Vermont Grass Biomass Energy

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Research Report

Nitrogen Fertilization, Time of Harvest, and Soil Drainage Effects on Switchgrass Biomass Production and Fuel Quality

2010 – 2012

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The UNIVERSITY of VERMONT

Plant and Soil Science

Nitrogen Fertilization, Time of Harvest, and Soil Drainage Effects on Switchgrass Biomass Production and Fuel Quality

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Soil fertility, soil drainage and harvest management are all important factors that affect grass biomass production and stand sustainability. Switchgrass, an important potential biomass crop, is recognized for its efficiency in utilizing soil nutrients. Research across the U.S. looking at N fertilization of switchgrass has resulted in mixed results. Some studies have shown that switchgrass responds to applications of N while others report no response. A recent study in New York State found in a field scale size study that switchgrass showed no yield response to nitrogen fertilizer in the first four years of the stand (Mayton et. al. 2011). In fact, in the fourth year of the stand, their no N treatment yielded significantly higher than their 100 lb of N/acre treatment by about a half ton of baled weight. Yet, most university recommendation guides in the northeast will recommend at least 50 to 75 lbs of N/acre for switchgrass when grown for biomass. The objective of this research was to assess the response of a mature stand of switchgrass yield, fuel quality and nutrient removal rates to nitrogen fertilization.

Nitrogen Response Studies

The first field trial was initiated in 2010 on a four year old stand of 'Cave-In-Rock' switchgrass located at the Borderview Farm in Alburgh, VT. The site was on a Benson rocky silt loam soil (over shaly limestone) that is somewhat excessively drained. Three treatments of nitrogen (0, 50 and 100 lbs. of N/acre) were applied in late May in a randomized block design with four replications. Plot size was 12' x 40' for each treatment for a total of twelve plots (**Figure 1**). The nitrogen treatments were repeated on the same **plots** for three consecutive years with harvests taken in 2010, 2011 and 2012.

Figure 1. N rate study of switchgrass, Alburgh, VT

A second trial with the same treatments and methods was initiated in Shelburne, VT in 2011 on a three year old stand of 'Cave-In-Rock' switchgrass at the Meach Cove Farm location. This site was on a Scantic silt loam soil that is somewhat to poorly drained. Harvests were made in 2011 and 2012.

Prior to each trial, a composite soil sample was collected across the whole study area at each location. At Borderview Farm, the soil test levels for P were low but optimum for K; whereas, at the Meach Cove site, P and K were medium just below optimum. However, since the objective of this project was to evaluate these grasses under "marginal" conditions, no additional fertilizer except nitrogen was applied since these grasses have been shown to grow in low fertile soils.

Plots were harvested using a Carter self propelled research harvester which flail chops and collects a three foot wide swath. Subsamples were collected, weighed fresh, then dried and reweighed to determine dry matter content. The same samples were ground and used for determining ash (and

mineral content in 2011). In 2010 at the Borderview Farm only, two biomass subsamples were collected out of each plot in mid July and mid-August using a 1.5 ft^2 quatrat sample cut at a four inch stubble height. These were dried, ground and analyzed for ash and mineral content.

In late October of 2012 after the plots were harvested, a composite of eight soil subsamples per plot was collected and analyzed for soil pH, P, K, Mg, and Ca at the UVM Agricultural Testing Lab using a Modified Morgan extract.

Statistical analysis included an analysis of variance (ANOVA) to compare treatment means of each parameter using a Least Significant Difference (LSD) test ($P<0.05$). Field notes of observations such as diseases and lodging of stands were also recorded throughout each season.

Results

Weather data for the experimental period is shown in Table 1. Generally, temperatures were at or above average except for June of 2010. Generally, rainfall was below average in all three years during June, July and August, the major growth period of switchgrass. The exception was June of 2010 in Alburgh when rainfall was 2.4 inches greater than normal.

Table 1. Average monthly temperature and precipitation in Alburgh and Shelburne, VT.

