SWITCHGRASS RESPONSE TO NITROGEN: TRADE-OFFS BETWEEN QUANTITY AND QUALITY

M.D. Ruark, K. Bray-Hoagland, M.J. Renz, and R.D. Jackson
University of Wisconsin-Madison, Madison, Wisconsin

Abstract

In 2009 and 2010, a study was conducted at four locations in southwest Wisconsin to determine optimal nitrogen (N) fertilizer rates and harvest timings for switchgrass quantity and quality. The study was conducted as a randomized complete block, split plot design with five main plot treatments (0, 56, 112, 168, and 224 kg ha^{-1} of N) and three split plot treatments (mid-fall, late-fall, and early spring harvest). Dry matter (DM) yields increased between 2009 and 2010 and were most often maximized with 112 kg ha^{-1} of N. Later harvest timings decreased DM yield. Chloride (Cl^-) concentration was used as an indicator of switchgrass quality for biomass burning. The Cl^- concentrations decreased with decreasing N rates and progressively later harvest timings. Energy content of the switchgrass material (MJ kg^{-1}) was greater when harvested in the spring compared to the previous fall, but the overall energy yield (GJ ha^{-1}) was greater for the fall harvest. Overall, it is clear that there is a trade-off between switchgrass quantity and burning quality. Growers will have to work with energy producers in order to select the appropriate N rate and harvest timing that ensures optimum quality and quantity.

Introduction

Studies on harvest timing of switchgrass grown for bioenergy have found that switchgrass yields are maximized in the Midwest and Great Plains when harvested from mid-August to mid-September with a single end of the season harvest, (Vogel et al., 2002; Parrish and Fike, 2005; Shinners et al., 2010). In spite of this, maximum yield is often not desirable to energy producers because of elevated levels of non-beneficial fuel constituents in switchgrass harvested during late-summer (Prochnow et al., 2009). Other studies suggest that by delaying harvest later into the fall, winter or spring the concentration of non-beneficial fuel constituents in switchgrass decreases; however, significant yield losses are also noted with delayed harvests (Hadders and Olsson, 1997; Adler et al., 2006; Sanderson et al., 2006). Depending on the fuel quality parameters mandated by energy producers, growers will need to understand the trade-off between improved fuel quality and yield loss with delayed harvest. Balancing yield loss and fuel quality will be a necessary expertise for a viable bioenergy production system to emerge for switchgrass.

The on-farm management practices of switchgrass grown as a solid fuel for bioenergy production will differ from how it historically has been managed as a forage crop. Growers will need to work closely with energy producers to understand fuel quality parameter and how much those parameters can be controlled through N fertilizer application and harvest timing. Also, the quantity and extent that switchgrass bioenergy cropping is able to perform ecosystem services, as discussed by McLaughlin and Walsh (1998), lacks understanding and academic research. Bioenergy switchgrass management applied across larger tracts of land will provide laboratories and dictate how future academic research understands the potential and extent of ecosystem service from switchgrass cropping systems. This research attempts to understand optimal on-farm management practices to so that growers and power plant operators can maintain adequate quantity and quality of their respective products.

Materials and Methods

The study was conducted over two years (May 2009 to May 2011) across four sites in Grant County, WI, which is located in the Driftless Area of southwestern Wisconsin. Sites 1, 2 and 3 were located on a Dubuque silt loam (fine-silty, mixed, superactive, mesic, typic, hapludalf), and site 4 was located on a Hixton loam (fine-loamy over sandy-skeletal, mixed, superactive, mesic, typic, hapludalf). Switchgrass (Cave-in-Rock) was planted in May of 2008 on a field previously under row crop management. Switchgrass was mowed, but not harvested in the establishment year. The experimental design at each site was a randomized complete block, split-plot with four replications. The whole plot factor was N fertilizer (ammonium nitrate) rate which was applied on 18 June 2009 and 21 June in 2010. The whole plot N rates were 0, 56, 112, 168 and 224 kg $ha^{-1}$of N. The split-plot factor within the whole plot N rate treatments was harvest timing. The split-plot treatments were three harvest times: mid-fall, late-fall, and early spring. Harvest times for the 2009 growing season were 19 October 2009 (mid-fall harvest), 11 November 2009 (late-fall harvest) and 9 May 2010 (spring harvest). For the 2010 growing season, harvest times were 25 October 2010 (mid-fall harvest), 23 November 2010 (late-fall harvest) and 31 March 2011 (spring harvest). Whole plots were 3.0 × 9.1 m and split plots were 3.0 × 3.0 m. Switchgrass was harvested 15 cm above the soil surface, weeds were removed, and plant material was dried at 60°C to determine dry matter (DM) yield.

