8-1-2009

Switchgrass for Forage and Bioenergy: II. Effects of P and K fertilization

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Publication Date:

08-01-2009

Series:

The Proceedings of the International Plant Nutrition Colloquium XVI

Publication Info:

The Proceedings of the International Plant Nutrition Colloquium XVI, Department of Plant Sciences, UC Davis, UC Davis

Permalink:

http://escholarship.org/uc/item/9w94d1c3

Keywords:

Nutrient mining, Biomass yield, Nutrient uptake, Ethanol

Abstract:

Switchgrass (Panicum virgatum L.) has been targeted for cellulosic ethanol production. Our objective was to evaluate effects of P and K fertilization on switchgrass biomass yields. Experiments were established in switchgrass (cv. Alamo) fields planted at three Oklahoma locations in 2007. Interactions of N and P fertilizer rates were evaluated on two sites that had low soil test P (6 to 9 kg/ha). Interactions of N and K fertilizer rates and harvest system were evaluated on a site that had low soil test K (134 kg/ha). In the N and P rate experiments, biomass yields during establishment were unaffected by treatments, averaging 2145 kg/ha in 2007. During 2008, main effects of location, N, and P rate were significant. Application of 134 kg N/ha increased yields from 7945 to 9967 kg/ha. Applying 101 kg P2O5/ha increased yields from 8528 to 10242 kg/ha. In the harvest system, N, and K rate experiment, biomass yields were unaffected by treatments in 2007 and 2008, averaging 4603 and 16145 kg/ha, respectively. Cutting biomass twice per year as opposed to once a year, however, removed more N,P, and K. Uptake of N, P, and K averaged 216, 24, 209 kg/ha within the two-cut system and 133, 13, and 36 kg/ha, within the one-cut system, respectively. Although low soil test P and K did not strongly limit biomass yields of these young stands, continued biomass harvesting and removal without nutrient replacement has the potential to mine soil of nutrients and constrain biomass yields as stands age.

Introduction

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 has been identified as a next-generation feedstock to be grown across the U.S. for cellulosic ethanol because of its high yields, broad adaptability, indigenous to North America, perennial life-form, and low fertilization requirements (Schmer et al., 2008). Although not commercially viable today, pilot-scale demonstration plants are expected to be producing cellulosic ethanol by 2012 (Biomass Research and Development Board, 2008).

In the meantime, crop and livestock producers need information on how to integrate and manage switchgrass in their present production systems. Switchgrass is capable of supplying young, early-season forage for grazing and hay production purposes and in the interim, may have value in beef cattle production systems. Previous research has shown that switchgrass responses to fertilizer and harvest management depend on origin and ecotype of cultivars. Cultivars selected from plant materials originating from 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 (Parrish et al., 2008). 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 (Parrish et al., 2008). Cultivars developed from southern lowland genotypes generally have the best yields and persistence under bioenergy harvest systems in the southern United States (Cassida et al., 2005).

Optimizing biomass yields of switchgrass is usually attained by appropriate nitrogen fertilizer rate management. Depending on switchgrass cultivar and region of production, biomass yields for bioenergy purposes have typically been maximized with application of 56 to 168 kg N/ha (Sanderson et al., 1999; Muir et al., 2001; Vogel et al., 2002). Studies evaluating effects of P and K fertilizer rates have generally found inconsistent biomass yield responses, although many of these studies have been short-term in duration (Friedrich et al., 1977; Morris et al., 1982; and Muir et al., 2001). Fixen (2007) noted that the developed of bioenergy systems has the potential to significantly impact nutrient use and removal over long-time periods.

Despite previous research, greater information about regional variation in switchgrass responses to fertilizer and harvest management is needed to improve management recommendations to growers of switchgrass for forage or bioenergy purposes. Short-term objectives of this study were to assess whether addition of P and K fertilizer on sites that have shown low soil test values for these nutrients affects biomass yields during establishment. Long-term goals are to determine rates at which nutrients are removed in biomass harvests, assess length of time required before yield-limiting nutrient deficiencies develop, and assess dependence of nutrient removal rates on nitrogen fertilizer rates and harvest systems. The effects of P and K rates were evaluated in independent trials at three locations in southern Oklahoma from 2007 to 2008.

