and transport to safe storage because of excessively high moisture.

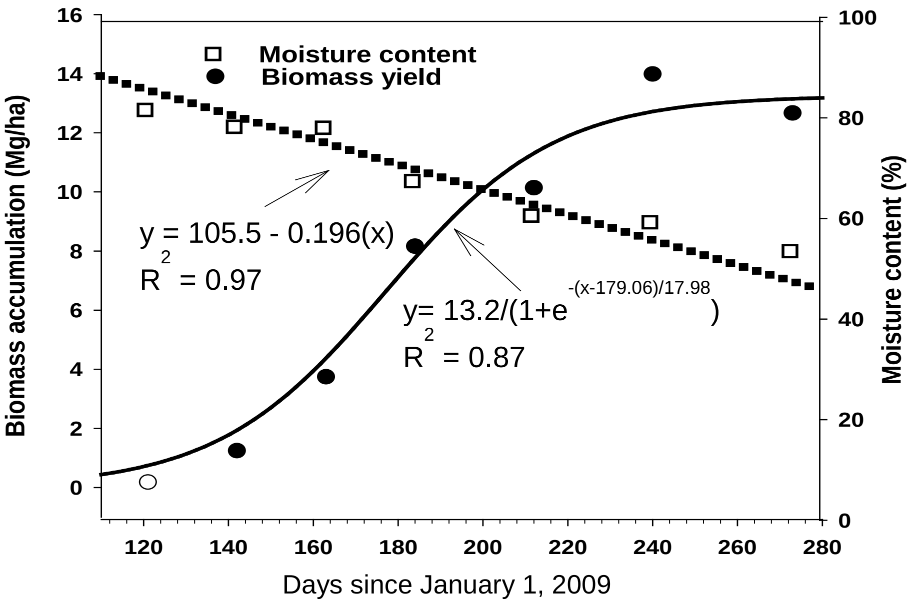

Figure 1. Changes in switchgrass moisture content (dotted line and open symbols) and biomass yield (solid line and closed symbols) for in-season dates in 2009-10.

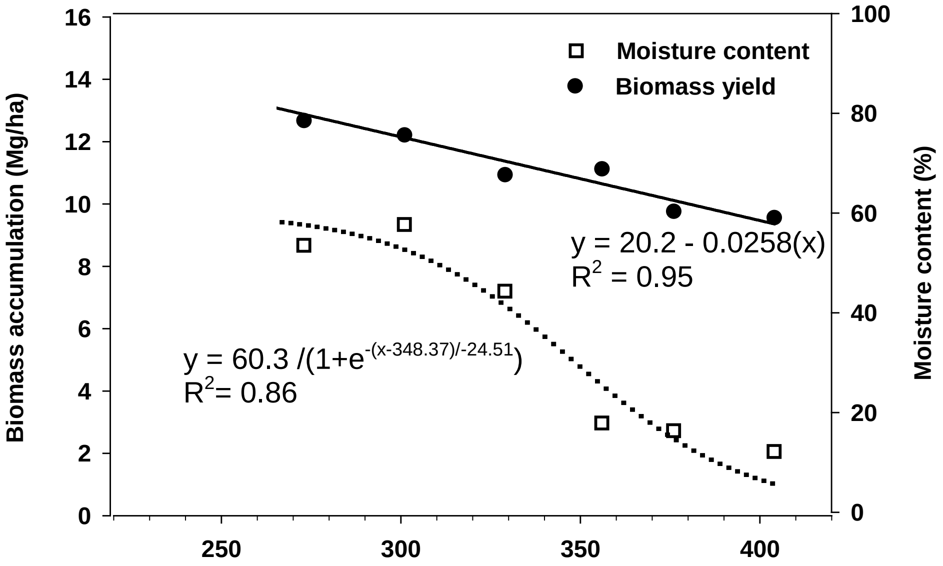

Figure 2. Changes in switchgrass moisture content (dotted line and open symbols) and biomass yield (solid line and closed symbols) for post-season date in 2009-10.

