

Management of Warm- and Cool-Season Grasses for Biomass on Marginal Lands: II. Composition and Nutrient Balance

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Abstract Organic fertilizers can improve soil health while providing nutrients for perennial grass growth for bioenergy feedstock, particularly under marginal soil conditions. The impact of organic fertilizer application on perennial grass composition needs clarification. Our objective was to evaluate feedstock composition, and N, P, and K dynamics of switchgrass (*Panicum virgatum* L.), tall fescue [*Lolium arundinaceum* (Schreb.)], and reed canarygrass (*Phalaris arundinacea* L.) provided with either inorganic or organic fertilizer sources. Grasses were established on a sandy soil and a clay soil at the Cornell University Willsboro Research Farm in Willsboro, NY. The experiment was a split-split plot randomization of a randomized block design with six replicates. Sites were whole plots, grass species were subplots, and fertility treatments were sub-subplots. Six treatments were (1) 168 kg ha⁻¹ of N fertilizer for cool-season grasses; 84 kg ha⁻¹ for switchgrass, (2) 56 kg ha⁻¹ of 0-46-0 P fertilizer plus N (#1), (3) 112 kg ha⁻¹ of 0-0-60 K fertilizer plus N (#1), (4) 89.6 Mg dairy manure ha⁻¹, (5) 44.8 Mg dairy manure compost ha⁻¹, and (6) a control without fertilizer. Organic fertilizers produced a net positive P and K balance, while other treatments had negative balances. Organic fertilizer treatments resulted in lower lignin and gross energy values, and higher total ash and Cl, compared to inorganic fertilizer treatments. Switchgrass biomass had higher fiber and gross energy, lower total ash, and much lower Cl

content under organic fertilizer applications than cool-season grasses, making switchgrass a more desirable feedstock regardless of conversion process.

Keywords Switchgrass · Tall fescue · Reed canarygrass · Biomass · Dairy manure · Compost

Abbreviations

N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
Cl	Chloride
GCV	Gross calorific value or high heating value
ANR	Apparent N recovery
TF	Tall fescue
RC	Reed canarygrass
SW	Switchgrass
IN	Inflorescence
LB	Leaf blade
LS	Leaf sheath
ST	Stem

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Introduction

It is advantageous to produce biomass crops on marginally productive cropland not well suited to food or feed production [1]. Herbaceous biomass feedstock variability can lead to significant biofuel conversion consequences [2], and organic fertilizers have the potential to significantly alter biomass composition. Total ash and fiber content can impact most

conversion processes, while specific elements such as K and Cl can have a major impact on direct combustion [3]. Soil contamination of herbaceous biomass feedstocks can also directly impact conversion [4].

Mineral content of switchgrass was strongly impacted by soil environment in a New Jersey study [5]. Nitrogen fertilization had a much greater impact on N concentration in *Miscanthus* spp. than switchgrass [6]. Concentrations of P, K, Ca, and Mg in standing switchgrass in fall did not consistently increase or decrease with increased inorganic N fertilizer rate [7]. Apparent N recovery of inorganic N fertilizer applied to cool-season grass was as low as 36.5% [8], but typically ranges from 45 to 60% in cool-season grasses [9–14].

Composting manure provides numerous benefits for soil and the environment in general [15] but also provides slow release of organically bound N, P, and K. With multiple rates of dairy manure compost applied to tall wheatgrass [*Thinopyrum ponticum* (Podp.) Barkworth & D.R. Dewey], N, P, and K removed in the biomass were quadratically related to manure application rate [16]. However, total N and ash concentrations in switchgrass were greater when fertilized with an inorganic N source, compared to cattle manure [17], and dairy manure application resulted in a similar response in reed canarygrass, compared to inorganic N fertilizer [12]. Apparent N recovery from dairy manure compost applied to cool-season grass was estimated at 15.1% [8], and only 5.7% when lime-stabilized biosolids were applied to switchgrass [18].

One method of improving feedstock quality is to leave biomass in the field allowing it to leach over the winter, either standing or mowed, followed by harvest in the spring [19]. Total ash content and some mineral nutrients were reduced in concentration in switchgrass, both due to leaching and to selective loss of morphological components [6, 20], and reed canarygrass feedstock quality also improved after overwintering in the field, followed by spring harvest [21–23]. The primary concern with overwintering of biomass in the field is, however, whether any increase in feedstock quality can offset the loss of DM yield.

The impact of organic fertilizer application (dairy manure or dairy manure compost) to perennial grasses in marginal environments on biomass composition needs clarification. Our objective was to evaluate feedstock composition, and N, P, and K dynamics of switchgrass and cool-season grasses provided with either inorganic or organic fertilizer sources.

Materials and Methods

Treatments Applied

Experimental methods are described more completely in Cherney et al. [24]. Thirty-six species blocks were established in 2006 [12 blocks each of switchgrass (*Cave-in-Rock*), reed

canarygrass (*Rival*), and tall fescue (*KY-31*)], each 6 m × 18 m. Eighteen blocks were on a sandy soil and 18 blocks were located on a clay soil, on the Cornell University Research Farm at Willsboro, NY. The sandy soil was a Stafford loamy fine sand (Mixed, mesic Typic Psammaquents), and the clay soil was a Kingsbury silty clay (Very-fine, mixed, active, mesic Aeric Endoaquents). Each site was a factorial experiment with three grass species and six fertility treatments. Each experiment was arranged in a split-split-plot randomization of a randomized block design with six replicates. Sites were whole plots, grass species were subplots, and fertility treatments were sub-subplots. Sub-subplot size was 5.5 m × 3 m. Fertility treatments were applied to a 5.5 m × 2 m area, leaving a 2-m unfertilized buffer strip between sub-subplots. At the start of the experiment, the Sand site was low in soil P and high in soil K, while the Clay site was medium in soil P and low in soil K. Initial soil pH and organic matter levels were adequate for perennial grass production.