Materials and Methods

Experiment Location and Design

Research was initiated in 2007 at three locations that had either low soil test P or low soil test K. On sites with low soil test P, treatments included applications of N (0 and 134 kg/ha), and P_2O_5 (0, 34, 68 and 101 kg/ha). Low soil test P sites were found at Howard Cattle Company in Jefferson County near Waurika, OK (34°18′ N; 97°79′ W) and at Noble Foundation Headquarters Farm-Unit 2 (HQ2) in Carter County near Ardmore, OK (34°19′ N; 97°08′ W). The experiments were designed as randomized complete blocks with a split-plot arrangement of treatments. Nitrogen rate was the whole plot treatment factor. Phosphorus rate was the subplot treatment factor. Blocks were replicated four times at each location. Phosphorus treatments were applied annually beginning in 2007. Nitrogen rates were applied annually beginning in 2008 to minimize competition from weeds during establishment. Potassium was not applied to either of these locations because available soil K was > 224 kg/ha, a sufficiency level of 95% for native grass hay production in OK (Johnson et al., 2000).

Interactions of K_2O (0 and 68 kg/ha), N (0 and 134 kg/ha), and harvest frequency (once and twice per year) were evaluated on a low soil test K site at the Noble Foundation Pasture Demonstration Farm (PDF) in Carter County near Ardmore, OK (34°22′ N; 97°21′ W). The experiment design was a randomized complete block with a factorial arrangement of treatments. Blocks were replicated four times. Potassium treatments were applied annually beginning in 2007. Nitrogen rates were applied annually beginning in 2008 to minimize competition from weeds during establishment. Harvest frequency treatments also were not begun until 2008. Phosphorus was not applied at this location because available soil P was > 22 kg/ha, a sufficiency level of 95% for native grass hay production in OK (Johnson et al., 2000).

Soil types were a Zaneis-Pawhuska complex (fine-loamy, siliceous, active, thermic Udic Argiustolls) at Waurika, a Normangee loam (fine, smectitic, thermic Udertic Haplustalfs) at Ardmore-HQ2, and a Chickasha loam (fine-loamy, mixed, active, thermic Udic Argiustolls) at Ardmore-PDF. Before the research, the sites were used for wheat (*Triticum aestivum* L.) hay production at Waurika, mixed-grass hay production at Ardmore-HQ2, and rye (*Secale cereale* L.) pasture at Ardmore-PDF.

Site Preparation and Switchgrass Establishment

Switchgrass (*Panicum virgatum* L. cv. Alamo) was seeded at 4.5 kg/ha pure live seed in a clean-tilled seedbed with a Brillion broadcast seeder at each location in May 2007. Seed from lot 6011A was purchased from Bamert Seed Company Inc., Muleshoe, Texas. A test in December 2006 showed the lot was 99% pure seed with 82% germination and 1% dormant seed for pure live seed of 82%. Noxious weed seed were not present.

At Waurika, soil tests from 0- to 15- and 15- to 30-cm depths on 20 April 2007 showed an average pH of 6.2, OM of 1.6%, and the soil to have 7 to 9 kg P/ha and 222 to 311 kg K/ha of extractable nutrient. A subsequent soil test taken on 22 Aug. 2007 showed consistent P deficiencies across plots (data not shown). Before planting switchgrass, the existing forage wheat was mowed and baled, and the site was disked three times to incorporate the stubble. Triple superphosphate was applied by treatment and incorporated before planting on 17 May 2007.

At Ardmore-HQ2, initial soil tests from 0- to 15- and 15- to 30-cm depths on 25 Apr. 2007 showed pH to range from 6.1 to 6.7, OM of 2.2%, and soil to have 6 kg P/ha and 300 to 327 kg K/ha of extractable nutrient. A subsequent soil test taken on 9 Jan. 2008 showed consistent P deficiencies across plots (data not shown). Before planting switchgrass, the site was fallow and covered with mixed-grass residue from the previous summer. Triple superphosphate was applied by treatment and incorporated before planting on 16 May 2007. The site was mowed at a 30-cm residue height on 18 July 2007 to reduce competition from annual grasses. Because of the presence of cool-season annuals, the site was sprayed with 2.4-D amine at 1.2 L/ha and glyphosate at 2.4 L/ha on 7 Feb. 2008.