The ALMANAC model was calibrated and corrected for local conditions, with the resulting simulation shown in Fig. 3 (page 3). Simulation was excellent except for the last three sampling dates, Dec. 23, Jan. 20 and Feb. 17. More correction is needed to predict senescent biomass losses. As data for the 2010-11 harvest year are not complete, they have not been incorporated into the ALMANAC model at this time.

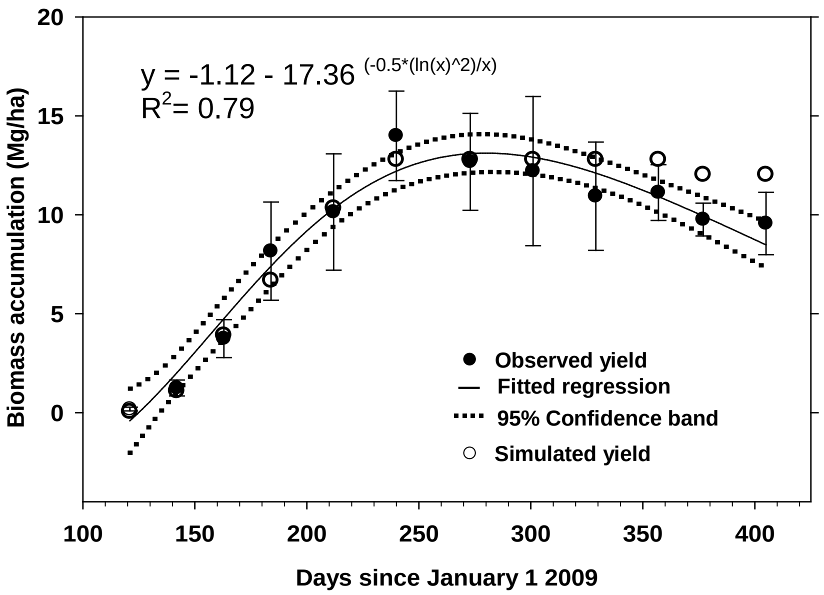

Figure 3. Post-calibrated ALMANAC simulation of switchgrass yield curve compared to observed yields, at Fayetteville, AR for the 2009-10 harvest year. Error bars are ±one standard deviation unit (n=6), and dashed line indicates 95% confidence interval.

Data for the 2010-11 harvest year trended similarly to that of 2009-10, in that the fitted regression showed the logistic curve during the growing season (Fig. 4). Observed peak yield (18.8 Mg/ha, 8.38 tons/acre) occurred at the August 27 sampling date (Day 239), virtually identical to first year. Yields for the 2010-11 harvest year were essentially level from August 12 (Day 224) to Dec 20 (Day 354), and would be expected to decline over the final harvest dates, as a result of weathering in the field.

