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Nitrogen, Phosphorus, Potassium, Magnesium and Calcium Removal by Brown Midrib Sorghum Sudangrass in the Northeastern USA

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With 5 tables

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Abstract

For the long-term sustainability of the dairy industry in the Northeastern USA, manure nutrient application rates should not exceed crop nutrient removal once above-optimum soil fertility levels are reached. Dairy producers have shown a growing interest in brown midrib (BMR) forage sorghum (*Sorghum bicolor* (L.) Moench.) × sudangrass (*Sorghum sudanense* Piper) hybrids (S × S) as a more environmentally sound alternative to maize (*Zea mays* L.) but data on S × S nutrient removal rates are scant. Our objectives were to determine N, P, K, Ca and Mg removal with harvest as impacted by N application rate, using six N rate studies in New York. One of the six sites had a recent manure history. Although site-to-site differences existed, N application tended to decrease P and K and increase N, Ca and Mg concentrations in BMR S × S forage. Nutrient removal and yield were highly correlated for all sites except one location that showed a K deficiency. The crop removed large amounts of P and K in the manured site, suggesting that BMR S × S is an excellent scavenger of these nutrients. If manure is applied mid-season, forage K levels are likely too high for feeding to non-lactating cows.

Key words: brown midrib — macronutrients — nitrogen — northeastern USA — nutrient removal — sorghum × sudangrass

Introduction

In the past 5 years, dairy producers in the northeastern USA have shown a growing interest in brown midrib (BMR) sorghum (*Sorghum bicolor* (L.) Moench.) × sudangrass (*Sorghum sudanense* Piper) hybrids (S × S) as an annual forage crop managed in a two-cut system. On dairy farms, S × S has environmental benefits over maize (*Zea mays* L.), as it is planted in June (vs. the April/May planting window for maize) and allows for manure application following first cutting in July/August when field conditions are less conducive to runoff and/or leaching in the humid northeastern USA. However, for the long-term sustainability of the dairy industry in the region, manure nutrient application rates should not exceed crop removal of nutrients once an above-optimum agronomic fertility status is reached. This is especially relevant for nitrogen (N) and phosphorus (P), nutrients of environmental concern (U.S. Environmental Protection Agency 2000), and for potassium (K), a nutrient that, if present in excess, could cause animal health problems in non-lactating cows (Beede 1996, Goff and Horst 1997).

For many forage crops in North America, average forage nutrient concentrations are available through published summaries (e.g. PPI/PPIC/FAR 2002), or electronic databases maintained by commercial forage laboratories (e.g. Dairy One 2006). However, data on S × S nutrient removal rates are scant.

Nitrogen is often limiting dry matter (DM) production of S × S (Beyaert and Roy 2005) and N application may impact P, K, calcium (Ca) and magnesium (Mg) concentrations in the forage. In a 2-year field study conducted in Central NY, N application rate did not impact K levels of BMR S × S, while K application increased forage K concentrations but did not impact DM yields (Ketterings et al. 2005a). Field trials conducted at seven locations in NY in 2002–2003 showed that P concentrations of BMR S × S were higher if N availability limited yields (Ketterings et al. 2004) and similar interactions are likely for Mg and Ca. However, additional research is needed to quantify such nutrient interactions and to investigate the possibility of deriving crop nutrient removal rates from DM yields across multiple locations.

Our objectives were to determine (i) impact of N application on N, P, K, Ca and Mg concentrations in a 2-cut forage BMR S × S system, and (ii) relationships between yield and nutrient removal with harvest across multiple locations.

Materials and Methods

Locations

Six N rate studies were conducted in 2004 in northern NY (Jefferson, St Lawrence, Essex Counties), eastern NY (Columbia County), and central NY (Cayuga and Tompkins Counties). Soils ranged from loamy fine sand in Essex County to silt loams in Jefferson and St Lawrence Counties (Table 1) and covered major agricultural areas in the state (Cline and Marshall 1977). Based on the Morgan soil test extraction (Morgan 1941) and soil fertility interpretations for New York (Cornell Cooperative Extension 2006), all sites were classified as high in available P and high or very high in magnesium (Mg). Two sites were low in K (Columbia and Essex County), two were medium in K (St Lawrence and Cayuga County), and the remaining sites were high in available K. Previous field histories varied from continuous corn to corn in rotation with wheat, barley or grass/legume sods. In St Lawrence County, the trial followed S × S (Table 1). The 2004 growing season (Table 2) was characterized by mean monthly temperatures that were slightly below average and rainfall that was above average for five of the six sites; the Columbia County site was warmer than average and received precipitation well-above average.

