

# Developing a Portfolio of Sustainable Bioenergy Feedstock Production Systems for the US Midwest: A Research and Demonstration Project

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## Issue At Hand

The US is embarking on an aggressive agenda to reduce dependency on fossil fuels. In response, the demand for feedstocks for liquid biofuels will continue to grow into the foreseeable future. While the Energy Independence and Security Act of 2007 acknowledges that grain-derived ethanol will meet much of the initial need, cellulosic materials (Fig. 1) are mandated to provide a growing portion of our bioenergy feedstocks. While such “second generation” feedstocks show numerous potential advantages compared to grain-based systems—including reduced energy and nitrogen inputs, higher rates of energy return, greater soil carbon sequestration, and reduced greenhouse gas emissions—it is unlikely that a single cellulosic biomass cropping system will meet all of these purposes in all agroecosystems. A portfolio approach is needed. Potential systems to be included in the bioenergy feedstock portfolio need to be developed, tested, and compared to conventional systems prior to their implementation over local, regional, and national scales.



Fig. 1 – Switchgrass, a potential cellulosic feedstock, being harvested for bioenergy production (photo: John Sellers).

## What We Expect to Accomplish

*Our goal is to develop, refine, and implement a portfolio of sustainable bioenergy feedstock production systems that together contribute significantly to reducing dependence on foreign oil; have net positive social, environmental, and rural economic impacts; and are compatible with existing agricultural systems. To accomplish this goal, we are developing several alternative biomass cropping systems and comparing them to a conventional continuous corn system. Alternative cropping systems were chosen because of their potential to provide:*

- Superior biomass yields (Triticale /Sorghum);
- Some biomass yield while mitigating some negative environmental impacts (Corn-Soy-Triticale/Soy and Corn-Switchgrass); or
- Some short-term biomass yield and superior long-term yield while strongly mitigating negative environmental impacts (Triticale/ Trees).

As crop performance is strongly tied to site factors, we are evaluating these biomass cropping systems across a series of landscape positions (Fig. 2). Our results will eventually allow for optimized bioenergy feedstock production across agricultural landscapes.

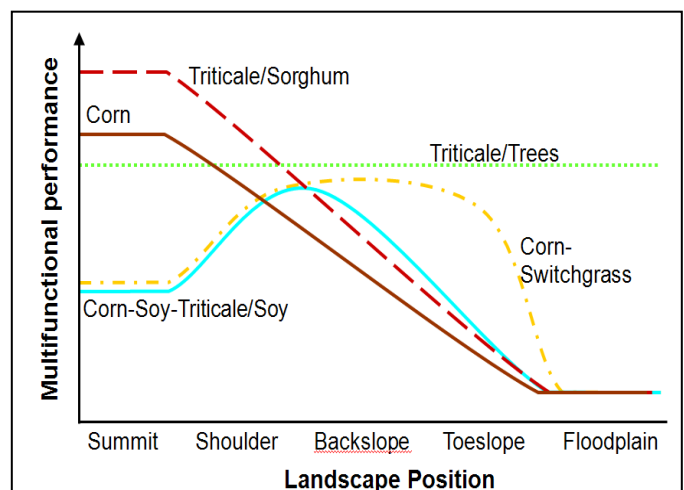


Fig. 2 - Hypothesized multifunctional (agronomic, economic, and environmental) performance of the experimental biomass cropping systems.

## How We Go About It

We have implemented a randomized, replicated block experiment that tests and compares the five cropping systems across five landscape positions (Fig. 3). Triticale was planted on a portion of the experimental plots in October 2008. The remainder of the cropping systems were established in April and May 2009. Our goal is to run the experiment for at least 10 years, beyond the initial harvest cycle for the tree-based system.



Fig. 3 – Experimental plots testing a portfolio approach to bioenergy feedstock production at the Iowa State University Uthe Farm, located in central Iowa.

Field and lab measurements evaluate and compare (1) energy/fertilizer inputs, (2) biomass outputs, (3) establishment, production, harvest, and transport costs, (4) water use and quality impacts, (5) above and belowground pools and fluxes of carbon and nitrogen, and (6) rates of greenhouse gas emissions across cropping systems and landscape positions.

Our project is also being extensively used for educational purposes. The experimental site, plus a demonstration site proximal to the Iowa State University BioCentury Research Farm, are being used to educate students, producers, individuals from the agribusiness and bioenergy industries, and the general public on the implementation, benefits, and costs of diverse, site appropriate biomass cropping systems.