Alburgh, VT[1]

	Average Monthly Temperature (F)						Average Monthly Precipitation (inches)					
	2010		2011		2012		2010		2011		2012	
	Ave.	[3]	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN
April	49	5.8	47	3.1	45	0.1	2.8	0.3	7.9	5.0	2.6	-0.2
May	60	3.0	59	2.1	61	4.1	0.9	-2.0	8.7	5.4	3.9	0.5
June	66	0.2	67	1.3	67	1.2	4.6	1.4	3.5	0.1	3.2	-0.5
July	74	3.0	74	3.3	71	0.8	4.3	0.9	3.7	-0.3	3.8	-0.4
August	70	1.4	70	1.6	71	2.3	5.5	1.6	10.2	6.4	2.9	-1.0
September	64	3.6	64	5.8	61	0.2	4.3	0.9	5.6	2.1	5.4	1.7
October	51	1.8	50	1.9	52	4.2	6.7	3.8	3.5	-0.1	4.1	0.5

Shelburne, VT[2]

	Average Monthly Temperature (F)						Average Monthly Precipitation (inches)					
	2010		2011		2012		2010		2011		2012	
	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN
April	49	4.4	45	0.5	46	1.6	3.3	0.5	6.4	3.6	2.4	-0.4
May	61	4.2	59	2.4	61	5	1.6	-1.8	6.2	2.7	3.9	0.4
June	66	-0.1	67	1.3	67	1.4	5.2	1.5	1.9	-1.8	2.8	-0.9
July	74	3.5	75	4.5	72	1.8	1.6	-2.6	2.5	-1.7	3.5	-0.6
August	70	1.5	72	3.1	72	2.9	2.2	-1.7	5.7	1.8	0.0	-3.9
September	63	2.7	65	4.5	62	1.4	3.7	0.1	3.9	0.3	5.1	1.5
October	49	0.7	51	2.4	53	4.7	3.9	0.3	1.9	-1.7	5.0	1.4

[1]Collected from the South Hero Weather Station

[2]Collected from the UVM Horticultural Research Farm Weather Station

[3]Departure from thirty year average

Biomass Yield – In 2010, the first year of the study at Borderview Farm, there was no statistical difference in yield amongst the nitrogen treatments (**Table 2**). The stand was four years old and studies in New York had found similar results in which switchgrass showed no response to additional N in the first four years of their study. By 2011 when the same N treatments were repeated, there was a significant increase in yield of 1.2 and 1.9 ton/acre difference in yield between the no-N treatment and the 50 or 100 lb N/acre treatments, respectively. In 2012, only the 50 lb rate had a significantly higher yield than the control. There was a similar response at Meach Cove. In the first year of the study, 2011, there was no yield response to N fertilization, but there was a significant increase in yield to added N in the second year when the treatments were repeated.

Lodging only occurred in 2010 at Borderview and was not a problem in other years or locations (Table 2 and Figure 2). Since there was no yield response to N that year, it is likely the additional N increased the ratio of nitrogen to carbon in the plant, which weakened the stems.

Table 2. Dry matter yields and lodging of 'Cave-N-Rock' switchgrass harvested for biomass in multiple years at Borderview Farm in Alburgh and at Meach Cove Farm in Shelburne.

	Biomass Yield[4]					Lodging Rating[6]				
Nitrogen[1]	Borderview Farm[5]			Meach Cove Farm[5]		Borderview Farm			Meach Cove Farm	
Rate	2010	2011	2012	2011	2012	2010	2011	2012	2011	2012
(lbs. N / acre)	----------		*tons dm/acre*	----------		----------		*numerical rating*	----------	
0	3.7	4.0 b[3]	4.4 b	4.3	2.9 b	1.0 a	1.0	1.0	1.0	1.0
50	3.9	5.2 a	5.4 a	3.9	3.6 ab	2.5 b	1.0	1.0	1.0	1.0
100	4.3	5.9 a	4.8 ab	4.1	4.3 a	3.3 c	1.0	1.0	1.0	1.0
Significance[2]	ns	*	*	ns	**	***	ns	ns	ns	ns

1 N was applied each year on the same respecitve plots at each location as a 28-0-0 in late May when grasses reached 4 inches of height.

2 Sig. catergories: ns - not significant (P>0.05); * - significant (P<0.05); ** - very significant (P<0.01); or *** - highly significant (P<0.001)

3 Columns with the same letter are not significantly (n.s.) different at P<0.05

4 Harvested at Borderview on 10/28, 10/20, 10/18 from 2010 to 2012 and at Meach Cove farm on 10/19 and 10/11 in 2011 and 2012, respectivel

5 Borderview stand planted in 2007; Meach Cove stand planted in 2009.

6 Visual lodging rating for each plot: 1- none; 2 - <25%; 3 - 26 to 50%; 4 - 51 to 75%; 5 >75%

Figure 2. Lodging of nitrogen fertilized switchgrass in 2010 in Alburgh, VT. Picture **A** was taken in August and shows lodging from a plot that received 100 lbs of N/a. Pictures **B** and **C** were taken at time of harvest in October. Lodging only occurred in one of five studies evaluating switchgrass and N.