Experimental design and crop management

Each trial was conducted as a complete randomized block design with six treatments and four replicates. Plots were 18 by 3.6 m. The trial in Columbia County received about 52 360 L manure ha^{-1} plowed down within 5 hr just prior to planting. This resulted in an application of 134 kg ha^{-1} available N assuming 65 % availability of inorganic N and an organic N release of 35 % (Ketterings et al. 2003). This trial had 5 N treatments (0, 56, 112, 168, and 224 kg N ha^{-1} per cut) as well as a control that had not received any manure or fertilizer since 2002. Nitrogen applications were carried out using urea in a broadcast application. All other trials had 6 N fertilizer treatments (0, 56, 112, 168, 224, and 280 kg N ha^{-1} per cut) and N applications in the form of ammonium sulfate (21 % N) to minimize volatilization losses. The site in Jefferson County was fertilized by the producer with 41 kg N ha^{-1} prior to establishment of the trial in the spring of 2004.

The Columbia County site received the equivalent of 94 kg P_2O_5 ha^{-1} with the manure application. Each of the other sites was fertilized with 22–50 kg P_2O_5 ha^{-1} (Table 1). The two sites that were low in K received ample K with fertilizer or manure to overcome K deficiency. At the other sites 22–67 kg K_2O ha^{-1} were applied (Table 1).

The BMR S × S was planted in June, 2004, using John Deere grain drills and a seeding rate of 67 kg of seed ha^{-1}. Two harvests were obtained at five of the six sites. Harvest areas were 0.9 m wide and 7–9 m long with the exception of the on-farm trials in Columbia and Jefferson County where harvested areas were 0.9 m wide and 1.5 m long. The Jefferson country trial had one cut only, due to late planting and limited growth following first cutting.

Harvest was initiated when the plots that had received 168 kg N ha^{-1} had reached a stand height of 90–110 cm to optimize forage quality (Kilcer et al. 2005). Stand height was measured from the surface of the soil to the horizontal curve of the tallest emerged leaf. Cutting height was 7.5–9.0 cm. Fresh weights were determined and subsamples were taken to determine moisture content and nutrient concentration. Samples were dried for three days at 65 °C and ground using a UDY cyclone sample mill (UDY Corporation, Fort Collins, CO, USA) with a 1.0-mm screen.

Forage analyses

All forage analyses were carried out at the Dairy One Forage Testing Laboratory, Ithaca, NY, USA. Nitrogen was determined by dry combustion (Leco Instruments, Inc., St Joseph, MI, USA). For all other nutrients, samples were dry ashed for 4 h at 500 °C, cooled, and then dried again on a 100–120 °C hot plate after addition of 3 ml of 6 *N* HCl (Greweling 1976). Ashed samples were extracted in dilute acid (1.5 *N* HNO_3 and 0.5 *N* HCl), and plant P, K, Ca, and Mg concentrations in the extract were determined using a Thermo Jarrel Ash IRIS Advantage Inductively Coupled Plasma Radial Spectrometer (Jarrell Ash, Franklin, MA, USA).

Soil analyses

Soil samples (0–20 cm) were taken at planting, dried at 65 °C, ground and passed through a 2-mm sieve prior to analyses. All soil fertility analyses were performed at the Cornell Nutrient Analysis Laboratory, Ithaca, NY, USA.

Table 1: Soil series and initial soil fertility status of the six sites where brown midrib sorghum × sudangrass trials were conducted in New York in 2004