At Ardmore-PDF, soil tests from 0- to 15- and 15- to 30-cm depths on 25 Apr. 2007 showed pH to range from 5.7 to 6.9 (moderately acidic to neutral), 1.4 to 2.0% OM and the soil to have 34 to 231 kg P/ha (marginal to sufficient) and 134 kg K/ha (deficient) of extractable nutrient. A subsequent soil test taken on 8 Jan. 2008 showed consistent K deficiencies across plots (data not shown). The site was disked twice to incorporate residue from the previous rye pasture before seeding switchgrass on 18 May 2007. On 11 Mar. 2008, the site was sprayed with 0.37 L/ha Raptor and 2.4 L/ha of crop oil to reduce presence of cool-season annual grasses.

Biomass Harvests and Analysis

Within the N and P rate experiments, biomass yields were determined once per year after a killing freeze in November 2007 and December 2008 at both locations. Within the harvest system, N and K rate experiment, biomass yields were determined either once per year after a killing freeze in November 2007 and December 2008 or twice per year at boot stage in July and after a killing freeze December 2008. Biomass was harvested 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 treatments ($P \leq 0.05$). Location, fertilizer rate, and harvest system were considered fixed effects and replications random.

Results and Discussion

Phosphorus Effects during Establishment

Biomass yields during the establishment year of 2007 were not affected treatment, averaging 2145 kg/ha. Location, however, affected concentrations and uptake of N, P, and K ($p<0.10$). Concentrations of N, P, and K averaged 1.31, 0.11, and 0.96% at Waurika and 0.74, 0.08, and 0.71% at Ardmore, respectively (SE of N, P, and K = 0.047, 0.003, and 0.037, respectively). Uptake of N, P, and K averaged 29.9, 2.7, and 22.4 kg/ha at Waurika and 12.5, 1.5, and 12.4 kg/ha at Ardmore, respectively (SE of N, P, and K = 3.70, 0.44, and 3.23, respectively).

Nitrogen and Phosphorus Effects on 2nd-Year Stands

In 2008, main effects of location ($p<0.0001$), N rate ($p=0.0340$), and P rate ($p=0.0492$) on yield were significant (Fig. 1). Across P and N rates, yields at Waurika averaged 12658 kg/ha, 140% more than the 5255 kg/ha obtained at Ardmore (SE=642.0). Across P rates and locations, application of 134 kg N/ha increased yields from 7945 to 9967 kg/ha (SE=618.5). Across N rates and locations, applying 101 kg P_2O_5/ha increased yield by 20%, from 8528 to 10241 kg/ha (SE=641.9).

Yields at Waurika were slightly lower than yields reported in other southern USA locations. Yields at Ardmore were substantially lower. Cassida et al. (2005) found that yield and persistence of switchgrass was lower for upland than lowland genotypes, and that lowland varieties such as Alamo yielded close to 14,970 kg DM/ha across sites in Texas, Arkansas, and Louisiana. Biomass yields of upland and lowland cultivars averaged 14,200 kg/ha in evaluations of long-term stands across the southeastern USA (Fike et al., 2006). The greater yields at Waurika than at Ardmore may be explained by the differences in precipitation between the two sites during summer. Between 15 June and 15 September, Waurika had 2.9 cm of rainfall compared to 0.9 cm at Ardmore. The soil at Waurika (mollisol) was also of better quality than soil at Ardmore (alfisol). Although soil analyses revealed comparable pH, OM, and K availability among the locations, the experiment at Ardmore was established in a field where the topsoil had been dozed and removed to provide fill for an adjacent experimental area. Consequently, removal of the topsoil may have contributed to the lower biomass yields at Ardmore.

