**Title:**
Switchgrass for Forage and Bioenergy: I. Effects of Nitrogen Rate and Harvest System

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**Abstract:**
Switchgrass (Panicum virgatum L.) has been targeted for cellulosic ethanol production. Our objective was to evaluate effects of location, harvest system, and N fertilizer rates on switchgrass biomass yield and N, P, and K removal. Randomized complete block experiments with four replications were established on one-year old stands of ‘Alamo’ switchgrass at two Oklahoma locations in 2008. Harvest system and N rate interactions affected total annual yield. Biomass yields ranged from 9020 to 10530 kg/ha across harvest systems when no N was applied. With application of 179 kg N/ha, biomass yields averaged 10715, 13912, and 16516 kg/ha when harvested at seed maturity (October), after a killing frost (December), and twice per year at boot stage (July) and after a killing frost, respectively. Nutrient removal tended to increase with N fertilization and was generally twice as great for each nutrient within the two-cut system relative to the one-cut systems. When 179 kg N/ha was applied, N removal was 198, 82, and 122 kg N/ha when cut twice, cut once at seed maturity, and cut once after frost, respectively. Phosphorus removal was 22, 12, and 11 kg/ha among these systems, respectively. Corresponding K removal was 203, 62, and 25 kg/ha. Applying N and harvesting once after frost ensures both high biomass production and reduces soil nutrient mining. Total biomass harvest, however, was greatest under the two-cut system, enabling a potential use of switchgrass early in the season for forage and availability of regrowth for bioenergy purposes.

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Agriculture and energy policies of the United States are currently favorable to investment in renewable energy research, development, and production. The Energy Independence and Security Act of 2007 increased the Renewable Fuel Standard in the United States, calling for 136 billion L of renewable fuels production by 2022, of which, 60 billion L of cellulosic ethanol were to be produced from cellulosic-containing biomass resources (Biomass Research and Development Board, 2008). Switchgrass (*Panicum virgatum* L.) has been identified as a next-generation feedstock to be grown across the U.S. for cellulosic ethanol because of its high yield potential, broad adaptability, indigenous to North America, perennial life-form, and low fertilization requirements (Schmer et al., 2008). Although not commercially viable today, cellulosic ethanol demonstration plants are expected to be producing by 2012.

In the interim, crop and livestock producers need information on how to integrate and manage switchgrass in their present production systems. Producers are reluctant to plant switchgrass for biofuels production because no market currently exists. In the southern Great Plains, beef cattle production is an important agricultural enterprise. Provided appropriate and timely management, switchgrass may have the potential to supply high quality forage for grazing and hay production purposes. Important to economical production of switchgrass (whether for forage or bioenergy) is defining how crop harvest management practices and nitrogen fertilization affects biomass supply, nutrient removal, and stand persistence.

Switchgrass responses to fertilizer and harvest management depend on origin and ecotype of cultivars. Cultivars developed from plant materials evolved in northern latitudes of North America flower earlier, yield less, and have a longer winter dormant period with better winter survival than southern ecotypes when grown at the same latitude. Lowland ecotypes tend to have bunch-type growth forms, thicker stems, produce short rhizomes, and are capable of greater biomass production than upland ecotypes when grown in favorable environments. Optimum biomass yields of 'Cave-in-Rock', a southern upland type, grown in the north-central U.S. were obtained when harvested once per year between boot and post-anthesis stages and fertilized at 118 kg N/ha (Vogel et al., 2002). Studies in Texas found biomass yields of Alamo, a southern lowland type were maximized with application of 168 kg N/ha under a one harvest per year system (Muir et al., 2001). Cultivars developed from southern lowland genotypes generally have the best yields and persistence under one harvest per year bioenergy systems in the southern United States (Cassida et al., 2005).

Despite previous research, information about regional variation of switchgrass responses to nitrogen fertilization and harvest management remains limited. In 2007, Alamo switchgrass was established at two Oklahoma locations with the overall objectives of determining effects of location, harvest system, and N fertilizer rate on biomass yield, forage quality, stand persistence, and N, P, and K removal rates in harvested biomass in the southern Great Plains. Locations differed in soil type (sandy loam and silt loam) and long-term average annual rainfall (762 and 965 mm). Treatments were applied to the one-year old stands beginning in 2008. This paper reports on biomass yields and N, P, and K removal rates collected during the first year of these experiments.