	Jefferson	St Lawrence	Columbia[1]	Essex	Cayuga	Tompkins
Soil series	Rhinebeck silt loam	Hailesboro silt loam	Knickerbocker fine sandy loam	Cosad loamy fine sand	Lima silt loam	Bath/Valois gravely silt loam
	Fine, illitic, mesic Aeric Endoaqualfs	Fine-silty, mixed, frigid Aeric Endoaqualfs	Sandy, mixed, mesic Typic Dystrudepts	Sandy over clayey, mixed, non-acid, mesic Aquic Udorthents	Fine-loamy, mixed, mesic Oxyaquic Hapludalfs	Coarse-loamy, mixed, mesic Typic Fragiudepts/ Dystrudepts
Cropping history	Following continuous corn	Following sorghum sudangrass	Following corn, third year after grass sod	Following grass/ legume sod	Following wheat (2003), barley (2002)	Following corn (2003), barley (2002)
Planting date	21 June	9 June	17 June	7 June	9 June	4 June
Harvest dates	16 August	4 August 28 September	3 August 14 September	26 July 27 September	4 August 20 September	3 August 20 September
Soil fertility status at the onset of trials[2]						
pH	6.1	6.4	5.8	6.5	7.8	6.7
OM (%)	4.3	4.1	4.6	3.4	4.0	7.6
P (mg kg^{-1})	7.2 (H)	5.2 (H)	7.3 (H)	14.0 (H)	6.0 (H)	8.0 (H)
K (mg kg^{-1})	58 (H)	53 (M)	33 (L)	24 (L)	47 (M)	103 (H)
Ca (mg kg^{-1})	1208	1327	902	1250	2800	2356
Mg (mg kg^{-1})	203 (VH)	223 (VH)	149 (VH)	91 (H)	259 (VH)	290 (VH)
Fertilizer addition at planting[3]						
P_2O_5 (kg ha^{-1})	43	50	94 (M)	22	34	22
K_2O (kg ha^{-1})	43	34	188 (M)	90	67	22

[1]Soil samples were not taken at the onset of this trial; mean values are for the 0 N plots (n = 4) sampled after the first cutting.
[2]L, low; M, medium; H, high; VH, very high. Sites classified as Low or Medium are likely to respond to additional fertilizer.
[3]M, added with 52 360 L manure ha^{-1}.

Table 2: Monthly precipitation and temperature for the six sites where brown midrib sorghum × sudangrass trials were conducted in New York in 2004

	June	July	August	September
Total monthly precipitation (cm)				
Jefferson	6.6	9.3	11.0	8.5
St Lawrence	8.7	13.5	13.8	3.0[1]
Columbia	8.7	15.4	18.6	22.0
Essex	6.3	9.8	NA[2]	NA[2]
Cayuga	4.4	13.9	14.1	10.5
Tompkins	6.7	17.3	NA[2]	11.4
Average monthly temperature (°C)				
Jefferson	15.7	19.6	18.3	16.3
St Lawrence	16.8	20.3	18.3	NA[2]
Columbia	18.8	21.5	21.1	18.1
Essex	17.4	20.9	NA[2]	17.6
Cayuga	18.1	20.8	20.0	18.3
Tompkins	16.6	19.4	NA[2]	17.4

Data were obtained from the weather station nearest to the sites (Northeast Regional Climate Center 2006).
[1]2 days of recording missing.
[2]Eight or more days of recording missing.

Soil organic matter was determined by loss on ignition (Nelson and Sommers 1996). Soil pH was measured in a 1 : 1 (w/v) water extract. The Morgan solution consisting of 1 *N* sodium acetate buffered at pH 4.8 (Morgan 1941) is the basis for fertility recommendations in New York State, Massachusetts, and Rhode Island. This test is also the basis for fertility recommendations in Ireland (Daly and Casey 2003). A slightly modified procedure that uses ammonium acetate instead of sodium acetate, also buffered at pH 4.8 (McIntosh 1969), is used for fertilizer recommendations in Vermont, Maine and Connecticut. All plots were analysed for Morgan extractable P, K, Ca and Mg by shaking dried samples in a 1 : 5 (v/v) ratio for 15 min and filtering the extract through a Whatman no. 2 equivalent filter paper. The extracts were analysed using a JY70 Type II Inductively Coupled Plasma Atomic Emission Spectrometer (Jobin Yvon, Edison, NJ, USA).

Statistical analyses

Trials were analysed individually using PROC MIXED of SAS Institute Inc. (1999) with block effects as random effects and N rate as fixed effect. Mean differences were considered significant if $P \leq 0.05$. PROC REG was used to determine the relationships between dry matter yield (independent variable) and nutrient removal (dependent variable).

Results and Discussion

Nutrient concentrations

The mean N concentration across all sites and cutting was 19.8 g N kg^{-1} with a standard deviation of 6.8 g kg^{-1}. Concentrations <10 g N kg^{-1} dry matter (DM) were measured for first cutting when no additional N was added in Essex County and when N applications were 112 kg ha^{-1} or less in Jefferson County (Table 3). This may be due to higher DM yields for first cutting in those two counties (data not shown). The highest N concentrations (>30 g kg^{-1}) were obtained in the manured trial in Columbia County. These concentrations are substantially higher than the 13 g kg^{-1} reported as average N concentration for maize silage but lower than the 82 g kg^{-1} reported by the Dairy One Forage Laboratory, Ithaca, NY, for high protein feeds such as soybean meal (Dairy One 2006). Forage N concentrations increased with N application (Table 3) but varied from location to location, consistent with observations by Beyaert and Roy (2005), who attributed variability over sites and years to water stress.