Although biomass yields responded to application of 134 kg N/ha, limited response to P was observed. These results are similar to what has been reported in other studies. Depending on switchgrass cultivar and region of production, biomass yields for bioenergy purposes have typically been maximized with application of 56 to 168 kg N/ha (Sanderson et al., 1999; Muir et al., 2001; Vogel et al., 2002). Studies evaluating effects of P and K fertilizer rates have generally found inconsistent biomass yield responses, although many of these studies have been short-term in duration (Friedrich et al., 1977; Morris et al., 1982; and Muir et al., 2001). Although low soil test P did not strongly limit biomass yields, the stands are young and continued biomass removal without nutrient replacement has the potential to mine soil of nutrients and constrain biomass yields as the stands age.

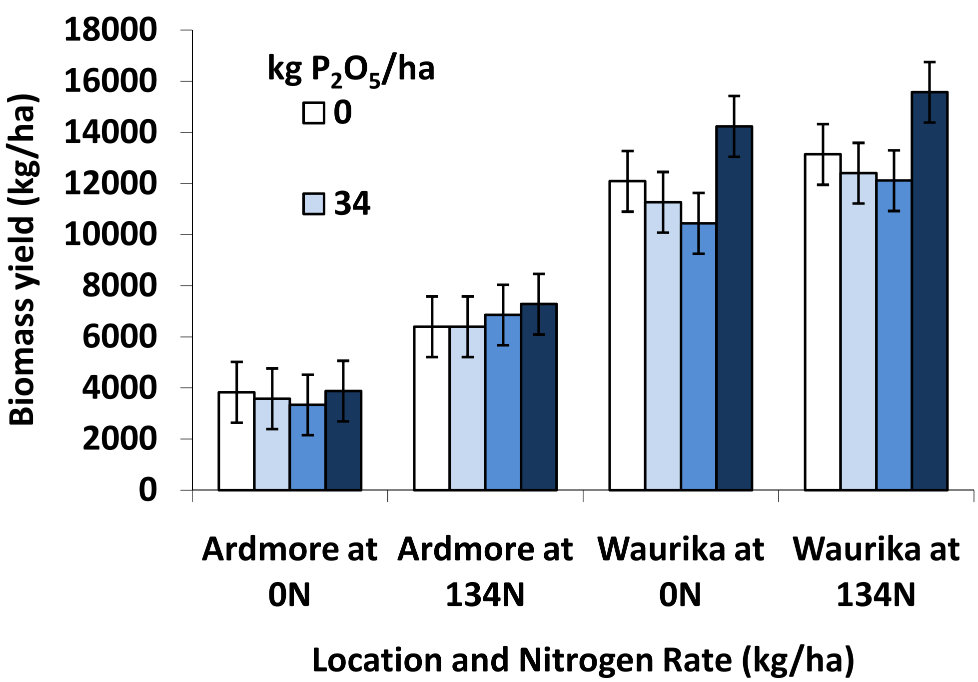

Figure 1. Effects of location (Ardmore and Waurika, Oklahoma, USA), N fertilizer rate, and P fertilizer rate (kg P_2O_5/ha) on biomass yields of 2nd-year stands of Alamo switchgrass harvested after a killing frost (December 2008).

Nitrogen concentrations and uptake were affected by interactions of P and location (p=0.008 and 0.0005, respectively). Addition of P increased concentration of N at Waurika but not at Ardmore (Table 1). Nitrogen removal averaged 12.5 kg/ha across P rates at Ardmore, but increased by 60%, from 107.6 to 173.6 kg/ha as P_2O_5 rate increased from 0 to 101 kg/ha at Waurika (Table 1).

Table 1. Effects of P fertilizer rate on N concentration and removal by 2nd year stands of Alamo switchgrass at Ardmore and Waurika, OK, USA, harvested after a killing frost (December 2008).