To date, over two dozen undergraduate, graduate students, and post-doctoral fellows have received training on the project (Fig. 4). Those with degree-related research include:

- Theo Gunther (M.S. student in Agronomy),
- Sarah Hargreaves (Ph.D. student in Ecol. & Evol. Biol.),
- Josh Henik (M.S. student in Agronomy),
- Bill Headlee (Ph.D. student in Forestry),
- Todd Ontl (Ph.D. student in Ecol. & Evol. Biol.),
- Brandi Sigmon (Post-doctoral fellow),
- Wade Walsh (M.S. student in Biorenew. Res. & Tech.), and
- Ryan Williams (Ph.D. student in Ecol. & Evol. Biol.).



Fig. 4 – Members of our research and education team.

## Potential Impact and Expected Outcomes

The output of this project will be a robust platform for policymakers, investors, the agribusiness industry, farmers, and society at large to make informed decisions about potential cropping systems to include in a sustainable bioenergy feedstock portfolio.

## Acknowledgements

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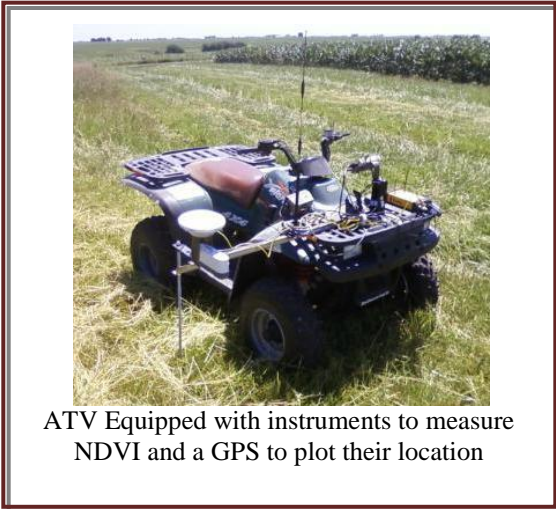
# Spatial Variability in Plant Stress as Influenced by Management

Joshua Henik, Allen Knapp Ph.D., Kenneth Moore Ph.D.

Iowa State University, Department of Agronomy

2011

Production agriculture has generally focused on managing cropping systems on large scales. This has often times been on a whole field basis of 80 or more acres. As technology has advanced and brought with it the opportunity to break fields into smaller management zones, the need has arose to understand how variability impacts crop production.



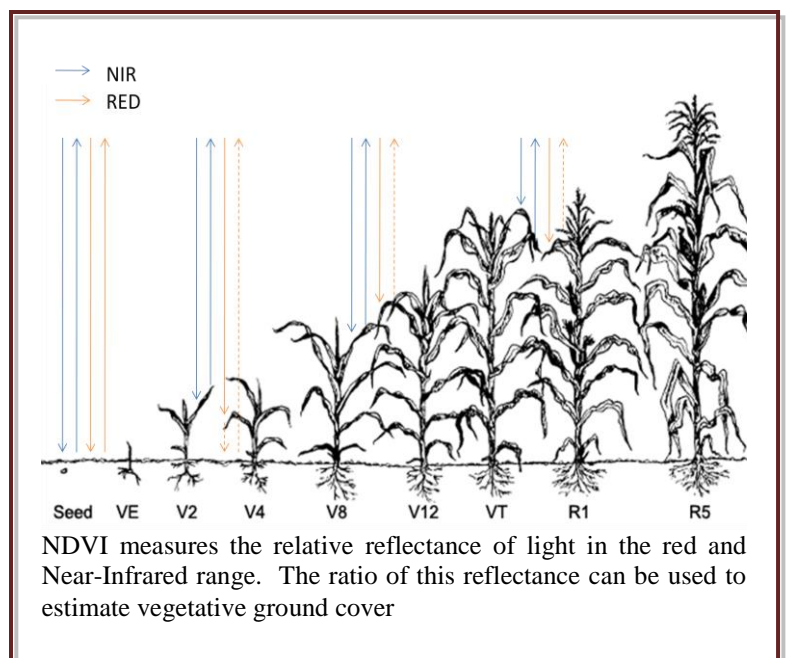
Much effort and research have been made on mapping and analyzing soil variability by incorporating soil testing and variable rate fertilizer application. Crop production is a highly intricate system with multiple inputs and sources of production differential. An area of study that hasn't been as intensively analyzed is a major source of energy for plant growth, sunlight. The major emphasis of this study has been to analyze light infiltration and canopy closure as it relates to plant growth and development across the landscape. This can be used as an indicator of in-season in-field variability. The question is: How can measuring, mapping, and understanding light variance across the landscape be utilized in understanding field variability and making

management decisions.