Tissue samples from the 0, 56, and 112 kg ha^{-1} N rate treatments for all three harvest treatments at sites 1 and 4 were analyzed for Cl^- concentration. Chloride was selected as an indicator of switchgrass quality because Cl^- can clog up boilers during burning. Chloride analysis was conducted by the University of Wisconsin Soil and Plant Analysis Laboratory (Madison, WI) using a digital chloridometer (LabConCo model # 442-5000, Labconco Corporation, Kansas City, MO). The thermal energy content of switchgrass from N rate treatments of 0 and 112 kg ha^{-1} was determined on a bomb colorimeter (Parr 1266 Isoperibol Bomb Calorimeter, Parr Instrument Company, Moline, IL).

Results

Yield

Dry matter (DM) yield of switchgrass ranged from 0.6 to 17.0 Mg ha^{-1} across treatments, sites and both growing seasons. There was one plot at spring harvest in the 2010 growing season where no switchgrass was collected because of a dominance of weeds. When averaged across sites and treatments by year, DM switchgrass yield improved from 5.5 Mg ha^{-1} in 2009 to 8.2 Mg ha^{-1} in 2010, an increase of 46%. The increase in switchgrass yield from the 2009 to 2010 growing season was expressed across all sites but was variable per site, with increases of DM Mg ha^{-1} ranging between 8% and 96%.

Nitrogen fertilizer positively increased switchgrass yield up to a rate of 112 kg ha^{-1} of N in both the 2009 and 2010 growing seasons when analyzed over all sites and harvest timings (Fig. 1). Averaged across harvest timing treatments in the 2009 growing season, the 112 kg ha^{-1} of N treatment produced a greater switchgrass yield than the 0 kg ha^{-1} of N treatment. The 112 kg ha^{-1} of N treatment produced a similar yield to the 56 kg ha^{-1}, 168 kg ha^{-1} and 224 kg ha^{-1} of N treatments. However, the 56 kg ha^{-1} of N treatment yielded less than the 168 and 224 kg ha^{-1} of N treatments. During the 2010 growing season, the 56 kg ha^{-1} of N treatment produced more switchgrass than the N rate of 0 kg ha^{-1}. The 112 kg ha^{-1} of N treatment yielded significantly more switchgrass than both the 0 and 56 kg ha^{-1} of N treatments and was not statistically different than yield the 168 or 224 kg ha^{-1} of N treatments.

Averaged across N rates, switchgrass yields were highest at mid-fall harvests in both the 2009 and 2010 growing seasons at 7.3 and 9.1 Mg DM ha^{-1}, respectively. In the 2009 growing season, yields significantly decreased with later harvest timings, relative to mid-fall harvest, to 5.4 Mg DM ha^{-1} at late-fall and 3.9 Mg DM ha^{-1} at spring harvest. Yield reductions across N rates were a reduction of 26% from mid-fall to late-fall harvest and a further reduction of 29% from late-fall to spring harvest (Table 1). During the 2010 growing season, switchgrass yield was not significantly different between the mid-fall and late-fall harvests. The switchgrass yield at spring harvest was 28% less than mid and late-fall harvest at 6.3 Mg DM ha^{-1}.

Quality

Chloride (Cl^-) was used as an indicator of switchgrass quality for burning. Averaged across harvest timings, concentrations of Cl^- in switchgrass were influenced by N rate treatments in both the 2009 and 2010 growing seasons (Fig. 2). Concentrations of N Cl^- in switchgrass increased with higher N rates (Fig. 2). Harvest timing treatment, when averaged across N rate, influenced concentrations of Cl^- in switchgrass grown during both growing seasons (Fig. 2). The concentrations of Cl^- had the greatest rate of decreased with each harvest in both the 2009 and 2010 growing seasons, falling by >70% from mid-fall to spring harvest.

Energy

The thermal energy content of switchgrass on a weight basis had low variability across treatments and years (CV=3%). The thermal energy content of switchgrass was not affected by N fertilizer rate or harvest timing with a mean thermal content of 18.3 MJ kg^{-1} (Fig. 3). The thermal energy yield from a hectare of switchgrass ranged from 60.0 to 230.1 GJ ha^{-1} across growing season, sites and treatments. When energy yield is averaged across harvest timing treatments, the thermal energy yield per hectare increased by 41% in 2009 and 38% in 2010 with the application of 112 kg ha^{-1} of N. Averaged across N rate, a harvest timing in the spring decreased the thermal energy yield decreased by 35% and 27% in the 2009 and 2010 growing seasons, respectively (Fig. 4). There was an interaction between N rate and harvest timing in 2010. While the mid-fall harvest's 0 and 112 kg ha^{-1} of N treatments were significantly different, spring's 0 and 112 kg ha^{-1} of N treatments were not significantly different from one another.