Nutrient Removal Rate – Since biomass crops remove the total above ground portions of the crop, it is important to determine the potential removal rate of the major soil nutrients (**Table 3**) in order to assess replacement needs over time. Removal rate of nutrients is calculated by multiplying the nutrient content (as a percentage of the dry matter) by biomass yield. Except for nitrogen and magnesium, nutrient content was generally not affected by N fertilization (data not shown). The increase of potassium (K_2O) removal rates at the Borderview site was primarily a function of increased yield. Since yield was not different in Alburgh in 2011 amongst the N fertilization rates (Table 2), there was no difference in K_2O removal rate at that location. Phosphorus was not affected by N fertilization in either location. Magnesium removal rate was increase with N fertilization at both locations but not to any great magnitude.

At the end of 2012, there were no differences in soil pH, soil test P or soil test K for any of the nitrogen treatments at either location (data not shown); however, considering the high removal rate of potassium and the moderate removal rates of phosphorus, supplementation will be necessary at some point in time when soil test levels drop below an optimum level for switchgrass.

Table 3. Nutrient removal rates of 'Cave-N-Rock' switchgrass harvested for biomass in 2011 at Borderview Farm in Alburgh, VT and at Meach Cove Farm in Shelburne, Vt.

Nitrogen[1]	Borderview Farm				Meach Cove Farm			
Rate	N	P_2O_5	K_2O	Mg	N	P_2O_5	K_2O	Mg
lbs N/a	*pounds of nutrient per acre per year*							
0	27 b[3]	12	46 b	8 b	52 b	27	51	11 b
50	41 ab	14	74 b	10 ab	55 b	26	46	12 b
100	57 a	14	76 a	12 a	63 a	29	51	15 a
Significance[2]	#	ns	*	*	*	ns	ns	**

[1] Nitrogen was applied as a 28-0-0 in late May when grasses reached 4 inches of height.
[2] ns - not sig, (P>0.10); # - sig, (P<0.10); * - sig, (P<0.05); ** - very sig. (P<0.01)
[3] Columns with the same letter are not significantly (n.s.) different at P<0.05
[4] Harvested in 2011 on 10/20 at Borderview Farm and on 10/19 at Meach Cove Farm.
[5] Borderview stand planted in 2009; Meach Cove stand planted in 2009.

N Fertilization and Fuel Quality - Ash content and certain minerals can have a significant effect on the fuel properties of grasses used for combustion. There is generally a high correlation between ash content of biomass combustion fuels with levels of undesirable minerals such as potassium (K), silicon (Si), chloride (Cl), and sulfur (S) that affect burn efficiency, fouling and slagging (Cherney and Verma, 2013). Generally, ash content in perennial grasses can range from 2% up to over 10 % depending on species, stage of maturity at time of harvest, soil texture and drainage, soil fertility and weather conditions, and soil contamination.

In this study, ash content of the switchgrass was not affected by N fertilization at either location (**Table 4**); however, it was affect by date of cut in the fall (**Table 5**) with the lowest ash content occurring with the latest harvest. All of these levels were above optimum for a newly proposed grass pellet fuel standards but still within an acceptable range (Cherney and Verma, 2013).

Potassium (K) content of grass biomass, along with other alkali metals and chloride, can have a significant effect on the potential to cause boiler corrosion along with fouling and slagging. In our study, K levels ranged from 0.47% to 1.0% which is above both the optimum for the newly proposed grass pellet fuel standards (Cherney and Verma, 2013). Nitrogen fertilization did not affect K content (**Table 4**); however, by delaying the harvest from mid –September to late October (**Table 5**), K levels dropped to within a 0.1 percentage unit above an acceptable range for the newly proposed standard.

Table 4. Ash and mineral content of 'Cave-N-Rock' switchgrass harvested for biomass in 2011 at Borderview Farm in Alburgh and at Meach Cove Farm in Shelburne.