Six treatments were applied to each subplot: (1) 168 kg ha⁻¹ of N fertilizer for cool-season grasses, split-applied, and 84 kg ha⁻¹ for switchgrass, no P or K fertilizer (N treatment); (2) recommended rate of P at 56 kg ha⁻¹ of 0-46-0 (same N rate as #1) (NP treatment); (3) recommended rate of K as KCl (112 kg ha⁻¹ of 0-0-60) plus P at 56 kg ha⁻¹ of 0-46-0 (same N rate as #1) (NPK treatment); (4) dairy manure, 89.6 Mg ha⁻¹ wet-basis, late April application (Manure treatment); (5) composted dairy manure, 44.8 Mg ha⁻¹ wet-basis, late April application (Compost treatment); and (6) a control treatment without any fertilizer (control treatment). Dairy manure and dairy manure compost were applied to sub-subplots by weighing the quantity required and spreading by hand on the soil surface. The goal was to apply similar quantities of organic N for both Manure and Compost [24]. Nitrogen fertilizer was applied to cool-season grasses in late April and after first harvest, with a single application to switchgrass in mid-May. Treatments were applied annually from 2009 to 2012.

Sample Collection and Analysis

Cool-season grasses were harvested twice per season, in early July and early October, while switchgrass was harvested once per season in early October [24]. Plots also were harvested in 2013 without any fertility treatments applied, to evaluate residual effects of previous fertility treatments. Samples were collected from each sub-subplot and dried at 65 °C for 48 h for dry matter determination. In addition, samples from two replicates of each site were cut at a 10.2-cm stubble height and collected in 2012 and separated into IN, LB, LS, and ST. The relationship between ash content and GCV of morphological components was determined.

Biomass samples from three of the six field replicates were analyzed by Dairyland Laboratories, Inc. (Arcadia, WI), for elemental composition using microwave nitric acid digestion

and inductively coupled plasma spectroscopy (AOAC Method 985.01) [25]. For chloride, samples were extracted in water, filtered, and measured by way of Corning 926 Chloride Analyzer. Nitrogen, NDF, ADF, ADL, and ash were determined using NIRS techniques by Dairyland Laboratories, Inc. Gross calorific value was determined using a Parr 6200 bomb calorimeter (Parr Instrument Co., Moline, IL).

Apparent N recovery (ANR) for inorganic N treatments was calculated by subtracting the total amount of N in the biomass when no N was applied from the amount of N in the biomass when N was applied, and dividing that value by the actual amount of inorganic N applied. Due to the assumptions required concerning loss of applied ammonia N, with an average of 20-fold more ammonia N in fresh Manure vs. Compost [24], and rate of decay assumptions for conversion of organic N to available N for plant uptake, we did not attempt to calculate apparent N recovery from organic fertilizers. Phosphorus and K balances were calculated by subtracting the quantity of the nutrient removed in biomass from the actual amount of nutrient applied.

Statistical Analyses

Data were analyzed using mixed model, split-split plot arrangement of treatments, with repeated-measures analysis [26], with sites, grass species, and fertility treatments considered as fixed effects and with blocks and years as random effects. Year-by-treatment terms were considered fixed effects, and years were treated as repeated measures. Responses to species and fertility treatments and their interactions were analyzed using orthogonal contrasts. Levene's test to check the assumption of homogeneous variances was not significant ($p > 0.05$). In all cases, "significant" in the following discussion refers to $p < 0.05$. "Sand" and "Clay" will be used throughout to refer to the sites with sand and clay soil types. Because Sand and Clay were not replicated, differences between sites cannot be tested in any way to make a conclusion about the main effect of Sand vs. Clay sites.

Results and Discussion

Biomass N

In general, N concentration of cool-season grass at both harvests was double that of switchgrass harvested in the fall (Table 1). While inorganic N treatments tended to result in greater N concentration for Cut 1, compared to organic fertilizer or the Check, there were significant interactions between treatment and species for both cuts (Fig. 1). Tall fescue did not respond as well as RC to organic N. Nitrogen concentration in cool-season species responded similarly to treatments in both Cuts 1 and 2 (Fig. 1). There was a significant interaction

between site and species for Cut 1, because N concentration in RC was much greater than in TF on the Sand site, but not on the Clay site. This was partly due to the fact that RC yield was significantly smaller than TF on the Sand site [24]. Nitrogen concentration in SW was not very responsive to N fertilization, regardless of the form of N (Fig. 1). High rates of N fertilizer do not guarantee a significant yield response in switchgrass [27], but are more likely to increase N concentration [7, 28]. A site \times treatment interaction for Cut 2 was caused by greater N concentrations for organic fertilizer treatments on Clay compared to Sand, but slightly smaller N concentrations for inorganic N treatments on Clay compared to Sand.

Apparent N recovery for the three inorganic N treatments was similar (Table 2), although calculated ANR data were considerably more variable than yield and composition data. No interaction terms were significant for ANR. Cool-season grasses had significantly greater ANR than SW, in spite of the fact that cool-season grasses received twice the application rate of inorganic N fertilizer. Cool-season grasses in past studies had similar or larger ANR than this study [10–12]. Low ANR for SW was caused by a combination of very low N concentration in SW biomass and relatively large Check yields for SW, which could not be overcome by large yields of SW in inorganic N treatments.

Biomass P

As with N, cool-season grass P concentrations in biomass for Cut 1 were double that of SW, on average (Table 1). There were no significant differences among inorganic N treatments for P concentration, and biomass in inorganic N treatments averaged 74% less P than organic N treatments for Cut 1. The site \times treatment interaction was significant for Cut 1, with greater P concentrations in organic fertilizer treatments on Clay vs. Sand. This was likely caused by high soil P availability on the Sand site vs. relatively low soil P on the Clay site, with the Sand site relatively unresponsive to the large amounts of P provided by the organic fertilizers. The species \times treatment interaction also was significant for Cut 1, with cool-season grasses responding more to organic fertilizers than SW, although species ranking for biomass P remained the same for all treatments. The site \times species \times treatment interaction was significant for Cut 1, primarily due to greater biomass P in organic fertilizer treatments on the Clay site, compared to the Sand site (Fig. 2).