Conclusions

As a nascent industry, the bioenergy sector has a considerable opportunity for optimization of how it produces biogenic fuel sources and how they are utilized. By understanding how crop management strategies affect the quantity and quality of switchgrass grown as solid fuel for use in industrial boilers, growers and energy producers will be able to expect certain quantities of acceptable quality for energy production. Quantity on an area basis is improved by applying N fertilizer to switchgrass, and fuel quality is improved by delaying harvest. While N fertilizer does not strongly affect fuel quality, delaying harvest decreases yield and the potential of slagging, fouling and corrosion of boilers. On-farm management strategies for switchgrass to meet the goals of the grower and the energy producer will necessitate collaboration between the two parties. Growers will need to work with energy producers to balance the trade-offs between yield and improved fuel quality in establishing crop management strategies. Fuel quality parameters will be based on the type and tolerances of the energy conversion technology that the energy producer employs. Because yield is lost through fuel quality improvements with delayed harvests, premiums will need to be paid on higher quality fuel will be necessary for viable remunerative compensation to bioenergy switchgrass growers. The quantity and extent that switchgrass bioenergy cropping is able to perform ecosystem services for a region lacks understanding and academic research. Further research is not only needed in harvest equipment technology for bioenergy crops but also breeding programs to improve quantity and fuel quality. Small-plot research is less likely to encompass an understanding of the geo-spacial effects switchgrass cropping will have on a region's aquatic ecosystem. To perform this research, significantly larger areas will need to be put into switchgrass production.

References

Adler, P.R., M.A. Sanderson, A.A. Boateng, P.I. Weimer, and H.J.G. Jung. 2006. Biomass yield and biofuel quality of switchgrass harvested in the fall or spring. 98:1518-1525.

Hadders, G. and R. Olsson. 1997. Harvest of grass for combustion in late summer and in spring. Biomass and Bioenergy 12:171-175.

McLaughlin, S.B. and M.E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy 14:317-324.

Parrish, D.J. and J.H. Fike. 2005. The biology and agronomy of switchgrass for biofuels. Crit. Rev. Plant Sci. 24:423-456.

Prochnow, A., M. Heiermann, M. Plochl, T. Amon, and P.J. Hobbs. 2009. Bioenergy from permanent grassland – A review: 2. Combustion. Bioresource Technol. 100:4945-4954.

Sanderson, M.A., P.R. Adler, A.A. Boateng, M.D. Casler, and G. Sarath. 2006. Can. J. Plant Sci. 86:1315-1325.

Shinners, K.J., G.C. Boettcher, R.E. Muck, P.J. Weimer, and M.D. Casler. 2010. Harvest and storage of two perennial grasses as biomass feedstocks. Trans. ASABE 53:359-370.

Vogel, K.P, J.J. Brejda, D.T. Walters, and D.R. Buxton. 2002. Switchgrass biomass production in the Midwest USA: Harvest and nitrogen management. Agron. J. 94:413-420.