Utilizing remote sensing techniques we have been able to collect, compare, and contrast crop growth and development over the course of time and spatial location. The use of NDVI, a vegetative indice that has garnished notoriety through its use with variable rate nitrogen, has been a major focus of our research. After one season of data collection we have seen a relationship between timing of canopy closure and landscape position. This relationship can also be associated with fertility levels.

An addition to this years research has been the use of a spectrometer. Where NDVI measures two wavelengths in the visible spectrem to calculate an indicie, a spectrometer measures the reflectence across a broad range of wavelengths. This will allow us to calculate more indicies and positions. Through this addition we will be able to compare and contrast indicies and identify which acts as a better indicator of plant stress relating to final grain yield.

Understanding early and mid-season growth is key in making management decisions . Having the tools to accurately evaluate a crop is important. Remote sensing can act as a means for understanding plant growth and stress. Accurately associating the appropriate indicies with the management questions being asked is the goal of this research.



# The Effect of Landscape Position and Biomass Cropping Systems on Greenhouse Gas Emissions From Soil

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## How do agricultural soils contribute to greenhouse gas emissions?

As concerns about global climate change have increased, the need to assess the relative contribution of agricultural soils to greenhouse gas (GHG) emissions has grown in importance. The GHG issue has become of increasing concern as researchers strive for sustainable methods to produce biomass crops for biofuel production. The production of these gases is highly dependent on soil properties and plant-microbe interactions occurring belowground. Interestingly, not all cropping systems contribute equally to the production of greenhouse gases. There is some evidence suggesting that perennial systems may contribute less to GHG emissions than annual systems. Also, it is known that management practices like nitrogen fertilization can have a large impact on GHG's, especially nitrous oxide ( $N_2O$ ), which produces around 300 times the warming effect of carbon dioxide ( $CO_2$ ). Topographic position can also play a large role in GHG emissions. Greater emission of  $N_2O$  has been found under corn in cultivated floodplains largely due to environmental factors such as greater amounts of organic matter and soil moisture. Methane ( $CH_4$ ) is usually produced from waterlogged soils, but can actually be consumed in drier upland soils. However, the consumption of methane can be greatly inhibited by nitrogen fertilization. The combination of varying cropping systems and landscape positions at Landscape Biomass Project at Uthe Farm allows us to analyze the interactive effect of management and landscape on the production of greenhouse gases.



Figure 1- Gas Sampling at the Uthe Farm site involves taking air samples from chambers placed within the experimental plots. (photo: Brandi Sigmon)

## How do we measure greenhouse gas emissions?

At the Landscape Biomass Project we are interested in measuring emissions of  $CH_4$ ,  $CO_2$ , and  $N_2O$  from soil under different biomass cropping systems across an agricultural landscape. We are looking at two annual systems (corn on corn and a double crop of sorghum and triticale) along with a perennial monoculture (switchgrass). Gas measurements are taken within these cropping systems at three different topographic positions: an upland position (summit), and two lower positions (backslope and toeslope). Sampling occurs several times through the growing season to capture gases generated by soil microbes and  $CO_2$  produced through plant root respiration.

## What will this teach us about greenhouse gas emissions from soil?

The unique feature of the Landscape Biomass Experiment is our ability to generate data about the interaction between landscape position and cropping system on GHG emissions. Using chemical and biological properties (e.g. microbial biomass, available nitrogen and carbon), we hope to link emission data with other soil data to better predict where and when gas emits across the landscape and what plant and microbial factors drive their production. This information will help producers to make informed decisions about choosing cropping systems and where planting occurs topographically in order to minimize their effects on climate change.

# Landscape Biomass: water quality and soil moisture

Wade Welsh, Matthew Helmers, Xiaobo Zhou

## Overview/theory

Evaluating the water quality impacts of biomass production systems will allow us to assess the potential differences in dissolved nutrient loss and associated environmental impacts among the cropping systems. Systems with lower fertilizer input requirements and or longer periods of plant growth are expected to have lower concentrations of dissolved nutrients. Measuring the soil moisture associated with the systems will give us the information needed to determine the potential differences in the soil water dynamics and hydrologic impact of each production system. Systems with lower soil moisture during high rainfall periods are expected to have greater water storage, less surface runoff, and have less nutrient loss through subsurface water flow.