P rate	N concentration		N removed	
	Ardmore	Waurika	Ardmore	Waurika
kg P_2O_5/ha	%		kg/ha	
0	0.26	0.86	14.0	107.6
34	0.25	1.15	12.9	132.8
68	0.22	1.13	10.9	124.7
101	0.24	1.16	13.7	173.6
Standard error	0.057		8.56	

Switchgrass had P concentrations of 0.06% at Ardmore and 0.09% at Waurika ($p<0.0001$; SE=0.002). Because of these differences and greater biomass yield at Waurika, P uptake was also greater at Waurika (11.5 kg/ha) than at Ardmore (3.0 kg/ha) in 2008 ($p<0.0001$; SE=0.56). Averaged across locations, application of 101 kg P_2O_5/ha caused a 25% increase in the amount of P removed, from 6.8 to 8.5 kg/ha, relative to the control ($p<0.05$; SE=0.56). Across locations and P rates, switchgrass receiving N fertilizer had a P concentration of 0.07% compared to 0.08% of non-N fertilized switchgrass (p=0.0408; SE=0.002). Nitrogen rate did not affect P uptake (p=0.25).

In 2008, K concentration was affected by interactions of location and N rate (p=0.03) and N and P rates (p=0.004). Application of 134 kg N/ha increased K concentration from 0.39 to 0.49% at Ardmore, but decreased it from 0.38% to 0.30% at Waurika (SE=0.037). Concentrations of K averaged 0.35% in non-P fertilized switchgrass at both 0 and 134-kg N/ha rates. Application of 68 kg P_2O_5/ha resulted in K concentrations of 0.39% and 0.47% in non-N and N-fertilized stands, respectively (SE=0.039). Uptake of K was affected by an interaction of N and location (p=0.0186). At Ardmore, application of 134 kg N/ha increased K removed by 130%, from 14 to 34 kg/ha (Fig.2). At Waurika, N fertilization had no effect on K uptake, which averaged 43 kg/ha (Fig. 2).