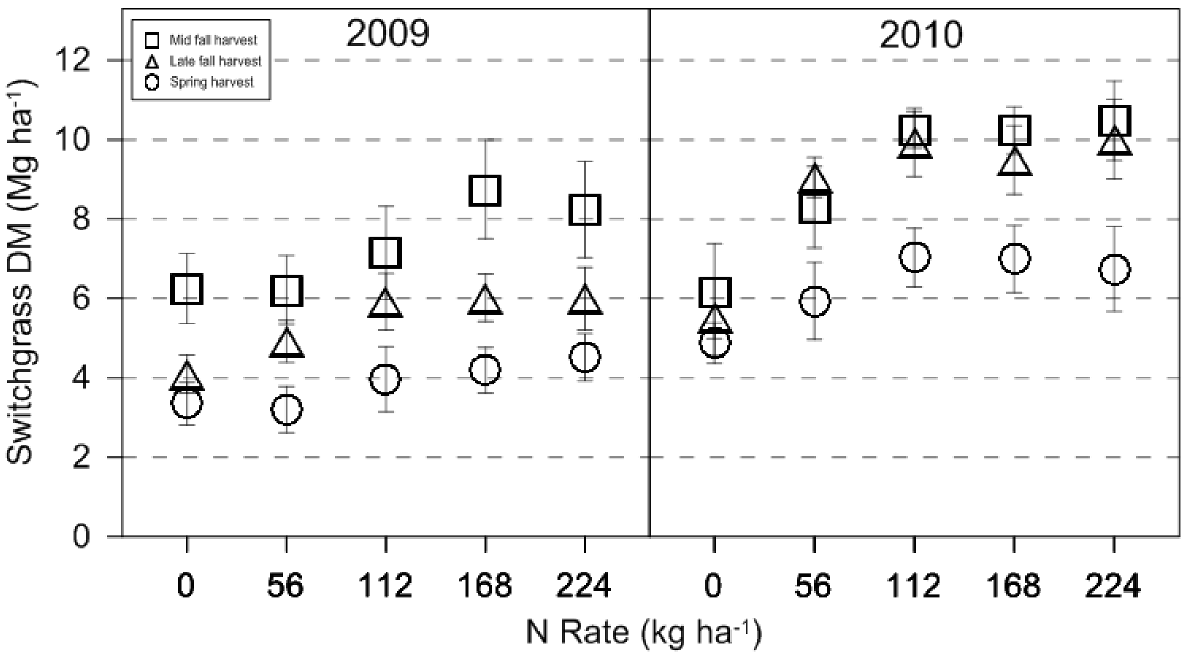

Figure 1. Average switchgrass DM yield (Mg ha^{-1}) in 2009 and 2010 for each harvest timing across each nitrogen (N) fertilizer rate. Data is averaged across all four sites. Error bars represent standard error.

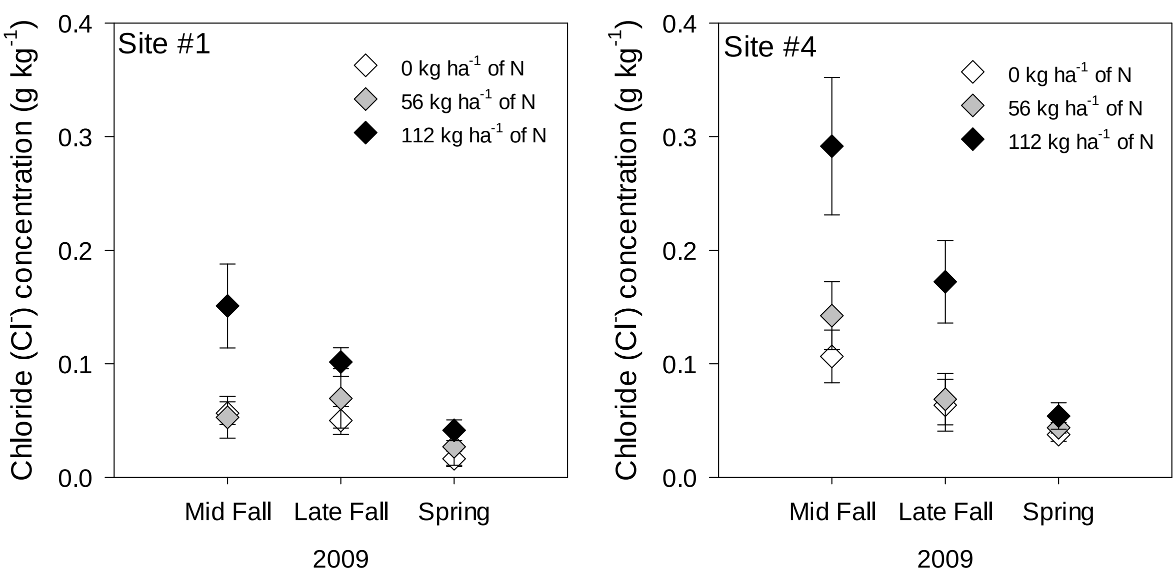

Figure 2. Average chloride (Cl^-) concentration in switchgrass for each harvest timing fertilized with 0, 56, or 112 kg ha^{-1} of nitrogen (N). Error bars represent standard error.