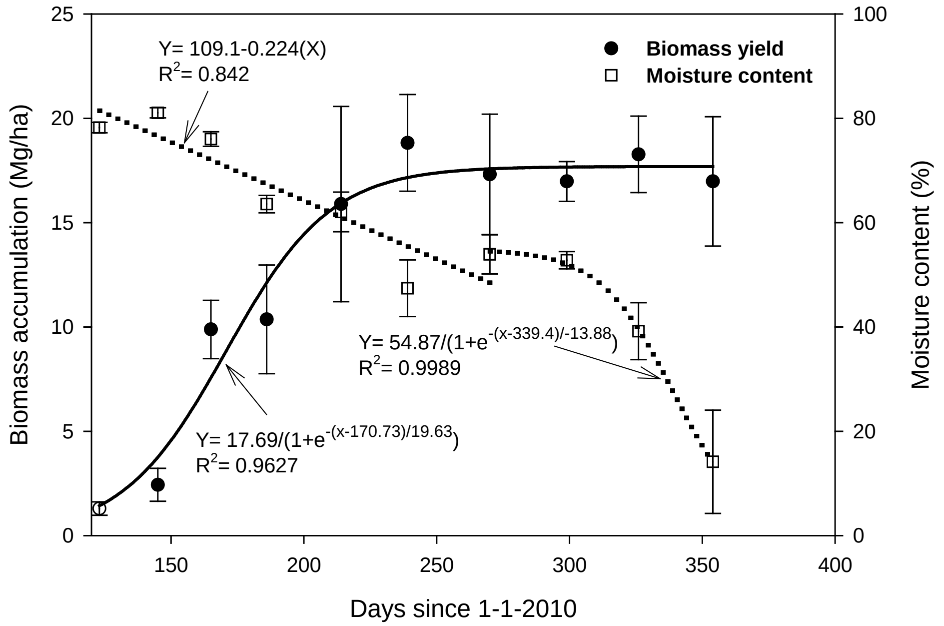

Figure 4. In-season and post-season changes in moisture content and biomass yield by harvest date in the 2010 harvest year.

In 2010, moisture content declined linearly to around 50% by September 28 (Day 271; Fig. 4). After October 26 (Day 299), moisture content declined sharply, reaching 16% by December 20 (Day 354). As in 2009, crop moisture content was not safe for direct chopping and immediate storage before December.

Nitrogen, P, and K concentrations were determined on biomass subsamples and multiplied by biomass dry matter yield to arrive at their uptake and removal in the harvested biomass (Fig. 5). In 2009, N exhibited a broad peak uptake between days July 3 and Sept. 27 (Days 184 to 270). The peak mean N removal was 80 kg/ha on Aug. 28 (Day 240), the same day as peak biomass yield. The senescent period showed N removal rates reduced to about half the peak level, ending at 30 kg/ha in mid-February.

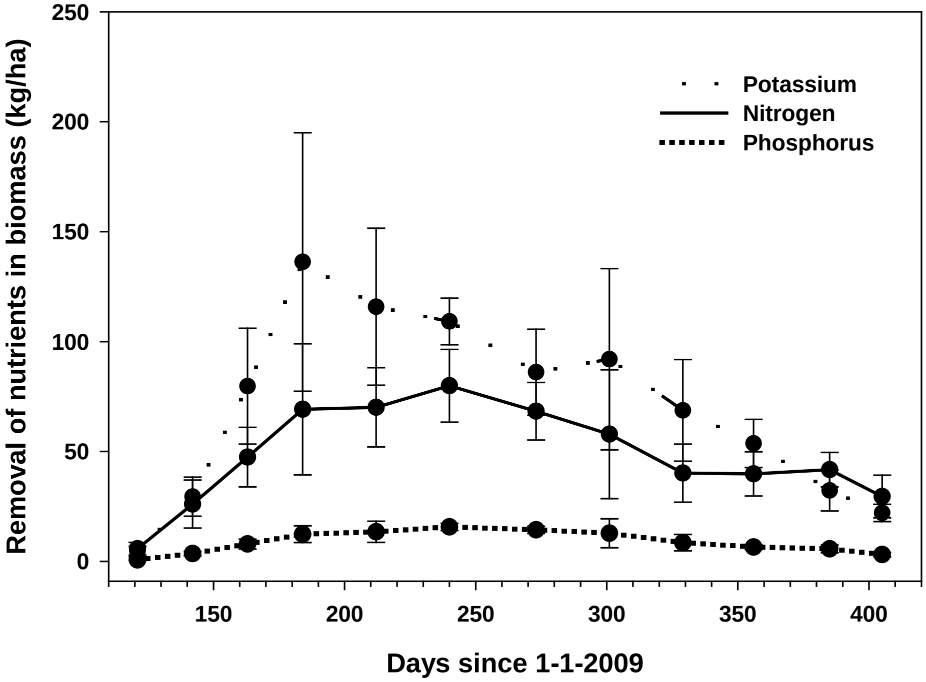

Figure 5. Trends in N, P, and K uptake (kg/ha) for the 2009 harvest year.