## Materials and Methods

Harvest management-by-nitrogen fertilizer rate trials were initiated in the spring of 2008 in 1-yr old stands of switchgrass (*Panicum virgatum* L. cv. Alamo) at Varner

Farms in Tillman County near Frederick, OK (34°23′ N; 98°85′ W) and at the Noble Foundation Red River Farm (RRF) in Love County near Burneyville, OK (33°89′ N; 97°29′ W). Soil types were a Foard silt loam (fine, smectitic, thermic Vertic Natrustolls) at Frederick and a Minco fine sandy loam (coarse-silty, mixed, superactive, thermic Udic Haplustolls) at Burneyville. Before establishing switchgrass in 2007, the fields were used for cotton production at Frederick and rye pasture at RRF. Soil samples from 0 to 15 and 15 to 30 cm depths on 20 April 2007 at Frederick showed pH of 8.2, organic matter of 1.9 to 2.4%, and soil to have 18 to 125 kg P/ha and 685 to 1189 kg K/ha of extractable nutrient. Soil tests from 0 to 6 inch depths on 20 March 2008 at RRF showed pH of 6.6 pH, organic matter of 1.0%, 74 kg P/ha, and 385 kg K/ha.

Treatments evaluated included N fertilizer rates (0, 45, 90, 134, 179, and 224 kg/ha) and harvest frequency/time periods (once – within 30 days after an autumn killing freeze (December); once – at physiological maturity (October); and twice – at ‘boot’ stage (July) and within 30 days after an autumn killing freeze. The experiments were randomized complete block designs with a split-plot arrangement of treatments and four replications. Harvest frequency/time periods were whole plots and N rates were the subplots.

Biomass was harvested according to treatment schedule with either a Carter forage harvester or a HEGE forage plot harvester. Subsamples of the harvested biomass were collected for dry matter determinations and forage nutrient analysis. Following drying at 60°C, samples were ground to pass a < 1 mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and prepared for nutrient analysis. Nutrient concentrations were estimated with near infrared spectroscopy analysis using equations developed by the NIRS Forage and Feed Testing Consortium (http://www.uwex.edu/ces/forage/nirs/home-page.htm) and included dry matter, N, P, and K.

Analysis of variance was conducted using the mixed models procedure in SAS to determine main effects and interactions of nitrogen fertilizer rate and harvest system. Location, nitrogen rate, and harvest system were considered fixed effects and replication random. Polynomial contrasts were computed to determine the quantitative relationship of N rate and biomass yield, nutrient concentration, and uptake.

## Results and Discussion

### Biomass yields

Total annual yield was affected by an interaction of harvest system and N rate (p=0.0457). Application of 45 kg N/ha increased yields by 10% under one-cut systems and by 19% under the two-cut system (Fig. 1). Application of 179 kg N/ha increased switchgrass yield relative to the control by 13% when harvested once per year after seed production (October), 42% when harvested once per year after a killing frost (December), and 57% when harvested twice per year at boot stage (July) and after a killing frost, respectively. Yields for the one-cut after frost and two-cut harvest systems produced an extra 3360 to 5040 kg/ha, respectively, at the 179 kg N/ha rate, indicating a potential for significant growth post seed production in N fertilized switchgrass.