Phosphorus concentrations ranged from <2.0 g kg^{-1} in the Jefferson County site to 4.4 g kg^{-1} in second cutting in the Columbia County site when no fertilizer N or manure was applied (Table 3), with a mean P concentration across all sites of 2.9 g P kg^{-1} (standard deviation = 0.7 g P kg^{-1}). These ranges and the mean concentration are comparable with those reported in Ketterings et al. (2004) and higher than the 2.3 g kg^{-1} average P concentration reported for maize across 71 sites throughout NY in 2001–2003 (Ketterings et al. 2005b) and 2.4 g kg^{-1} reported as a 5-year average for maize by the Dairy One (2006). The BMR S × S P concentrations are similar to those reported for small grains, clovers and other

Table 3: Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) concentrations of first and second cutting as impacted by N fertilization rate in six BMR sorghum × sudangrass studies in New York[1] (see Table 1 for a description of the sites)

Kg N	Jefferson		St Lawrence		Columbia[2]		Essex		Cayuga		Tompkins	
ha^{-1} cut^{-1}	First	Second	First	Second	First	Second	First	Second	First	Second	First	Second
Nitrogen (g N kg^{-1} of dry matter)												
0	–	–	16.3 c	13.5 d	17.2 d	13.1 c	9.8 b	12.6 b	15.4 b	14.1 c	15.4 a	15.9 d
0 + M	–	–	–	–	22.8 cd	18.3 bc	–	–	–	–	–	–
43	9.1 bc	–	–	–	–	–	–	–	–	–	–	–
56	8.4 c	–	19.7 bc	15.3 cd	28.9 bc	22.1 b	14.2 ab	11.6 b	16.4 b	13.4 c	14.2 a	18.3 cd
112	8.9 bc	–	18.1 bc	19.0 bc	34.0 ab	30.3 a	20.2 ab	14.6 ab	18.7 ab	14.2 c	17.8 a	21.3 bc
168	13.9 b	–	23.2 ab	22.9 ab	32.4 ab	32.7 a	20.5 ab	15.7 a	19.8 ab	18.3 b	21.5 a	22.0 bc
224	19.9 a	–	27.0 a	25.1 a	36.2 a	33.2 a	22.4 a	16.0 a	21.9 a	18.7 b	22.2 a	25.0 ab
280	22.3 a	–	27.2 a	26.4 a	–	–	19.2 ab	17.4 a	23.2 a	22.6 a	17.2 a	28.1 a
Phosphorus (g P kg^{-1} of dry matter)												
0	–	–	3.2 a	4.3 a	3.0 ab	4.4 a	2.6 a	4.1 a	3.0 a	3.5 a	4.0 a	3.8 a
0 + M	–	–	–	–	3.3 a	4.0 ab	–	–	–	–	–	–
43	1.9 a	–	–	–	–	–	–	–	–	–	–	–
56	1.6 ab	–	3.2 a	3.7 b	3.0 ab	3.8 b	2.7 a	3.0 b	2.7 a	2.9 b	3.6 a	3.6 ab
112	1.2 b	–	2.9 a	3.2 c	2.7 ab	3.5 b	2.2 a	2.4 b	2.9 a	2.5 bc	3.3 a	3.5 ab
168	1.4 b	–	3.1 a	3.0 c	2.5 b	3.5 b	2.2 a	2.3 b	2.8 a	2.4 bc	3.4 a	3.2 b
224	1.4 b	–	2.9 a	2.9 c	2.8 ab	3.7 b	2.3 a	2.0 b	2.7 a	2.4 c	3.4 a	3.2 b
280	1.4 b	–	2.9 a	2.9 c	–	–	2.3 a	2.4 b	2.6 a	2.4 c	3.6 a	3.1 b
Potassium (g K kg^{-1} of dry matter)												
0	–	–	27.3 a	17.6 a	23.9 a	18.7 ab	21.2 a	16.9 a	28.3 a	19.9 a	29.2 a	22.7 a
0 + M	–	–	–	–	29.3 a	20.2 a	–	–	–	–	–	–
43	23.3 a	–	–	–	–	–	–	–	–	–	–	–
56	22.1 a	–	25.0 a	16.6 a	30.1 a	17.0 ab	17.0 ab	9.7 b	25.9 a	18.2 ab	28.7 a	22.9 a
112	20.7 a	–	25.5 a	15.6 a	28.3 a	13.8 b	15.9 ab	9.2 b	27.5 a	16.2 bc	28.2 a	22.7 a
168	19.8 a	–	23.8 a	15.4 a	22.9 a	16.4 ab	14.2 ab	9.3 b	26.6 a	15.4 c	29.0 a	19.6 a