	Ash Content[4]					Mineral Content From 2011					
Nitrogen[1]	Borderview Farm[5]			Meach Cove Farm[5]		Borderview Farm			Meach Cove Farm		
Rate	2010	2011	2012	2011	2012	N	K	S	N	K	S
(lbs. N / acre)	% of dry matter					% of dry matter					
0	5.0	5.7	5.1	5.1	4.8	0.33	0.47	0.05	0.61 b	0.50	0.06
50	5.0	5.0	4.9	5.0	5.0	0.39	0.60	0.05	0.69 ab	0.48	0.07
100	5.2	4.9	4.9	4.6	4.8	0.47	0.53	0.05	0.77 a	0.52	0.07
Significance[2]	ns	ns	ns	ns	ns	ns	ns	ns	#	ns	ns

[1] Nitrogen was applied each year on the same respecitve plots at each location as a 28-0-0 in late May when grasses reached 4 inches of height.

[2] Significance catergories: ns - not significant (P>0.05); * - significant (P<0.05); ** - very significant (P<0.01); or *** - highly significant (P<0.001)

[3] Columns with the same letter are not significantly (n.s.) different at P<0.05

[4] Harvested at Borderview on 10/28, 10/20, 10/18 from 2010 to 2012 and at Meach Cove farm on 10/19 and 10/11 in 2011 and 2012, respectivel

[5] Borderview stand planted in 2007; Meach Cove stand planted in 2009.

Table 5. Ash and mineral content of 'Cave-N-Rock' switchgrass harvested for biomass in 2010 at Borderview Farm in Alburgh.

Nitrogen[1] Rate	Ash				Potassium				Sulfur			
(lbs. N/acre)	- % of dry matter -				- % of dry matter -				- % of dry matter -			
	16-Aug	15-Sep	28-Oct	Mean	16-Aug	15-Sep	28-Oct	Mean	16-Aug	15-Sep	28-Oct	Mean
0	5.5	5.6	5.0	5.4	0.86	0.80	0.55	0.73	0.072	0.071	0.057	0.067
50	5.6	5.6	5.0	5.4	0.91	0.87	0.56	0.78	0.074	0.069	0.058	0.067
100	5.8	5.5	5.2	5.5	1.00	0.88	0.55	0.81	0.074	0.068	0.056	0.066
Mean	5.6 a[3]	5.6 a	5.1 b		0.92 a	0.85 b	0.55 c		0.074 a	0.069 b	0.057 c	
Significance[2]												
Date (D)		**				***				***		
Nitrogen Trt (N)		ns				ns				ns		
D x N		ns				ns				ns		

[1] N was applied as a 28-0-0 in late May when grasses reached 4 inches of height.

[2] Sig. catergories: ns - not significant (P>0.05); * - significant (P<0.05); ** - very significant (P<0.01); or *** - highly significant (P<0.001)

[3] Rows with the same letter are not significantly (n.s.) different at P<0.05

Nitrogen (N) and sulfur (S) content of biomass can indicate potential for NO_x and SO_x emissions, respectively, and in this study, all the N fertilization treatments (**Table 4**) were above optimum but within acceptable ranges for quality fuel standards recently proposed for grass pellets (Cherney and Verma, 2013). Adding 100 lbs of N fertilizer did increase the N content at the Meach Cove site (Table 4) but there was no statistical difference between the zero and 50 lb treatment. Delaying harvest from mid-September to late October significantly reduced S content (**Table 5**). N was not analyzed in that 2010 study.

Effect of Soil Drainage on Switchgrass Growth and Yield

Although switchgrass will grow and persist on a wide range of soil conditions, yield is best when grown on moderate to well drained soils. Although not a formal research study, the following observation was made at the Meach Cove Farm study site. A poorly drained swale ran down the middle of a one acre site. When we harvested for the N study, we carefully harvested the three separate sections. Overall, there was over one to one and a half ton difference between the yields in the swale compared to the better drained parts of the field (**Figure 3**). The density of the stand was similar and yield response to N fertilization was similar (**Figure 4**). Only the difference in drainage affected yield.