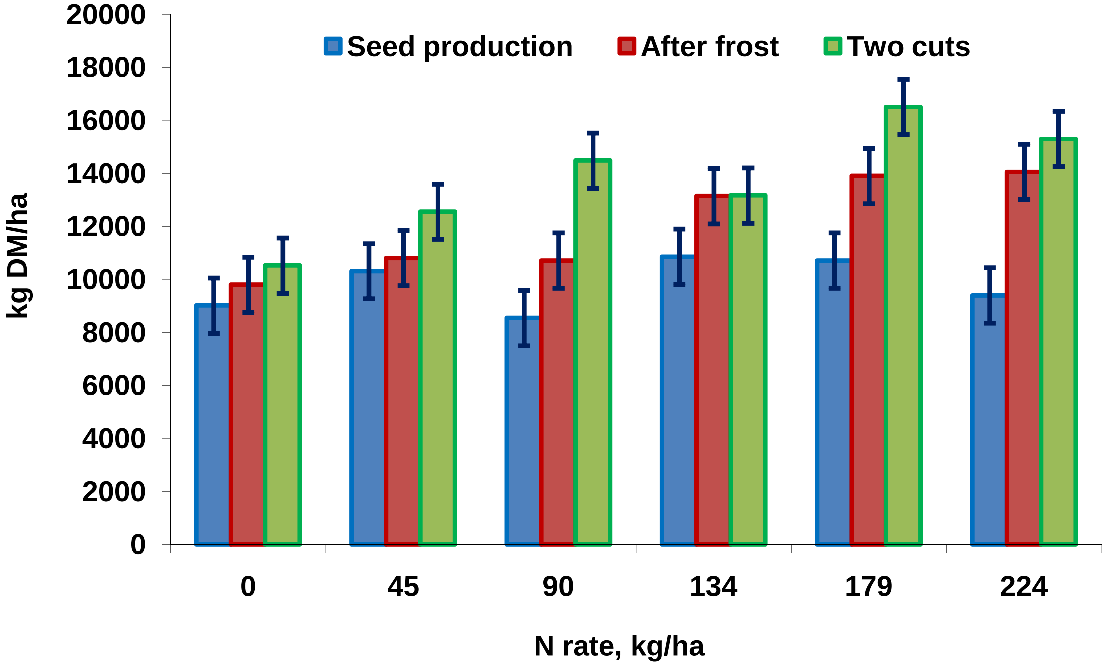

Figure 1. Interactive effects of harvest system (1-cut after seed production; 1-cut after frost and 2-cuts at boot stage and after frost) and N rate on switchgrass biomass yields. Data are averaged across two locations (n=8).

Within the two-cut system, biomass yields during the boot-stage harvest were affected by N rate (p=0.0001). Across locations, application of 45 kg N/ha increased yield by 30% from 6800 to 9054 kg/ha, while 179 kg N/ha increased yield by 70% to 11726 kg/ha. Across N rates, biomass yields at boot stage averaged 10796 and 9150 kg/ha at Burneyville and Frederick, respectively. Re-growth biomass yields harvested after frost within the two-cut system were not affected by N rate, although they were greater at Burneyville (5077 kg/ha) compared to Frederick (2811 kg/ha). Consequently, total biomass yields were greater at Burneyville (15,865 kg/ha) than Frederick (11,660 kg/ha) within the 2-cut system, but not in the one-cut system at either seed production or after frost stages (farm x harvest system interaction; p<0.05). Greater regrowth at Burneyville was associated with greater precipitation at this location following the initial boot stage harvests.

Total annual yields from the single cut after frost system were comparable to those obtained for Alamo in other southern locations (Muir et al., 200; Fike et al., 2006) and slightly greater than upland switchgrass cultivars in the north-central U.S. (Vogel et al., 2002; Vogel and Mitchell, 2008). While the regrowth at Frederick was comparable to those found in other harvest per year systems, regrowth at Burneyville was higher (Vogel et al., 2002).

## Nutrient uptake

Harvest system and N rate interactions affected annual N and P removal (p=0.0015 and p=0.0112, respectively). The control for the two-cut system removed 2-fold more P than harvesting once per year after frost (Table 1). Increasing N rate increased P removed by 35 to 70% in all harvest systems. The two-cut system removed more N annually than single cut systems. Applying N at 179 kg/ha increased N uptake by 75% and 100% in a single after frost cut and a two cut system, respectively, relative to non-N fertilized controls. Annual N uptake was also affected by the interaction of harvest system and location (p=0.0011). More N was removed in Burneyville than at Frederick for same level of N applied (data not shown).

Table 1. Effects of harvest system and N rate on N, P, and K concentrations and removal (1 = cut once at seed maturity; 2 = cut once after frost; and 3 = cut twice at boot stage and after frost). Data are averaged across locations (n=8).