For Cut 2, NP and NPK treatments did result in significantly more biomass P than the N treatment, with no difference between TF and RC. The study \times treatment interaction was significant with greater P concentrations in organic fertilizer treatments on Clay vs. Sand, following an identical pattern as Cut 1. The species \times treatment interaction for Cut 2 also was significant, with slightly greater P concentrations for RC

Table 1 Biomass N, P, and K concentrations, main effect means, 2009 to 2012

	Treatment						Species		
	N	NP	NPK	Manure	Compost	Check	TF	RC	SW
Cut 1	g kg ⁻¹								
N	12.09a	12.04a	11.70ab	11.39ab	10.67bc	10.59c	13.48a	13.64a	7.12b
P	1.62 e	1.85d	1.79d	2.25a	2.48b	2.06c	2.35a	2.46a	1.21b
K	12.13de	11.57 e	13.55c	17.94a	15.70b	12.54cd	17.73a	16.49b	7.25c
Cut 2									
N	17.98a	16.82b	16.17bc	15.58cd	15.19d	15.78cd	14.47b	18.04a	
P	2.38c	2.59bc	2.56bc	3.23a	3.33a	2.72b	2.70a	2.72a	
K	14.46c	12.93 d	14.45c	17.85a	16.78b	14.33c	16.94a	14.33b	

Different letters within rows among treatments, species, or sites denote significant differences at $p \leq 0.05$ level of probability

NN fertilizer, NP N and P fertilizer, NPK N, P, and K fertilizer, *Manure* fresh dairy manure, *Compost* dairy manure compost, *Check* no fertilizer applied, *TF* tall fescue, *RC* reed canarygrass, *SW* switchgrass

compared to TF for all treatments except the Check, which had slightly greater P for TF.

Inorganic fertilizer P inputs did not offset biomass P removal (Table 2). Phosphorus balance with SW was slightly but significantly greater than the balance for cool-season grasses. Because the compost treatment provided the most P, it had a large positive P balance, followed by the Manure treatment. The NP and NPK treatments produced a significantly smaller negative P balance than the N treatment. The significant site \times species \times treatment interaction shows that P inputs for SW came very close to balancing biomass P removal for both sites, and for all three grasses for the Clay site (Fig. 3). The larger quantity of P provided by Compost

resulted in a larger P balance compared to Manure. A significant species \times treatment interaction for P balance may be due to SW removing slightly more P than cool-season grasses for the Check treatment (Fig. 3). A significant site \times treatment interaction primarily was due to differences in magnitude; P balance for the Clay site was greater than the Sand site for all treatments.

Biomass K

Similar to P concentrations, K concentration was over twice as great for both cuts of cool-season grasses compared to SW (Table 1). Because the Manure treatment provided over 2-fold more K than the Compost treatment, K concentration was significantly greater for Manure than the rest of the treatments for both cuts. Biomass from the Compost treatment also was greater than the inorganic fertilizer treatments for both cuts. However, all interaction terms were significant for K for Cut 1. The site \times species \times treatment interaction (Fig. 4) helps to explain the two-factor interactions.

For study \times treatment, organic and Check treatments produced greater biomass K content on the Sand site, compared to Clay, but the three inorganic fertilizer treatments produced greater K content on the Clay site, compared to Sand. This was the case, even though soil K was consistently greater on the Clay site compared to Sand, except for the Manure treatment. A species \times treatment interaction for Cut 1 resulted from TF exceeding RC in K content under NPK and organic treatments only. Reed canarygrass was considerably smaller in K concentration than TF on the Clay site, but greater in K concentration than TF on the Sand site for Cut 1, partly due to the relatively poor yield of RC on the Sand site. Reed canarygrass responded to inorganic N fertilization in a previous study with decreasing P and K content as N fertilizer rate increased [29]. The study \times treatment interaction for Cut 2 followed the same pattern as that interaction in Cut

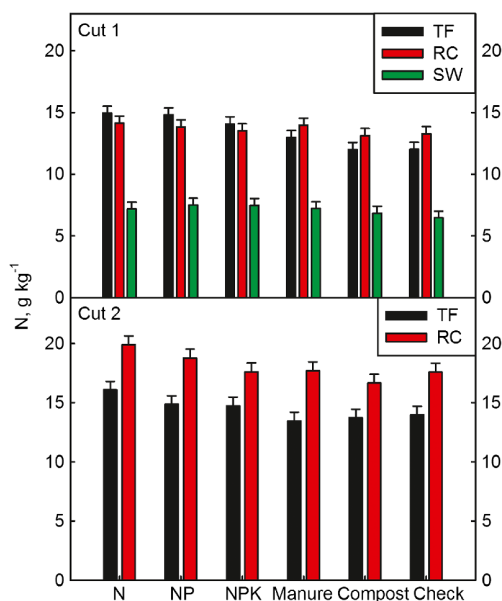


Fig. 1 Nitrogen concentration of biomass in one or two harvests, species \times treatment interactions, 2009 to 2013. Means were calculated from four years, two sites, and three blocks ($n = 24$), and error bars are ± 1 standard error of the mean

Table 2 Apparent N recovery for inorganic N treatments, and P and K balance of nutrients added minus nutrients removed, 2009 to 2012

	Treatment						Species		
	N	NP	NPK	Manure	Compost	Check	TF	RC	SW
%									
ANR ^a	46.9a	47.0a	49.8a				53.6a	52.2a	37.9b
kg ha ⁻¹									
P balance ^b	-17.09 e	-7.18c	-9.15c	54.61b	62.78a	-11.91d	10.59b	9.89b	15.54a
K balance	-104.9d	-101.2d	-72.0c	253.2a	54.6b	-70.2c	-30.9c	-12.7b	23.4a

Different letters within rows among treatments, species, or sites denote significant differences at $p \leq 0.05$ level of probability

NN fertilizer, NP N and P fertilizer, NPK N, P, and K fertilizer, Manure fresh dairy manure, Compost dairy manure compost, Check no fertilizer applied, TF tall fescue, RC reed canarygrass, SW switchgrass

^a Apparent N recovery

^b P balance = fertilizer P inputs minus biomass P removal, K balance = fertilizer K inputs minus biomass K removal

1, with inorganic fertilizer treatments resulting in biomass with greater K concentrations on the Clay site compared to Sand, but smaller K concentrations on organic and Check treatments on Clay compared to Sand. Both P and K concentrations in switchgrass were within the range of a set of switchgrass standard samples, which had a 3.7- and 2.2-fold range among only five samples for P and K [30].