Potassium uptake peaked on July 3 (Day 184) at 136 kg/ha (2 months before peak biomass yield) and declined to 22 kg/ha by February 17 (Fig. 5). There was substantially more K than N removed during June through August, but they declined to similar low levels by winter. From peak removal to mid-February, N removal declined by 62% and K removal by 84%. Interestingly, peak dates of N and K removal did not coincide; however, high variability in this measurement prevents identifying a specific date of peak removal.

Phosphorus removal increased gradually and at very low levels to July 31, at 15.7 kg/ha, and then declined to nearly zero by mid-February. Soil-test P level was medium to medium high (generally 30-35 ppm in the surface 10 cm), which is generally not considered deficient for switchgrass; however, P requirements for switchgrass are not well known. Loss of all three nutrients in the latter half of the sampling year likely resulted from a combination of leaf and seed droppage (not measured) during senescence, remobilization of mobile nutrients for next year's growth to roots and the crown, and by leaching from the leaves. The low P removal suggests a low P requirement by switchgrass; however a P fertilizer response trial would be needed to evaluate the P requirement.

The breakdown of the ICP spectrometer at the UA Diagnostic Services Laboratory has prevented the timely analysis of samples from the 2010 season. Those data will be added as an amendment to this report as soon as they are available. However, we projected nutrient removal for the 2010 harvest season using 2010 yield data and 2009 plant nutrient concentrations (Fig. 6). These estimated data suggest similar overall trends in nutrient removal for N, P, and K, with 1.5- to two-times greater overall removal due to higher biomass production in 2010. However, it is possible that with the increased biomass in 2010, the nutrient concentrations were actually reduced. Thus, the trends depicted in Fig. 6 are general and preliminary. Research planned for 2011 will emphasize nutrient recovery and biomass response to varying levels of P and K fertilizer to update soil test recommendations.

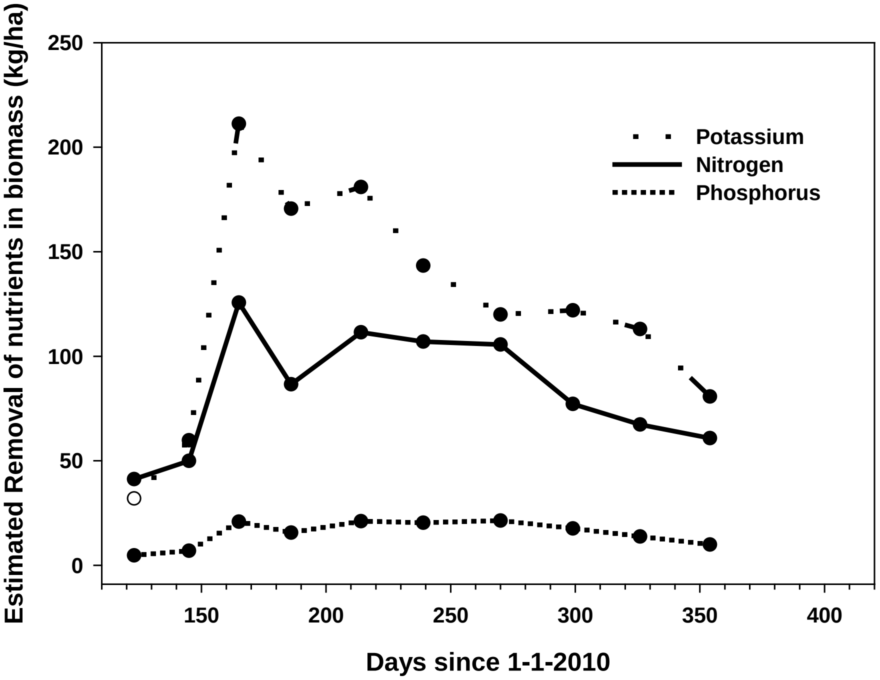

Figure 6. Estimated trends in N, P, and K uptake (kg/ha) for the 2010 harvest year. Estimates are based on 2010 biomass yields and nutrient concentration from 2009.