| Harvest system | N rate (kg/ha) | Nutrient concentration (%) | | | Nutrient removed (kg/ha) | | |
|---|---|---|---|---|---|---|---|
| | | N | P | K | N | P | K |
| 1 | 0 | 0.53 | 0.010 | 0.59 | 46.5 | 7.7 | 37.3 |
| 1 | 45 | 0.61 | 0.104 | 0.55 | 64.5 | 10.8 | 44.7 |
| 1 | 90 | 0.66 | 0.110 | 0.61 | 56.0 | 8.8 | 44.5 |
| 1 | 134 | 0.76 | 1.105 | 0.58 | 82.4 | 8.8 | 38.9 |
| 1 | 179 | 0.79 | 0.112 | 0.59 | 82.1 | 12.1 | 62.2 |
| 1 | 224 | 0.76 | 0.106 | 0.57 | 70.1 | 8.8 | 34.6 |
| 2 | 0 | 0.59 | 0.065 | 0.17 | 59.8 | 6.6 | 11.6 |
| 2 | 45 | 0.84 | 0.071 | 0.30 | 92.2 | 6.3 | 11.5 |
| 2 | 90 | 0.76 | 0.077 | 0.29 | 83.6 | 9.2 | 12.3 |
| 2 | 134 | 0.74 | 0.077 | 0.32 | 91.7 | 9.1 | 30.2 |
| 2 | 179 | 0.88 | 0.078 | 0.18 | 121.7 | 10.6 | 25.0 |
| 2 | 224 | 0.80 | 0.075 | 0.29 | 111.7 | 9.7 | 21.6 |
| 3 | 0 | 0.86 | 0.117 | 0.89 | 96.7 | 16.7 | 138.9 |
| 3 | 45 | 0.88 | 0.112 | 0.89 | 114.8 | 17.8 | 141.0 |
| 3 | 90 | 0.97 | 0.120 | 1.02 | 145.0 | 19.5 | 170.6 |
| 3 | 134 | 1.16 | 0.122 | 1.03 | 154.3 | 16.9 | 147.8 |
| 3 | 179 | 1.18 | 0.122 | 1.05 | 198.5 | 21.4 | 203.3 |
| 3 | 224 | 1.28 | 0.126 | 1.08 | 201.5 | 21.8 | 160.8 |
| SE | | 0.08 | 0.005 | 0.06 | 12.9 | 1.7 | 15.1 |

Total annual K removal was affected by the interaction of location, harvest time, and N rate (p=0.0047). The two-cut system removed more K than the one-cut systems, and the amount removed was higher at Frederick (45 kg/ha) than at Burneyville (14.5 kg/ha). Total K uptake for N fertilized switchgrass was also 3 to 4-fold higher in the two-cut system than in one-cut systems.

Within the two-harvest per year system, N fertilizer rate affected N, P, and K uptake during the boot-stage harvest (Table 3; p<0.05). Location also affected amount of N and K removed. Switchgrass removed more N and less K at Burneyville compared to

Frederick. At Burneyville, 133 kg N/ha and 138 kg K/ha were removed in boot-stage harvests, while 77 kg N/ha and 166 K/ha were removed at Frederick. Nitrogen uptake increased with N rate within re-growth of the two-cut system (Table 3; $p<0.05$).

Table 3. Effect of N rate on N, P, and K removal by switchgrass harvested twice-per year at boot stage and regrowth after frost. Data are averaged across locations (n=8).

| Harvest system | N rate (kg/ha) | Nutrient concentration (%) | | | Nutrient removed (kg/ha) | | |
|---|---|---|---|---|---|---|---|
| | | N | P | K | N | P | K |
| Boot | 0 | 0.76 | 0.146 | 1.34 | 57.7 | 9.7 | 92.5 |
| | 45 | 0.78 | 0.141 | 1.37 | 77.2 | 12.5 | 120.4 |
| | 90 | 1.00 | 0.156 | 1.53 | 107.0 | 16.4 | 159.7 |
| | 134 | 1.17 | 0.156 | 1.6 | 113.5 | 15.3 | 155.2 |
| | 179 | 1.20 | 0.154 | 1.58 | 140.3 | 17.8 | 182.4 |
| | 224 | 1.33 | 0.161 | 1.68 | 145.5 | 17.6 | 182.1 |
| | SE | 0.07 | 0.004 | 0.07 | 10.0 | 1.3 | 13.0 |
| Regrowth | 0 | 0.94 | 0.083 | 0.43 | 39.0 | 3.0 | 13.2 |
| | 45 | 0.94 | 0.079 | 0.4 | 37.5 | 2.7 | 11.0 |
| | 90 | 1.14 | 0.080 | 0.49 | 38.1 | 3.0 | 17.1 |
| | 134 | 1.16 | 0.084 | 0.44 | 40.9 | 2.9 | 14.0 |
| | 179 | 1.16 | 0.087 | 0.52 | 58.1 | 2.8 | 20.9 |
| | 224 | 1.23 | 0.086 | 0.48 | 56.0 | 3.5 | 17.5 |
| | SE | 0.11 | 0.006 | 0.07 | 12.0 | 0.7 | 4.9 |