As with P, inorganic K inputs did not offset biomass K removal (Table 2). The Manure treatment resulted in a very high K balance, as Manure provided 2.4-fold more K than Compost. The NPK treatment produced a significantly smaller negative K balance than the N and NP treatments. A significant site × treatment interaction for K balance was due to differences

in magnitude of response. A species × treatment interaction for K balance may have been due to a similar response of species for the Check treatment, while TF was lowest and SW highest for other treatments. The site × species × treatment interaction (Fig. 5) exhibited a consistent species response for K balance for NP, NPK, and Manure treatments, but a slightly different pattern for N, Compost, and Check treatments. In a 4-year study comparing inorganic N fertilizer with dairy manure applied to tall fescue, grass uptake of K over the season was greater in the inorganic N fertilizer treatment in the first 2 years, while smaller than K uptake in the dairy manure treatment in the last 2 years [31]. In tall wheatgrass fertilized with dairy manure compost, it required 40 Mg ha⁻¹ for P and 35 Mg ha⁻¹ for K to equal the

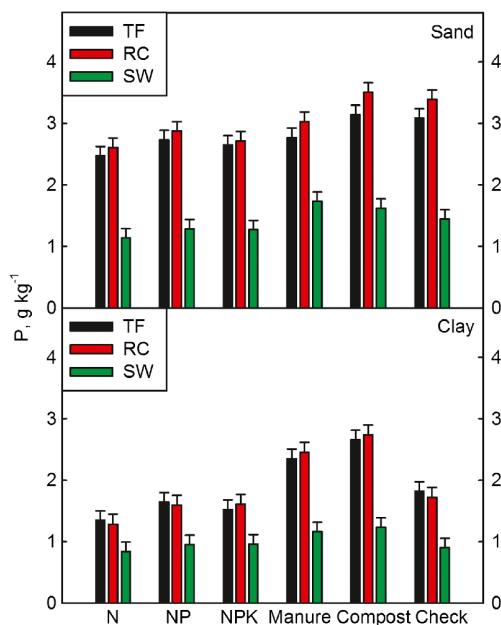


Fig. 2 Phosphorus concentration in Cut 1 of biomass, species × treatment × site interaction, 2009 to 2012. Means were calculated from four years and three blocks ($n = 12$), and error bars are ± 1 standard error of the mean

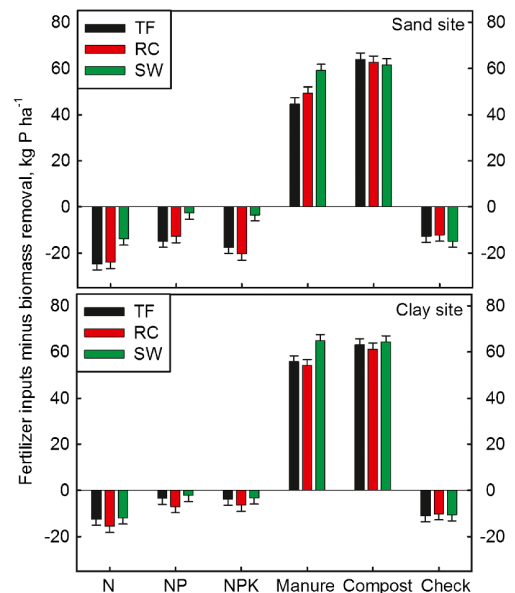


Fig. 3 Fertilizer P inputs minus biomass P removal, species × treatment × site interaction, 2009 to 2012. Means were calculated from four years and three blocks ($n = 12$), and error bars are ± 1 standard error of the mean

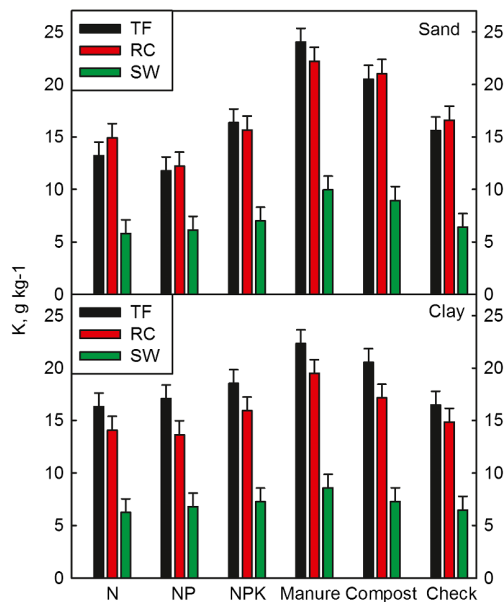


Fig. 4 Potassium concentration in Cut 1 of biomass, species \times treatment \times site interaction, 2009 to 2012. Means were calculated from four years and three blocks ($n = 12$), and error bars are ± 1 standard error of the mean

removal of P and K due to an inorganic N fertilizer rate of 224 kg ha^{-1} [16].