Experiment 2. This trial consisted of 4 rates of nitrogen applied as urea (0, 50, 100, and 150 kg/ha) on the first week of May in both 2009 and 2010 on 4 replications. Biomass yield was measured on one cutting date in each season: October 28, 2009 and November 1, 2010. Yield was not significantly affected by N rate in 2009, the first year after stand establishment (Table 1). However in 2010, N fertilization significantly (*P*=0.025) increased biomass yield. The mean yield in 2009 was 10.0 Mg/ha (4.5 tons/acre), which increased to 17.1 Mg/ha (7.6 tons/acre) in 2010, owing likely to plant tillering and a deepening root system accessing more water and nutrients. Even though the quadratic term was not significant, the means suggest diminishing returns with increasingly greater N fertilization rate in 2010. Figure 7 shows calculated N response slopes for each successive increment in N fertilization. The last increment of N showed substantially lower response to urea. Moisture contents averaged 60% in 2009 and 51% in 2010, with no effect of N fertilization (Table 1).

Table 1. Biomass moisture content at harvest as affected by rate of N fertilizer application for the 2009 and 2010 harvest years.

Nitrogen Rate	2009		2010	
	Biomass yield		Moisture	
kg/ha	- - - - - Mg/ha - - - - -		- - - - - - - % - - - - - - -	
0	8.68	14.20	63.4	52.4
50	10.20	16.53	57.0	50.9
100	9.47	18.45	61.3	50.9
150	11.63	19.19	57.4	50.7
	P = 0.30	*P* = 0.02	*P* = 0.30	*P* = 0.11
	NS	*	NS	NS

Linear regression of biomass yield 2010 on N rate: Yield = 14.62 + 0.0332(N rate). The quadratic term was not significant.

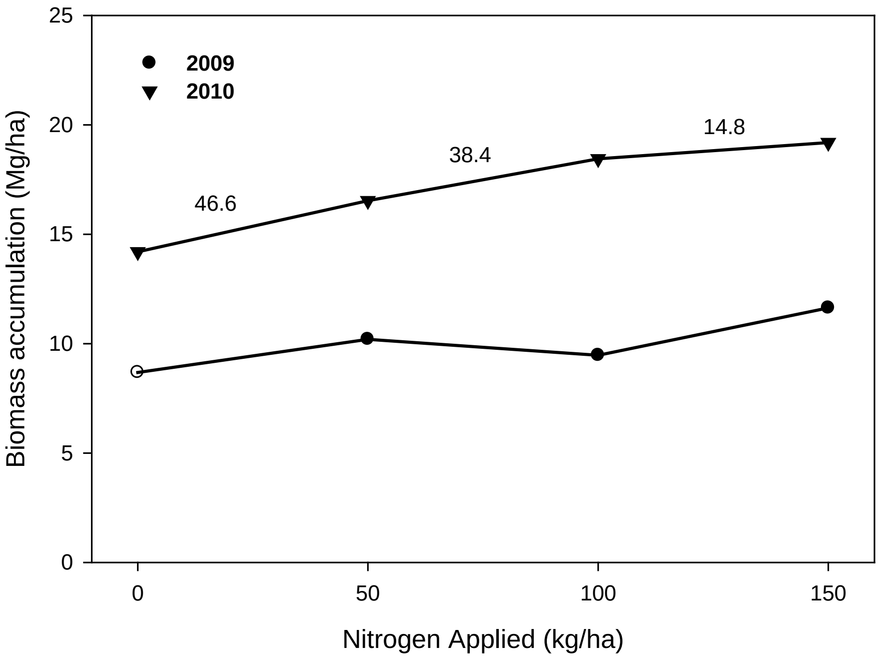

Figure 7. Biomass yield as affected by N application rate. No significant differences were detected in 2009. Yields increased linearly in 2010. Incremental N response coefficient (kg yield increment/kg incremental N=slope) is indicated between data points for the 2010 harvest year.