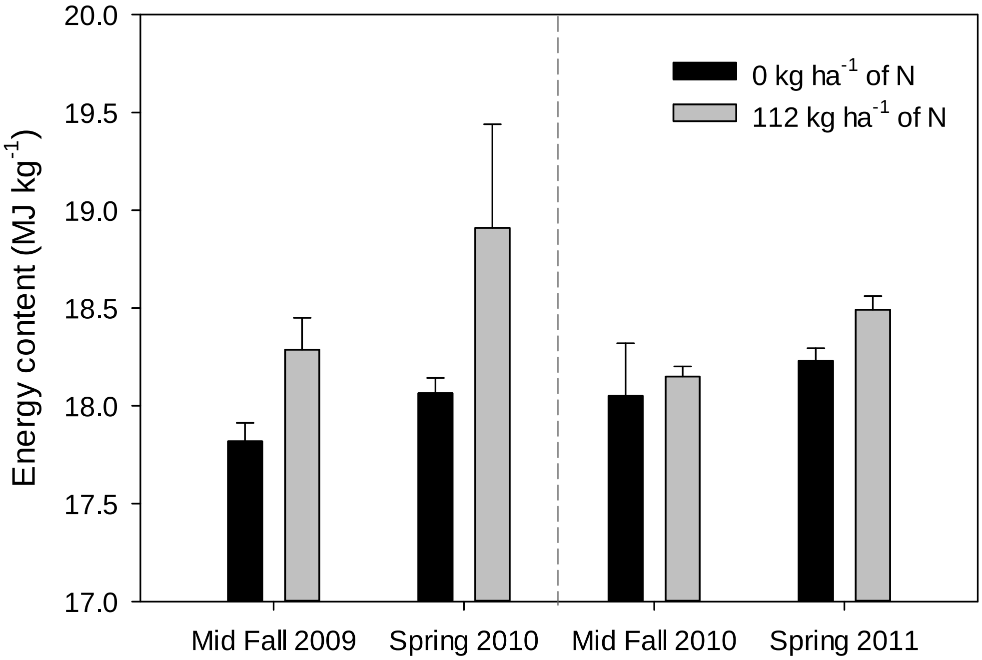

Figure 3. Energy content of switchgrass harvested in mid-fall or early spring and fertilized with 0 or 112 kg ha^{-1} of nitrogen (N) fertilizer. Error bars represent standard error.

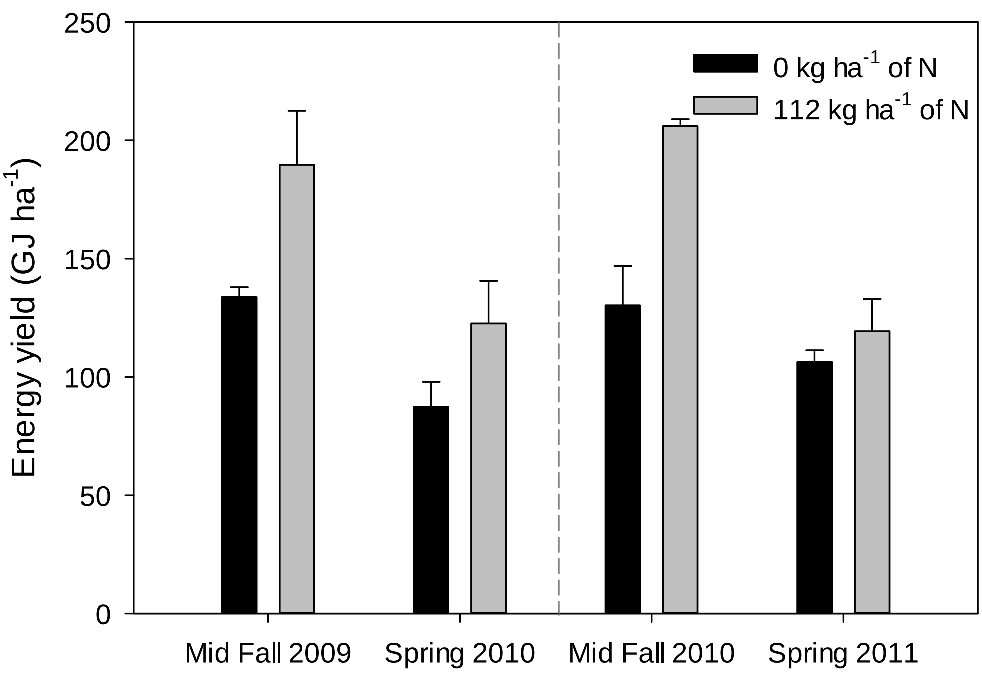

Figure 4. Energy yield of switchgrass harvested in mid-fall or early spring and fertilized with 0 or 112 kg ha^{-1} of nitrogen (N) fertilizer. Error bars represent standard error.

PROCEEDINGS OF THE

41^{st}

NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 27

November 16-17, 2011
Holiday Inn Airport
Des Moines, IA

Program Chair:

Peter Scharf
University of Missouri
Columbia, MO 65211
(573) 882-0777
scharfp@missouri.edu

Published by:

International Plant Nutrition Institute
2301 Research Park Way, Suite 126
Brookings, SD 57006
(605) 692-6280
Web page: www.IPNI.net