Other Biomass Components

Species \times treatment interactions were significant for all components in Table 3, except ADL for Cut 1 and Ca for Cut 2. Some site \times species and site \times treatment interactions also were significant. Interactions not simply due to changes in magnitude of response are discussed. Site \times species \times treatment

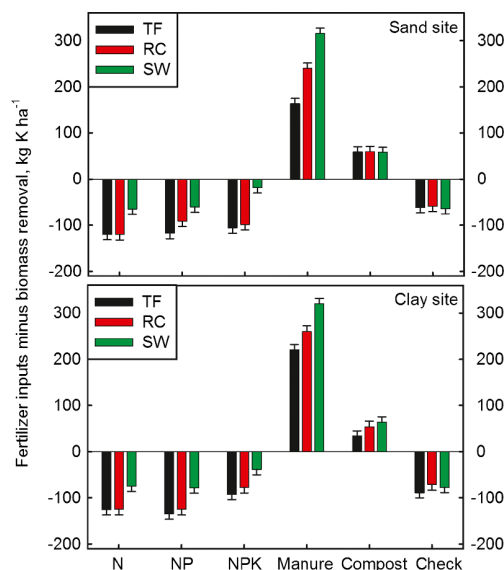


Fig. 5 Fertilizer K inputs minus biomass K removal, species \times treatment \times site interaction, 2009 to 2012. Means were calculated from four years and three blocks ($n = 12$), and error bars are ± 1 standard error of the mean

interactions were significant only for NDF, ADL, and Ash for Cut 2, with no noticeable trends to explain these three-way interactions. Fiber components were relatively consistent among treatments, although there were significant differences, particularly for Cut 2 (Table 3). Acid detergent lignin concentration was consistently smaller in organic fertilizer treatments compared to inorganic fertilizer treatments in both cuts. Fiber concentrations were greater in cool-season grasses fertilized with dairy manure, compared to inorganic N fertilizer [11, 12]. Fiber concentration also increased in reed canarygrass with increasing inorganic N fertilizer [29]. Switchgrass had much greater fiber and lignin concentrations, compared to TF and RC, while RC had greater lignin content than TF in both cuts. All three grass species increased in lignin concentration as a result of inorganic N fertilization. Mature reed canarygrass under inorganic fertilizer treatments averaged 63.5 g kg^{-1} ADL, similar to that found by Casler et al. [32] across Iowa, New York, and Wisconsin, but much greater than the 20 g kg^{-1} [33] and 25 g kg^{-1} [34] averages in the Midwestern USA. Concentrations of fiber constituents did not differ due to N fertilizer rate on switchgrass [7].

Biomass from Manure and Compost treatments was similar in ash content, but approximately 13% greater in ash than inorganic fertilizer treatments for both cuts. Switchgrass ash concentration was considerably smaller than the cool-season grasses, even though upland ecotypes such as Cave-in-Rock are known to accumulate more ash compared to lowland ecotypes [35]. Switchgrass ash content was considerably smaller than that found by Johnson and Gresham [20], but similar to switchgrass in a Canadian study [6]. Locations were significantly different in total ash content, and elemental concentrations can vary greatly due solely to location [5].

Magnesium and Ca concentration in biomass responded similarly to treatments, with generally greater concentrations in biomass from inorganic fertilizer treatments compared to organic fertilizers (Table 3). For Cut 1, species were different from each other in Mg and Ca, with TF highest and SW lowest. For Cut 2, RC had greater Ca concentration than TF. The significant species \times treatment interaction for both Mg and Ca was primarily caused by considerably greater concentrations for TF in the inorganic fertilizer treatments, compared to other treatments (Fig. 6). In a 5-year study on the impact of N and K fertilization on reed canarygrass, increased N fertilization increased Ca and Mg content of the biomass, and increased K fertilization decreased Ca and Mg content of biomass [29].

Significant site \times treatment interactions for both cuts were all due to greater concentrations of Mg and Ca in inorganic fertilizer treatments on the Sand site compared to Clay, with similar or smaller concentrations in the remaining treatments on Sand vs. Clay. Calcium, Mg, and S concentrations for RC with inorganic fertilizer treatments were similar to those found in Sweden by Burvall [21] and in Wisconsin by Dien et al. [34]. Sulfur concentration in biomass was significantly greater

Table 3 Biomass composition, main effect means, 2009 to 2012

	Treatment						Species		
	N	NP	NPK	Manure	Compost	Check	TF	RC	SW
Cut 1	g kg ⁻¹								
aNDF	683ab	689a	689a	690a	686a	676b	625c	654b	778a
ADF	432b	436ab	439ab	440a	436ab	424c	397c	413b	494a
ADL	66.7a	67.4a	67.1a	63.0b	62.5b	61.9b	56.6b	60.4b	77.3a
Ash	75.7c	73.9c	76.8bc	87.0a	84.5a	79.9b	91.9a	90.7a	56.3b
Mg	1.89ab	1.94a	1.79bc	1.51d	1.59cd	1.69c	2.10a	1.68b	1.42c
Ca	4.08ab	4.16a	3.97ab	3.14d	3.44c	3.88b	4.22a	3.70b	3.41b
S	1.19b	1.18b	1.15b	1.23b	1.45a	1.42a	1.52a	1.62a	0.67b
Cl	2.08d	1.75d	4.77c	7.68a	6.09b	2.35d	4.93a	5.24a	2.19b
MJ kg ⁻¹									
GCV	18.7a	18.7a	18.6b	18.3d	18.3d	18.4c	18.2c	18.4b	18.9a
Cut 2	g kg ⁻¹								
aNDF	578bcd	584ab	588a	580abc	573cd	570d	600a	558b	
ADF	349bc	353ab	359a	352ab	348bc	344c	360a	342b	
ADL	50.4a	51.7a	52.1a	46.0b	45.1b	46.0b	46.5b	50.5a	
Ash	95.1bc	91.8c	92.5c	104.8a	105.3a	97.8b	92.6b	103.2a	
Mg	2.34ab	2.38a	2.31abc	2.22bc	2.18c	2.24bc	2.43a	2.13b	
Ca	5.49abc	5.73a	5.37ab	4.58d	5.11bc	5.61ab	4.99b	5.65a	
S	2.24bc	2.17bc	2.10c	2.39b	2.82a	2.76a	2.14b	2.76a	
Cl	2.15d	1.88d	3.79c	7.18a	5.86b	2.63d	3.67a	4.16a	
MJ kg ⁻¹									
GCV	18.6a	18.6a	18.5a	18.3b	18.2b	18.3b	18.5a	18.4a	

Different letters within rows among treatments, species, or sites denote significant differences at $p \leq 0.05$ level of probability

NN fertilizer, NP N and P fertilizer, NPK N, P, and K fertilizer, Manure fresh dairy manure, Compost dairy manure compost, Check no fertilizer applied, TF tall fescue, RC reed canarygrass, SW switchgrass, aNDF neutral detergent fiber, ADF acid detergent fiber, ADL acid detergent lignin, GCV gross calorific value