The switchgrass stands were in their third year, considering that the establishment year, 2008, was Year 1. Biomass yield in 2010, Year 3, was substantially greater than that of Year 2, even in the 0 N treatment, indicating continued stand development. We intend this to be a long-term trial to track differences in yield response to N as the stand matures. Yields in the 17 Mg/ha range, when harvested in late October, are expected to remove >50 kg/ha of N, >100 kg/ha of K, and around 10 kg/ha of P, judging from the removal rates observed in Experiment 1. The longer-term effects of N fertilization on macronutrient removal is unknown.

Plans for 2011- Efforts will be expanded to assess switchgrass response to N, P, and K to fill gaps in the data needed to define fertilizer recommendations. The outline below, while not final, proposes three trials.

Experiment 1 – Harvest Timing
This will entail a redesign from the previous two years. Instead of 12 harvest dates, there will 4 dates corresponding to key points in the annual trend of nutrient uptake, biomass yield, and losses of biomass and nutrients.

1. Mid to late July, when N and K uptake and removal are at or near their peak.
2. Late August, when biomass yield is at its peak and before significant senescence.
3. Late October, when biomass yield is still high, but after a killing frost.
4. Early December, when moisture content drops below 20% (safe for direct-chop storage).

Measurements will include biomass yield above a 15-cm cutting height, stubble biomass yield at harvests 3 and 4. Cutting the stubble at earlier harvests (pre-frost) will essentially kill the plants. Analysis of nutrients (N, P, K and others on ICP) will be carried out to determine concentrations and to calculate removal amounts (biomass yield x concentration). These data will contribute to enhancing the ALMANAC simulation model to provide predictions of N and P removal. There is no logic in the model to account for K uptake. The design will entail larger measurement areas than the plots used in the previous years to reduce variability in the data. Our intention is to terminate this trial at the end of the 2012 growing season, at which time crowns and roots will be excavated, soil removed, and crown and root dry biomass and N, P, and K concentrations and mass measured. That task will be part of a funding request in 2012. As part of another study, the entire trial area will be grid sampled for total N and carbon in the surface 15 cm to calculated changes in N and C mass that have occurred since 2008.

Experiment 2 – Nitrogen Rate Response, with an added location.
Repeat the N rate trial at Fayetteville, but in 2011 analyze harvested samples for N, P and K. Plus, add a new location at Pine Tree, Arkansas (Lat. 35.13, Long. 90.97, Elev. 215 ft.). This trial would be superimposed on an existing stand at the experiment station consisting of the same cultivar of switchgrass, and which was planted in 2009. There will be 4 N rates (0, 50, 100, and 150 kg/ha) in 5 replications. Each of the 20 plots will be 1.8 m x 7 m.

Experiment 3 – Phosphorus and Potassium Responses.
This trial will also be located at Pine Tree, on the same existing stand of switchgrass as the new N rate trial. Treatments will consist of 3 rates of P and 3 rates of K, plus a nonfertilized control (10 treatments), replicated 4 times. The exact rates to use will be determined after consulting with Dr. Nathan Slaton. Plots will be 1.8 m x 7 m, for a total of 40 plots. This soil is very low to low in Mehlich III extractable P (8-20 ppm) and low to medium in extractable K (50-100 ppm). This is a location where switchgrass yields in 2010 were quite low (3 tons/acre). Drought may

explain part of that low yield; however, low soil test levels and persistently low biomass yields in a nearby variety trial indicate that this site would be appropriate for testing response to fertilization. Results will contribute to validating and possibly modifying Arkansas soil test recommendations for switchgrass for biomass. Current recommendations pertain to native grasses managed for grazing or conservation purposes.