224	18.0 a	–	23.0 a	16.3 a	30.1 a	16.7 ab	15.8 ab	9.1 b	25.0 a	15.3 c	27.7 a	20.8 a
280	21.9 a	–	23.7 a	16.2 a	–	–	11.4 b	8.1 b	25.0 a	15.7 c	28.7 a	23.9 a
Calcium (g Ca kg^{-1} of dry matter)												
0	–	–	5.3 b	5.7 a	5.2 a	5.2 b	6.2 b	6.2 a	5.3 c	4.9 b	4.0 b	3.4 a
0 + M	–	–	–	–	5.3 a	5.3 b	–	–	–	–	–	–
43	4.1 a	–	–	–	–	–	–	–	–	–	–	–
56	4.1 a	–	5.6 b	6.3 a	5.8 a	5.7 ab	7.6 ab	6.6 a	5.6 bc	5.3 bc	4.0 ab	3.5 a
112	3.9 a	–	5.4 b	6.1 a	6.0 a	6.7 a	8.1 a	7.1 a	5.8 abc	5.6 abc	4.2 ab	3.7 a
168	4.0 a	–	5.5 b	6.1 a	5.1 a	6.8 a	8.3 a	7.0 a	5.9 ab	5.8 ab	4.2 ab	3.5 a
224	4.1 a	–	6.0 ab	6.0 a	6.4 a	6.6 ab	8.3 a	6.9 a	6.1 ab	5.9 ab	4.8 a	3.6 a
280	4.5 a	–	6.4 a	6.3 a	–	–	8.6 a	7.5 a	6.2 a	6.3 a	4.0 ab	3.8 a
Magnesium (g Mg kg^{-1} of dry matter)												
0	–	–	3.6 c	3.8 b	5.2 b	5.9 b	3.2 a	3.6 a	3.1 c	2.3 d	2.1 a	2.3 d
0 + M	–	–	–	–	5.8 b	6.5 b	–	–	–	–	–	–
43	2.0 a	–	–	–	–	–	–	–	–	–	–	–
56	2.0 a	–	3.9 c	4.7 a	6.6 ab	7.5 ab	4.5 a	4.7 a	3.6 bc	3.0 c	2.1 a	2.6 cd
112	2.0 a	–	4.2 bc	5.1 a	6.4 ab	9.1 a	4.2 a	4.1 a	3.8 ab	3.3 bc	2.4 a	2.9 bc
168	2.2 a	–	4.7 ab	5.0 a	5.9 ab	9.5 a	4.4 a	3.8 a	3.9 ab	3.8 ab	2.8 a	3.1 abc
224	2.0 a	–	4.8 ab	4.7 a	7.9 a	9.5 a	4.3 a	3.7 a	4.0 ab	3.6 abc	3.0 a	3.3 ab
280	2.0 a	–	5.0 a	4.8 a	–	–	4.6 a	4.3 a	4.2 a	3.9 a	2.4 a	3.5 a

[1]Average values within columns with different letters (a, b, c) are statistically different ($P \leq 0.05$).
[2]This site received manure at a rate of 52 360 L ha^{-1} plowed down within 5 hr resulting in an application of 134 kg available N ha^{-1}, 94 kg P_2O_5 and 188 kg K_2O ha^{-1}.

legumes by Brink et al. (2001). Nitrogen application significantly reduced P concentrations in either the first or the second cutting or in both, depending on location. This is also consistent with findings reported for BMR S × S trials conducted in NY in 2002–2003 (Ketterings et al. 2004).

Mean K concentrations decreased with N application, although differences were not statistically significant in the Jefferson, St Lawrence and Tompkins County sites. Potassium concentrations were < 25 g kg^{-1} for second cuttings at all sites, making second cuttings suitable for non-lactating cows, even at the site where manure was applied (Table 3). In previous studies with BMR S × S (Ketterings et al. 2005a), we concluded that K availability and concentration had little influence on yield, while N fertilizer greatly increased yield. Cherney et al. (1998) summarized literature on elemental concentration shifts in grass herbage when either N or K was applied and concluded that N fertilizer will increases both K uptake and plant K concentration if there is enough K available in the soil. When K becomes limiting, increasing N fertilizer results in a decreased plant K concentration (a dilution effect). Our results are consistent with such a decrease in K availability.