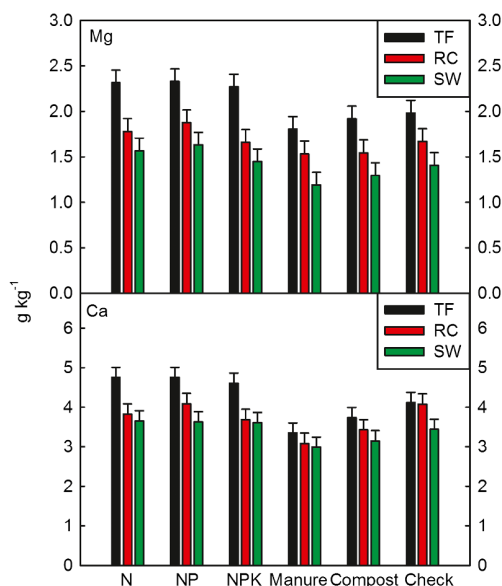


Fig. 6 Magnesium and Ca concentration in Cut 1 of biomass, species × treatment interaction, 2009 to 2012. Means were calculated from four years, two sites, and three blocks ($n = 24$), and error bars are + 1 standard error of the mean

in Compost and the Check, compared to the rest of the treatments, for both cuts (Table 3), with no meaningful interactions. Switchgrass, as with other elements, had significantly smaller S concentration than cool-season grasses.

Chloride Issues

For the two years that chloride was measured in organic fertilizers, the amount of Cl applied in the Manure treatment was twice that of Compost, and the amount of Cl applied in Compost was approximately 50% greater than with KCl fertilizer application for the NPK treatment [24]. Because Cl is very soluble, it is typically immediately available for plant uptake and that was reflected in the biomass. Cut 1 of the first year of treatment applications contained a large concentration of Cl in cool-season grass biomass, averaging 13.22 g Cl kg⁻¹ for Manure. The three treatments that included Cl application to soil were significantly different from one another in both cuts, and resulted in significantly greater Cl in biomass than all other treatments in both cuts (Table 3). Switchgrass Cl

concentration was much less than that of cool-season grasses, and SW responded much less to Cl applications than cool-season grasses. Cool-season grasses exhibited luxury Cl uptake, and RC had consistently greater Cl than TF in both cuts. Species \times treatment and site \times treatment interactions were significant for both cuts, and were due to changes in magnitude of response; species ranking was consistent over treatments (Fig. 7).

It was only possible to compare quantity of Cl applied vs. plant Cl uptake in 2010 and 2012 (Fig. 8), the two years that organic fertilizers were analyzed for Cl content. Switchgrass Cl concentration increased by 0.011 g kg^{-1} for every 1 kg ha^{-1} of Cl applied to soil. Although Cl recovery from compost application was more variable, Cl concentration in biomass was highly correlated with Cl application to soil. Because Cl applications were in early spring, the response was greater for Cut 1 compared to Cut 2 for cool-season grasses (Fig. 8). Chloride concentrations here under NPK fertilization were similar to those found in reed canarygrass [21] and in switchgrass [20], although Cl content of cool-season grasses will be strongly influenced both by Cl fertilization events and by native Cl status of the soil.

Energy Value

Gross calorific value was greatest for SW in Cut 1, followed by RC and TF (Table 3). Average GCV for switchgrass was 18.9 MJ kg^{-1} , very similar to the 18.8 MJ kg^{-1} for fall-harvested switchgrass in a Canadian study [6], and the 18.7 MJ kg^{-1} in fall-harvested Cave-in-Rock switchgrass from Nebraska [34], but greater than the 17.7 MJ kg^{-1} for fall-harvested switchgrass in Minnesota [20]. A large selection of reed canarygrass germplasm sources grown using commercial N fertilization ranged in GCV from 17.9 to 18.1 MJ kg^{-1} [32], and mature reed canarygrass from Wisconsin was 17.7 MJ kg^{-1} [34], compared to an average of 18.6 MJ kg^{-1} for N-fertilized RC in this study. Gross calorific value was significantly smaller for organic fertilizer treatments compared to inorganic fertilizer

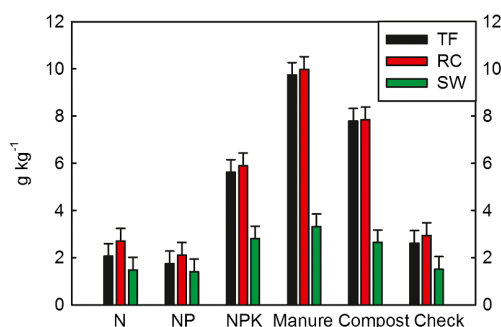


Fig. 7 Chloride concentration in Cut 1 biomass, species \times treatment interaction, 2009 to 2012. Means were calculated from four years, two sites, and three blocks ($n = 24$), and error bars are $+ 1$ standard error of the mean

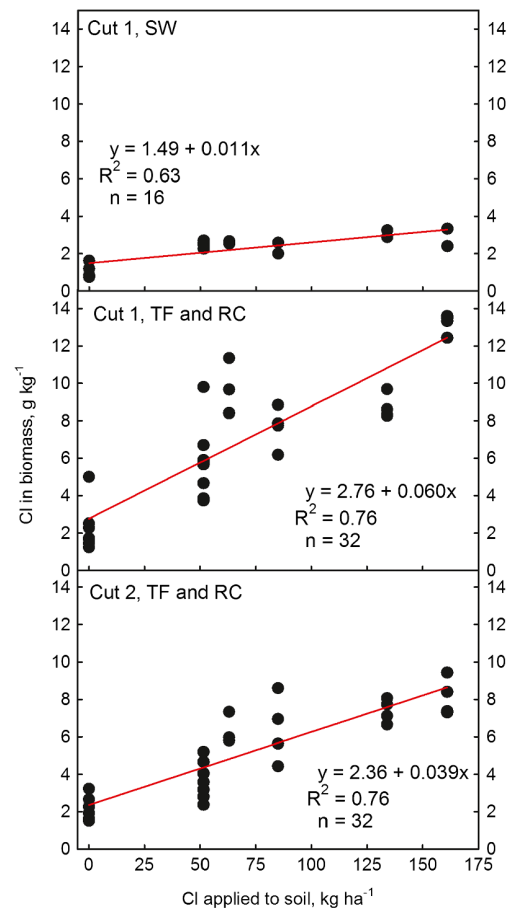


Fig. 8 Concentration of Cl in grass biomass as influenced by Cl application (KCl, compost, or manure) to soil in early spring at two sites in 2010 and 2012. Means of three replicates