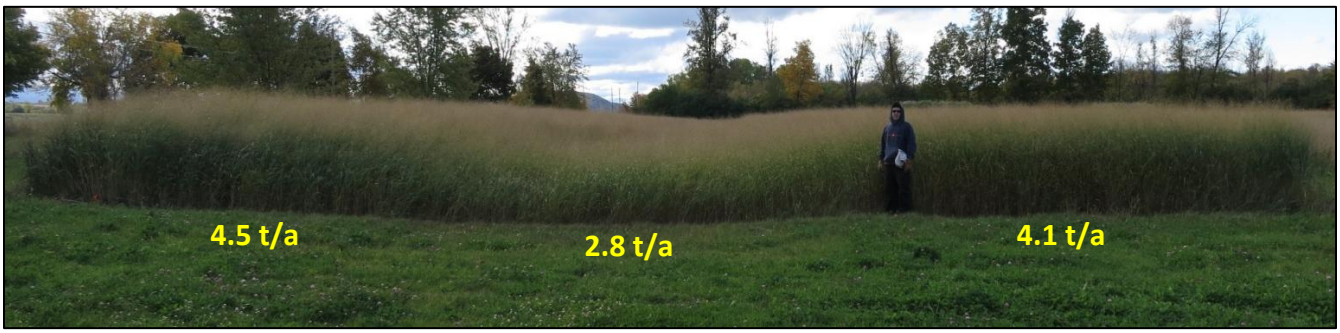
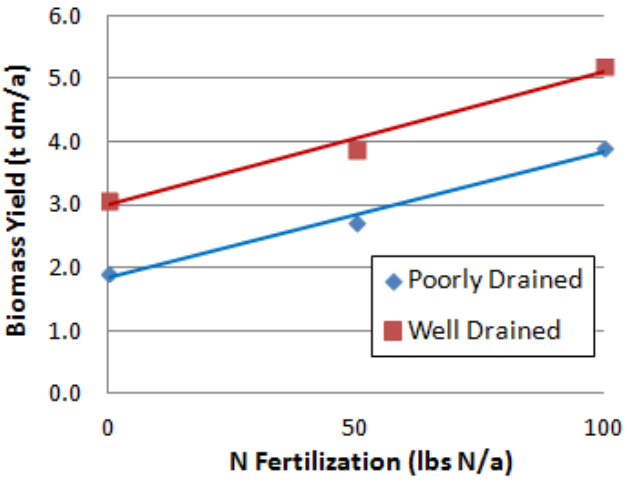


Figure 3. Differences in biomass yield (tons of dry matter per acre) of a four year old stand of 'Cave-In-Rock' switchgrass in the better drained outside locations compared to the poorly drained swale in the middle, October 2012, Meach Cove Farms, Shelburne, VT.

Figure 4. Biomass yield of 'Cave In Rock' switchgrass as affected by N fertilization rate in the well drained portion of the strip plots compared to the poorly drained areas. The well drained section in this graph represents western side of the plots (the right side in the picture above).



Summary of Switchgrass Nitrogen and Harvest Trials

Based on these studies, an application of 50 to 75 lbs of N per acre per year, starting when the stand is about four to five years old, could increase yields by about 1.5 to two tons per acre. Applying nitrogen to a stand three years old or younger is likely to be uneconomical. The drainage of the soil will have as great an influence on switchgrass yield than just N fertilization. Generally, yields will be better on moderate to well drained soils.

Note - It is important to avoid applying N fertilizer too early in the spring; otherwise, it will just promote the growth of other cool season grasses that could compete with the switchgrass. Wait until it is clear that the switchgrass has begun its new growth and is at four to six inches in height.

When yield was increased due to N fertilization, we found an increase in nutrient removal rates of nitrogen, potash and magnesium. Potash removal rate ranged from 46 to 76 lbs K_2O per acre per year. Phosphorus removal rate ranged from 12 to 29 lbs of P_2O_5 per acre per year and was not affected by N fertilization.

In terms of fuel quality for combustion, nitrogen fertilization did not appear to influence ash content in switchgrass or the content of nitrogen, potassium or sulfur. Time of harvest did affect these parameters with the lowest levels occurring with delayed harvest until late October or November.

References

Cherney JH and VK. Verma. 2013. Grass pellet Quality Index: A tool to evaluate suitability of grass pellets for small scale combustion systems. Applied Energy 103: 679-684. http://dx.doi.org/10.1016/j.apenergy.2012.10.050

Mayton, Hilary, Julie Hansen, Ryan Crawford, Jamie Crawford, and Don Viands. 2011. Field-Scale Yield of Switchgrass Under Varying Nitrogen Management Treatments in New York State. Annual Meetings of the ASA-CSSA-SSSA Abstracts, San Antonio, TX. (2011 Madison, WI).

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For More Information on Grass Biomass, go to: http://pss.uvm.edu/vtcrops/?Page=energycrops.html

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