Phosphorus removal within the re-growth of the two-cut system was not affected by N fertilizer rate, averaging 3 kg P/ha. Harvesting of regrowth within the two-cut system removed an average of 14 kg K/ha. The higher N, P, and K removal with the two-cut system relative to one-cut systems is attributed to greater concentrations of nutrients in aboveground tissues during boot stages than during harvests at seed maturity and after frost-kill. Plants are fully senesced, and nutrients are translocated to roots when harvests are delayed until after frost (Adler et al 2006). This significantly reduces the concentration of nutrients in standing material and therefore amount removed in the harvest. At seed maturity, the amount of N, P, and K removed, although lower than that in summer harvest, was still higher than that of harvest after frost. This may be due to some actively growing vegetative material that retains sizeable amounts of nutrients in their tissues. However, the amount of N and P removed at seed maturity compared well to those reported for switchgrass by other researchers (Reynolds et al., 2000; Sanderson et al., 2001; Vogel et al., 2002; and Cassida et al., 2005).

## Conclusions

For sustained yield of warm season grasses yearly application of N fertilizer will be necessary. However, given that a substantial amount of P and K are also removed, periodic analysis of soil should be undertaken in switchgrass production sites. This will allow for potential nutrient deficiencies that may arise after years of production to be captured. By so doing, corrective measures like P and K fertilization may be taken early enough before yields are compromised. Applying N and harvesting once after frost ensures both high biomass production and reduces soil nutrient mining. Total biomass production, however, was greatest under the two-cut system, enabling a potential use of switchgrass early in the season for forage and availability of regrowth for bioenergy purposes.

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## References

Adler PR, Sanderson MA, Boateng AA, Weimer PJ, and Jung HG. 2006. Biomass yield and biofuel quality of switchgrass harvested in fall or spring. *Agron. J.* 98:1518–1525.

Biomass Research and Development Board. 2008. National Biofuels Action Plan. Online. http://www.brdisolutions.com/default.aspx.

Cassida KA, Muir JP, Hussey MA, Read JC, Venuto BC, and Ocumpaugh WR. 2005. Biomass yield and stand characteristics of switchgrass in south central U.S. environments. *Crop Sci.* 45:673-681.

Cassida KA, Muir JP, Hussey MA, Read JC, Venuto BC, and Ocumpaugh WR. 2005. Biofuel component concentrations and yields of switchgrass in south central U.S. environments. *Crop Sci.* 45:682-692.

Fike JH, Parrish DJ, Wolf DD, Balasko JA, and Green Jr. JT. 2006. Long-term yield potential of switchgrass-for-biofuel systems. *Biomass and Bioenergy* 30:198-206.

Muir JP, Sanderson MA, Ocumpaugh WR, Jones RM, and Reed RL. 2001. Biomass production of 'Alamo' switchgrass in response to nitrogen, phosphorus, and row spacing. *Agron. J.* 93:896-901.

Reynolds JH, Walker CL , and Kirchner MJ. 2000. Nitrogen removal in switchgrass biomass under two harvest systems. *Biomass and Bioenergy* 19: 281-286.

Sanderson MA, Jones RM, McFarland MJ, Stroup J, Reed RL, and Muir JP. 2001. Nutrient movement and removal in a switchgrass biomass–filter strip system treated with dairy manure. *J. Environ. Qual.* 30:210–216 (2001).

Schmer MR, Vogel KP, Mitchell RB, and Perrin RK. 2008. Net energy of cellulosic ethanol from switchgrass. *Proc. National Academy of Sciences* 105:464-469.

Vogel KP, Brejda JJ, Walters DT, and Buxton DR. 2002. Switchgrass biomass production in the Midwest USA: harvest and nitrogen management. *Agron. J.* 94:413-420.

Vogel KP and Mitchell RB. 2008. Heterosis in switchgrass: biomass yield in swards. *Crop Sci.* 48: 2160-2164.