Manure was only applied at the onset of the trial in Columbia County, and forage K concentrations will likely exceed recommended levels for non-lactating cows if a second manure application takes place following first cutting. The K concentrations in the second cutting in Essex County may suggest a K deficiency, although K response trials need to be conducted to confirm a deficiency as sufficiency ranges for this crop are not known.

Magnesium concentrations ranged from 2.0 g kg^{-1} in the single cut in Jefferson County site to 9.5 g kg^{-1} in second cutting of the manured site in Columbia County, with a mean across all sites of 4.2 g Mg kg^{-1} (standard deviation = 1.9 g kg^{-1}). Magnesium concentrations in the forage at the Tompkins County site were comparable with values reported in Ketterings et al. (2005a) for a N × K trial conducted in 2002–2003 in the same county. The mean Ca concentration across all sites was 5.6 g kg^{-1} (standard deviation = 1.4 g kg^{-1}). Mean Ca and Mg concentrations increased with N application at all sites except for the Jefferson County site and the Essex County site, where similar trends were observed but means were not statistically significant. An increase in Ca and Mg may be due to the decreased K concentrations with N addition on these high Mg fertility soils. These results are consistent with observations by Cherney et al. (1998) for grass forage; N fertilizer tends to increase plant Mg, but has inconsistent effects on plant Ca concentrations, and N effects on Ca and Mg can be enhanced by limited K availability.

Nutrient removal

Nitrogen removal ranged from 30 kg N ha^{-1} at the lowest N rate in the one-cut system in Jefferson County to 510 kg N ha^{-1} with the highest N additions in the manured site (Table 4). The manured site showed the highest N uptake increase per Mg DM (43 kg N Mg^{-1} DM), consistent with the 251–393 kg N ha^{-1} uptake reported for forage S × S by McLaughlin et al. (2004). Dry matter yield accounted for 80–91 % of the variability in N removal for all sites except the one-cut system in Jefferson County (47 %) and the site that followed plowdown of a grass/legume sod in Essex County (Table 5). At this site, the low K fertility status and absence of a second K application following first cutting, may have caused a K deficiency that impacted the N response.

Dry matter yield accounted for > 85 % of the variability in P removal at the sites in St Lawrence, Columbia, Cayuga and Tompkins counties, with P uptake increases in these four counties ranging from 5.30 kg P_2O_5 Mg^{-1} DM in Cayuga County to 7.14 kg P_2O_5 Mg^{-1} in Tompkins County (Table 5). In the single cut system in Jefferson County, 61 % of the variability in P removal was explained by dry matter yield while for Essex County, DM production only explained 43 % of the variability, possibly due to a K deficiency. Phosphorus removal rates in the manured site were only slightly lower than the 101–129 kg P_2O_5 ha^{-1} obtained with forage S × S in swine manure fertilized fields in Mississippi and higher than the other warm season grasses studied by McLaughlin et al. (2004).

Potassium removal rates were substantial, ranging from 98 kg K_2O ha^{-1} without N addition in the Jefferson County site to almost 500 kg ha^{-1} with the highest N application in the manured site (Table 4). These results suggest that high yields will quickly deplete available soil K.

The K removal rates at the highest N treatments in the manure site (Table 5) were similar to those reported for swine manure amended fields in Mississippi (McLaughlin et al. 2004). Dry matter yields explained 80–95 % of the variability in K removal in four of the six sites. Exceptions were the one-cut system in Jefferson County, where yield explained only 64 % of the variability, and the Essex County site, where the relationship between dry matter yield and K removal was not significant (Table 5). The latter supports the observations that this site was K deficient during the second part of the growing season.