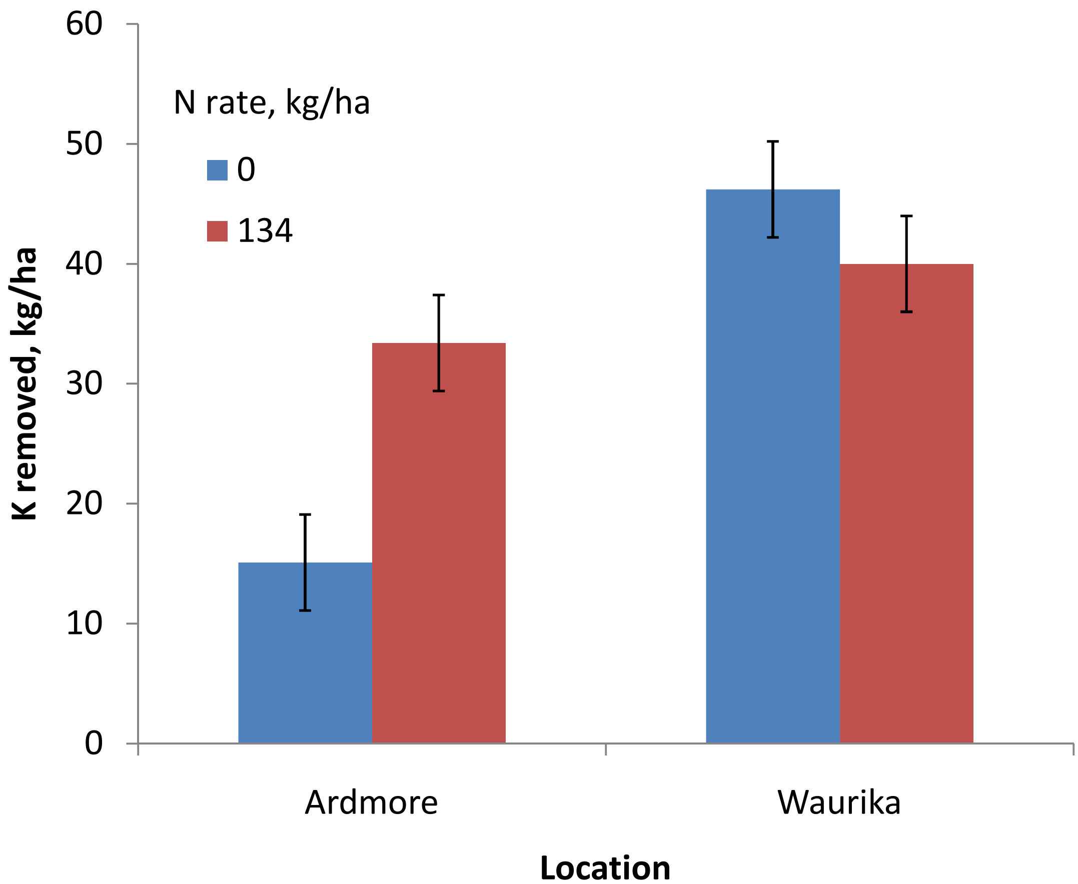

Figure 2. Effects of location and N rate on total K removed from 2nd-year switchgrass stands harvested once per year after a killing frost (December 2008) in Oklahoma, USA.

Harvest, Nitrogen, and Potassium Effects on One-Year Old Stands

During the establishment year of 2007, no effects of K were observed, as biomass yields averaged 4603 kg/ha and N, P, and K concentrations were 1.13, 0.12, and 0.70%, respectively. Total N, P, and K removed in harvested material was 54, 6, and 32 kg/ha, respectively.

In 2008, total biomass yields were not affected by harvest system, N, or K rate, averaging 16705 kg/ha. Biomass yields of switchgrass harvested at boot stage averaged 12366 kg/ha. Biomass yields of re-growth following the July harvests averaged 4789 kg/ha. Biomass yields from switchgrass harvested once annually after frost averaged 16255 kg/ha. Nitrogen and K rate also did not affect yields of the boot-stage and regrowth harvests.

Nitrogen concentrations were affected by N rates ($p=0.001$) and harvest system ($p<0.001$). Nitrogen concentrations averaged 1.00% in non-N-fertilized switchgrass and 1.24% in N-fertilized switchgrass (SE=0.043). Concentration of N was greater in switchgrass harvested twice per year (Table 2). Overall N removed was also affected by N rate ($p<0.01$) and harvest system ($p<0.001$). Nitrogen fertilized switchgrass removed 197 kg N/ha, while non-N fertilized removed 152 kg N/ha annually (SE=11.3). Nitrogen removed was also greater when switchgrass was harvested twice per year (Table 2).

Table 2. Effects of one harvest (after frost) and two harvest (at boot stage and after frost) per year systems on concentration and uptake of N, P, and K by 2nd year stands of Alamo switchgrass across south-central OK, USA.

Nutrient	Nutrient concentration				Nutrient removed			
	p	One cut	Two cuts	SE	*p*	One cut	Two cuts	SE
	%				kg/ha			
N	0.001	0.82	1.41	0.043	0.930	133	216	11.6
P	0.001	0.08	0.13	0.004	0.001	13	24	1.0
K	0.001	0.22	0.98	0.041	0.001	36	209	10.3

Phosphorus concentrations and uptake was also affected by harvest system (Table 2). Switchgrass harvested twice per year had a greater concentration of P than switchgrass harvested once per year ($p<0.001$). More P was also removed in the two-cut than one-cut system ($p<0.001$). Nitrogen and K rates did not affect concentration and uptake of P ($p>0.05$).

Concentration and removal of K was also greater in the two-cut system relative to the one-cut system (Table 2). Average annual K concentration for the one-cut after frost system was 0.22% compared to 0.98% in the two-cut system. Potassium removal averaged 209 and 36 kg/ha within the two-cut and one-cut systems, respectively. Concentration and uptake of K was not affected by N or K application rates.

Conclusions

Harvesting switchgrass twice per year makes a large difference in the amount of N, P, and K concentrated within stem and leaf tissues and the total amount removed from biomass feedstock production systems, without much gained in total biomass production. Therefore, one cut systems harvested after a killing frost would be the most sustainable biomass feedstock production system for cellulosic biofuels. After two years of evaluation, limited effects of P and K application to switchgrass were observed. In time, repeated harvesting and removal of biomass without subsequent fertilization has the potential to limit biomass yields, with effects likely developing sooner within two-cut than one-cut per year systems. After two years of evaluation, biomass yield responses to 134 kg N/ha were observed within two of the three experiments.

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