treatments in both cuts; however, the species \times treatment interaction was significant in both cases (Fig. 9). For Cut 1, GCV dropped much more for TF and RC vs. SW, when using organic fertilizers compared to inorganic fertilizers. In Cut 2, TF was greater in GCV than RC for the inorganic fertilizers, but not for the organic fertilizers.

There was a relationship between GCV and ash content in morphological components of switchgrass in 2012 (Fig. 10). Distinct point clouds for this relationship in each morphological component were apparent, with a consistent relationship between ash and GCV for each component. Points representing the Manure treatment were typically on the lower half of this point cloud, and points representing inorganic N treatments were on the upper half of the point clouds. On a whole plant basis, ash content will be negatively correlated with GCV [4, 20].

Summary

Fresh manure or compost application can provide sufficient nutrients for grass growth while at the same time improving

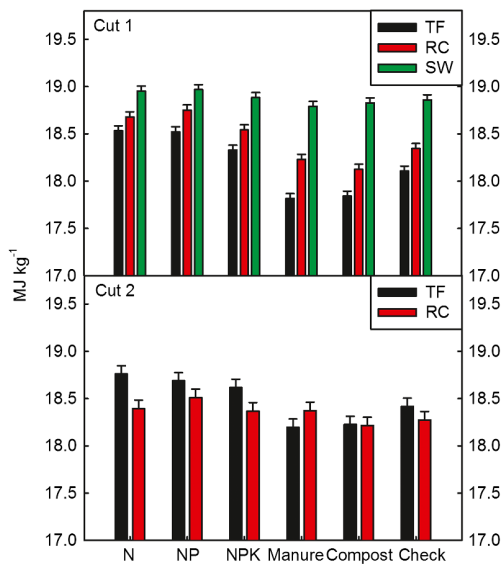


Fig. 9 Gross calorific value (GCV) in Cut 1 and Cut 2 biomass, species × treatment interaction, 2009 to 2012. Means were calculated from four years, two sites, and three blocks ($n = 24$), and error bars are + 1 standard error of the mean

soil health, but on the other hand can result in excessive quantities of undesirable elements in biomass from a feedstock conversion standpoint. Switchgrass biomass maintained a low concentration of N, P, and K upon fertilizer addition compared to cool-season grasses, and this resulted in a relatively low apparent N recovery for switchgrass. Organic fertilizers resulted in a net positive P and K applied to soil, while all other treatments had negative P and K balances. The greater yield of switchgrass overcame the smaller P and K concentration in switchgrass and produced a more positive net P and K balance compared to the cool-season grasses when fertilized with fresh dairy manure. Grass species differed significantly in most fiber and elemental components, with switchgrass being greater in fiber and lignin, and smaller in total ash and mineral concentrations, compared to the cool-season grasses. Biomass from organic fertilizer treatments was similar in fiber,

but contained less lignin than inorganic N treatments. Organic treatments produced biomass greater in total ash than inorganic N fertilizer treatments, primarily due to high P and K concentrations. Feedstock Cl concentration was extremely high for the fresh dairy manure treatment, very high for the Compost treatment, and high for the NPK treatment, reflecting the quantities of Cl applied as fertilizer. Organic fertilizer treatments resulted in feedstock with smaller gross energy values compared with inorganic fertilizers, particularly for cool-season grasses. We conclude that the combination of greater fiber and gross energy content, smaller total ash, much smaller N, P, and K content, and much smaller Cl content under organic fertilizer applications make switchgrass a more desirable feedstock regardless of the conversion process.

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References

1. Mitchell RB, Schmer MR, Anderson WF, Jin V, Balkcom KS, Kiniry J, Coffin A, White P (2016) Dedicated energy crops and crop residues for bioenergy feedstocks in the central and eastern USA. *Bioenerg Res* 9:384–398
2. Williams CL, Westover TL, Emerson RM, Tumuluru JS, Li C (2015) Sources of biomass feedstock variability and the potential impact on biofuels production. *Bioenerg Res* 9:1–14
3. Cherney JH, Verma VK (2013) Grass pellet quality index: a tool to evaluate suitability of grass pellets for small scale combustion systems. *Appl Energy* 103:679–684
4. Cherney JH, Ketterings Q, Cherney DJR (2016) Soil contamination of grass biomass hay: measurements and implications. *Bioenerg Res* 9:773–781
5. Serapiglia MJ, Mullen CA, Boateng AA, Cortese LM, Bonos SA, Hoffman L (2015) Evaluation of the impact of compositional differences in switchgrass genotypes on pyrolysis product yield. *Ind Crop Prod* 74:957–968
6. Kludze H, Deen B, Dutta A (2013) Impact of agronomic treatments on fuel characteristics of herbaceous biomass for combustion. *Fuel Process Technol* 109:96–102
7. Ibrahim M, Hong CO, Singh S, Kumar S, Osborne S, Owens V (2017) Switchgrass biomass quality as affected by nitrogen rate, harvest time, and storage. *Agron J* 109:86–96
8. Lynch DH, Voroney RP, Warman PR (2004) Nitrogen availability from composts for humid region perennial grass and legume-grass forage production. *J Environ Qual* 33:1509–1520
9. Cherney DJR, Cherney JH (2006) Split application of nitrogen on temperate perennial grasses in the northeast USA. *Forage Grazinglands*. <https://doi.org/10.1094/FG-2006-1211-01-RS>
10. Cherney DJR, Cherney JH, Mikhailova EA (2002a) Orchardgrass and tall fescue utilization of nitrogen from dairy manure and commercial fertilizer. *Agron J* 94:405–412