Table 4: Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) removal with harvest as impacted by N fertilization rate in six BMR sorghum × sudangrass forage studies in New York[1] (see Table 1 for a description of the sites)

Kg N ha^{-1} cut^{-1}	Jefferson	St Lawrence	Columbia[2]	Essex	Cayuga	Tompkins
Nitrogen (kg N ha^{-1})						
0	–	56 c	77 d	71 b	58 d	40 b
0 + M[2]	–	–	211 c	–	–	–
43	30 c	–	–			
56	34 bc	102 b	320 bc	140 ab	99 cd	95 b
112	44 bc	131 b	358 b	186 a	125 bc	166 a
168	78 ab	189 a	386 b	194 a	153 ab	179 a
224	118 a	198 a	510 a	205 a	169 a	228 a
280	106 a	225 a	–	185 a	167 a	222 a
Phosphorus (kg P_2O_5 ha^{-1})						
0	–	30.0 c	38.6 b	46.4 a	27.4 b	24.1 c
0 + M	–	–	79.1 a	–	–	–
43	14.9 a	–	–	–	–	–
56	14.7 a	45.9 b	91.2 a	71.7 a	41.2 ab	48.6 b
112	13.8 a	49.5 ab	76.7 a	57.1 a	47.0 a	66.6 a
168	17.2 a	57.3 a	78.1 a	53.6 a	47.8 a	64.3 ab
224	19.0 a	51.5 ab	101.5 a	53.2 a	49.1 a	72.2 a
280	15.9 a	55.3 ab	–	55.2 a	42.4 a	80.5 a
Potassium (kg K_2O ha^{-1})						
0	–	112 c	141 c	171 a	134 b	91 d
0 + M	–	–	334 ab	–	–	–
43	98 a	–	–	–	–	–
56	119 a	155 bc	402 ab	190 a	194 a	199 c
112	131 a	186 ab	326 b	179 a	219 a	283 b
168	143 a	207 a	321 b	163 a	219 a	265 bc
224	137 a	195 ab	496 a	169 a	220 a	301 ab
280	140 a	215 a	–	128 a	200 a	356 a
Calcium (kg Ca ha^{-1})						
0	–	19.8 d	25.4 c	41.0 b	19.8 c	9.7 c
0 + M	–	–	52.8 b	–	–	–
43	14.3 a	–	–	–	–	–
56	17.1 a	35.1 c	69.4 ab	76.5 a	35.6 b	22.0 b
112	19.0 a	40.5 bc	69.0 ab	79.7 a	43.1 ab	33.3 ab
168	22.1 a	48.0 ab	68.4 ab	81.0 a	47.5 a	32.4 ab
224	24.1 a	45.6 ab	92.7 a	81.8 a	49.6 a	41.2 a
280	21.7 a	52.6 a	–	81.5 a	45.6 ab	40.8 a
Magnesium (kg Mg ha^{-1})						
0	–	13.2 c	26.5 c	22.4 a	11.2 c	5.7 d
0 + M	–	–	60.0 b	–	–	–
43	7.3 a	–	–	–	–	–
56	8.3 a	25.6 b	83.4 b	50.1 a	21.7 b	13.4 c
112	9.9 a	33.3 ab	81.9 b	44.5 a	26.7 ab	22.5 b
168	11.9 a	40.0 a	85.8 b	43.9 a	30.9 a	24.6 ab
224	11.4 a	36.4 a	120.8 a	43.2 a	31.4 a	30.4 a
280	9.7 a	41.1 a	–	45.7 a	29.7 a	29.0 ab

[1]Average values within columns with different letters (a, b, c) are statistically different ($P \leq 0.05$).
[2]This site received manure at a rate of 52 360 L ha^{-1} plowed down within 5 hours resulting in an application of approximately 134 kg N ha^{-1}, 94 kg P_2O_5 and 188 kg K_2O ha^{-1}.

Calcium removal increased upon the addition of N, although increases were not significant in the Jefferson County trial. Calcium removal increased from 3.86 kg Mg^{-1} in Jefferson County to 9.45 kg Mg^{-1} DM in Essex County, with dry matter yield explaining 81–97 % of the variability

Table 5: Linear regression (nutrient removal = intercept + slope × yield) for phosphorus, potassium, calcium and magnesium for six New York brown midrib sorghum × sudangrass N rate trials