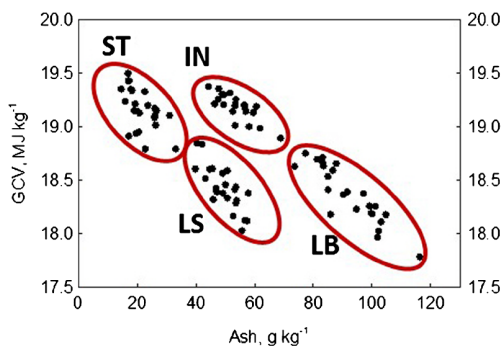


Fig. 10 Relationship between ash concentration and gross calorific value (GCV) for switchgrass morphological separations of inflorescence (IN), leaf blade (LB), leaf sheath (LS), and stem (ST) in 2012. Values consist of six treatments, two sites, and two blocks ($n = 24$) for each morphological component

11. Cherney JH, Ketterings QM, Cherney DJ, Davis MH (2010a) Timing of semisolid dairy manure application does not affect yield and quality of orchardgrass. *Agron J* 102:553–558
12. Cherney JH, Ketterings Q, Davis M, Cherney DJR (2010b) Split application of nitrogen vs. dairy manure on temperate perennial grasses. *Forage and Grazinglands*. <https://doi.org/10.1094/FG-2010-0215-01-RS>
13. Hall MH, Beegle DB, Bowersow RS, Stout RC (2003) Optimum nitrogen fertilization of cool-season grasses in the Northeast USA. *Agron J* 95:1023–1027
14. Vetsch JA, Randall GW, Russelle MP (1999) Reed canarygrass yield, crude protein, and nitrate N response to fertilizer N. *J Prod Agric* 12:465–471
15. Bow JR, Muir JP, Weindorf DC, Rosiere RE, Butler TJ (2008) Integration of cool-season annual legumes and dairy manure compost with switchgrass. *Crop Sci* 48:1621–1628
16. Butler TJ, Muir JP (2006) Dairy manure compost improves soil and increases tall wheatgrass yield. *Agron J* 98:1090–1096
17. Lee DK, Owens VN, Doolittle JJ (2007) Switchgrass and soil carbon sequestration response to ammonium nitrate, manure and harvest frequency on conservation reserve program land. *Agron J* 99:462–468
18. Liu XJA, Fike JH, Galbraith JM (2015) Biosolids amendment and harvest frequency affect nitrogen use dynamics of switchgrass grown for biofuel production. *Bioenerg Res* 8:560–569
19. Adler PR, Sanderson MA, Boateng AA, Weimer PJ, Jung H-JG (2006) Biomass yield and biofuel quality of switchgrass harvested in fall or spring. *Agron J* 98:1518–1525
20. Johnson JMF, Gresham GL (2014) Do yield and quality of big bluestem and switchgrass feedstock decline over winter? *Bioenerg Res* 7:68–77
21. Burval J (1997) Influence of harvest time and soil type on fuel quality in reed canary grass (*Phalaris arundinacea* L.). *Biomass Bioenergy* 12:149–154
22. Landström S, Lomakka L, Andersson S (1996) Harvest in spring improves yield and quality of reed canary grass as a bioenergy crop. *Biomass Bioenergy* 11:333–341
23. Nordin A (1994) Chemical elemental characteristics of biomass fuels. *Biomass Bioenergy* 6:339–347
24. Cherney, JH, Ketterings, Q, Davis, M, Cherney, DJR, Paddock, KM (2017b) Management of warm- and cool-season grasses for biomass on marginal lands: I. Yield and soil fertility status. *Bioenerg Res* (submitted)
25. Association of Official Analytical Chemists (1990) Official methods of analysis, 15th edn. AOAC, Arlington
26. Little RC, Milliken GA, Stroup WW, Russell RD (1996) SAS System for Mixed Models. SAS Institute, Cary
27. Casler MD, Sosa S, Hofmann L, Mayton H, Ernst C, Adler P, Boe AR, Bonos SA (2017) Biomass yield of switchgrass cultivars under high- vs. low-input conditions. *Crop Sci* 57:821–832
28. Hong CO, Owens VN, Bransby D, Farris R, Fike J, Heaton E, Kim S, Mayton H, Mitchell R, Viands D (2014) Switchgrass response to nitrogen fertilizer across diverse environments in the USA: a regional feedstock partnership report. *Bioenerg Res* 7:777–788
29. Cherney JH, Cherney DJR, Casler MD (2003) Low intensity harvest management of reed canarygrass. *Agron J* 95:627–634
30. Vogel KP, Medill R, Masterson SD, Mitchell RB, Sarath G (2017) Mineral element analysis of switchgrass biomass: comparison of the accuracy and precision of laboratories. *Agron J* 109:735–738
31. Cherney JH, Mikhailova EA, Cherney DJR (2002b) Tetany potential of orchardgrass and tall fescue as influenced by fertilization with dairy manure or commercial fertilizer. *J Plant Nutr* 25:1501–1525
32. Casler MD, Cherney JH, Brummer EC, Dien BS (2015) Designing selection criteria for use of reed canarygrass as a bioenergy feedstock. *Crop Sci* 55:1–8
33. Tahir MHN, Casler MD, Moore KJ, Brummer EC (2011) Biomass yield and quality of reed canarygrass under five harvest management systems for bioenergy production. *Bioenerg Res* 4:111–119
34. Dein BS, Jung HJG, Vogel KP, Casler MD, Lamb JFS, Iten L, Mitchell RB, Sarath G (2009) Chemical composition and response to dilute-acid pretreatment and enzymatic saccharification of alfalfa, reed canarygrass and switchgrass. *Biomass Bioenergy* 30:880–891
35. El-Nashaar HM, Banowetz GM, Griffith SM, Casler MD, Vogel KP (2009) Genotypic variability in mineral composition of switchgrass. *Bioresour Technol* 100:1809–1814