	Intercept (P > F)	Slope (P > F)	Model adjusted R^2	Model P > F
Nitrogen (kg N ha^{-1}) removal with harvest (Mg ha^{-1}, first and second cut combined)				
Jefferson	−37.50 (0.1250)	22.03 (0.0001)	0.47	< 0.0001
St Lawrence	−73.90 (0.0010)	32.87 (< 0.0001)	0.86	< 0.0001
Columbia	−137.47 (0.0003)	42.05 (< 0.0001)	0.90	< 0.0001
Essex	−57.82 (0.2265)	22.42 (< 0.0001)	0.49	< 0.0001
Cayuga	−31.57 (0.0766)	23.07 (< 0.0001)	0.80	< 0.0001
Tompkins	−34.38 (0.0338)	24.99 (< 0.0001)	0.91	< 0.0001
Phosphorus (kg P_2O_5 ha^{-1}) removal with harvest (Mg ha^{-1}, first and second cut combined)				
Jefferson	3.19 (0.1574)	2.64 (< 0.0001)	0.61	< 0.0001
St Lawrence	11.34 (< 0.0001)	5.42 (< 0.0001)	0.93	< 0.0001
Columbia	5.60 (0.3831)	6.76 (< 0.0001)	0.86	< 0.0001
Essex	5.77 (0.6346)	5.11 (0.0003)	0.43	0.0003
Cayuga	5.63 (0.0483)	5.30 (< 0.0001)	0.90	< 0.0001
Tompkins	5.47 (0.0695)	7.14 (< 0.0001)	0.96	< 0.0001
Potassium (kg K_2O ha^{-1}) removal with harvest (Mg ha^{-1}, first and second cut combined)				
Jefferson	25.46 (0.1337)	21.31 (< 0.0001)	0.64	< 0.0001
St Lawrence	27.12 (0.0043)	22.17 (< 0.0001)	0.94	< 0.0001
Columbia	−66.76 (0.1467)	37.88 (< 0.0001)	0.80	< 0.0001
Essex	–	–	–	0.2588
Cayuga	49.28 (0.0003)	21.34 (< 0.001)	0.89	< 0.0001
Tompkins	6.38 (0.6464)	32.18 (< 0.001)	0.95	< 0.0001
Calcium removal (kg Ca ha^{-1}) removal with harvest (Mg ha^{-1}, first and second cut combined)				
Jefferson	1.13 (0.5686)	3.86 (< 0.0001)	0.81	< 0.0001
St Lawrence	−3.95 (0.0290)	6.49 (< 0.0001)	0.97	< 0.0001
Columbia	−9.07 (0.0486)	6.76 (< 0.0001)	0.93	< 0.0001
Essex	−19.77 (0.0332)	9.45 (< 0.0001)	0.84	< 0.0001
Cayuga	−3.78 (0.0826)	6.32 (< 0.0001)	0.95	< 0.0001
Tompkins	−2.58 (0.0947)	4.31 (< 0.0001)	0.97	< 0.0001
Magnesium removal (kg Mg ha^{-1}) removal with harvest (Mg ha^{-1}, first and second cut combined)				
Jefferson	−0.12 (0.9213)	2.05 (< 0.0001)	0.76	< 0.0001
St Lawrence	−8.18 (< 0.0001)	5.83 (< 0.0001)	0.97	< 0.0001
Columbia	−20.98 (0.0035)	9.14 (< 0.0001)	0.92	< 0.0001
Essex	−23.01 (0.0258)	6.54 (< 0.0001)	0.66	< 0.0001
Cayuga	−5.99 (0.0041)	4.49 (< 0.0001)	0.93	< 0.0001
Tompkins	−3.92 (0.0132)	3.28 (< 0.0001)	0.95	< 0.0001

See Table 1 for a description of the sites.

in Ca removal (Table 5). Calcium removal rates at the manured site in Columbia County were lower than determined in the swine manured fields in the study in Mississippi possibly due to higher Ca levels in the calcareous silty clay soils in Mississippi (McLaughlin et al. 2004).

Magnesium removal increased with the addition of N, although increases were not significant in the Jefferson County and Essex County trials (Table 4). Magnesium removal rates were high in the sites in Essex and Columbia County most likely due to a K deficiency (Essex County) and manure addition (Columbia County). At five sites, DM yield explained more than 75 % of the variability in Mg removal. The exception was the Essex County site (66 %), again suggesting a potential K deficiency.

Nutrient removal rates and forage nutrient concentrations were not clearly associated with initial soil fertility levels with the exception of the Essex County trial, where a one time application of 90 kg K_2O ha^{-1} was insufficient to overcome K deficiency.

Conclusions

Although site-to-site differences existed, N application tended to decrease P and K concentrations and increase N, Ca and Mg concentrations in BMR S × S forage. Increases in yield resulted in highly significant positive relationships between nutrient removal and N application for all sites except one site that showed a K deficiency. We conclude that dry matter yields can be used to determine crop nutrient removal but that forages need to be analysed for nutrient content to take site-to-site differences into account. Uptake of all nutrients except Ca was highest in the manured site. The crop removed large amounts of K in the manured site. If manure is applied mid-season, forage K levels are likely too high for feeding of the forage to non-lactating cows.

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