## Approach

Two suction lysimeters (PVC tube w/ porous cup on end at a depth of 60cm) are installed per plot. Vacuum is applied and water samples are extracted 1-2 weeks later (depending on precipitation). These are analyzed for  $\text{NO}_3\text{-N}$ , dissolved reactive phosphorus, and DOC. Overall, samples are taken once per month. Two access tubes (2" PVC) are installed per plot. Volumetric water content is measured at 20cm intervals to a depth of 1.2m once per month. Decagon devices have been installed this year that will give us soil moisture and temperature readings at a 5 minute interval for selected treatments and landscape positions (cont. corn, switchgrass, sorghum/triticale and summit, backslope, and toeslope).

## Preliminary results

We are still in the initial stages of analyzing the data but, it appears that the  $\text{NO}_3\text{-N}$  concentrations are associated with fertilizer inputs. We have seen relatively high concentrations early in the growing season in the corn plots and also following the planting and fertilization of sorghum (Figure 1).

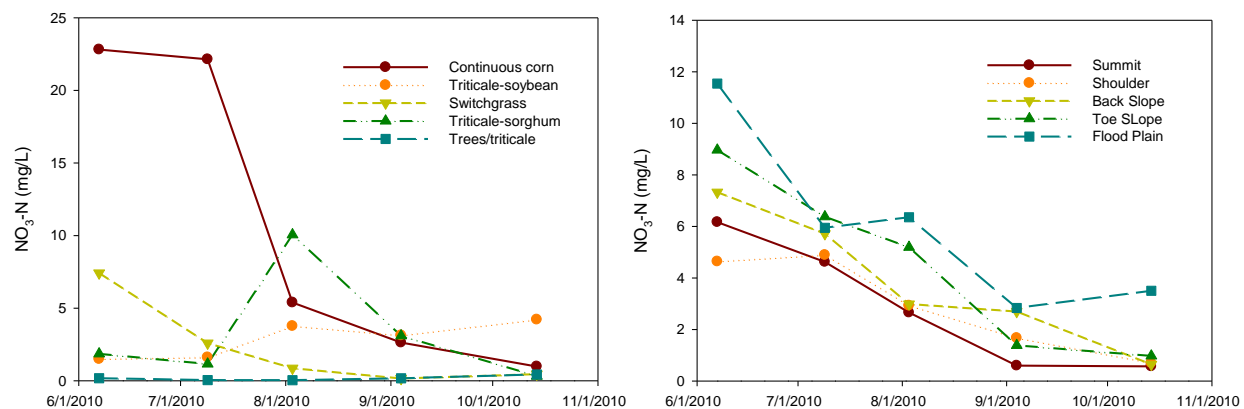


Figure 1:  $\text{NO}_3\text{-N}$  concentration by (a) treatment and (b) landscape position.

There has been little water quality difference among the landscape positions, but there is an indication of  $\text{NO}_3\text{-N}$  concentrations decreasing over time during the growing season and increasing as you move down the landscape (Figure 1b). It appears that there is a trend of increasing moisture content as you move down the hillslope. We have not collected and analyzed enough data to determine soil moisture differences among the cropping systems.

# Biomass Cropping Systems Productivity Across a Landscape Gradient

Theo Gunther *Graduate Researcher, Iowa State University Department of Agronomy*

**Overview:** Because it is unlikely a single cellulosic biomass cropping system will satisfy multifunctional performance criteria in all agroecosystems, we are comparing the performance of corn, switchgrass, sorghum/triticale, triticale/soybean and trees/triticale over a five landscape positions. Biomass samples are collected to represent the production of different feedstocks across the site. At the end of the 2011 growing season all treatments will complete a third growing season.

**Preliminary Results:** In 2009 corn was the superior yielding feedstock in all positions (Fig.2). Grain yield is significantly greater for continuous corn than corn with switchgrass (Fig.1). Over all corn treatments average there is no significant difference in grain yield between landscape positions (Table 1). Grain and stover yield was greatest in control. Proportional grain and stover fractions respective to landscape position and treatment are shown in Fig.1. Switchgrass underseeding reduced both total dry matter and grain yield with the greatest yield reduction occurring in the toeslope position. In spring following establishment year there were adequate switchgrass stands in most plots. Floodplain and backslope positions had the lowest stand frequencies on average (Fig.3).

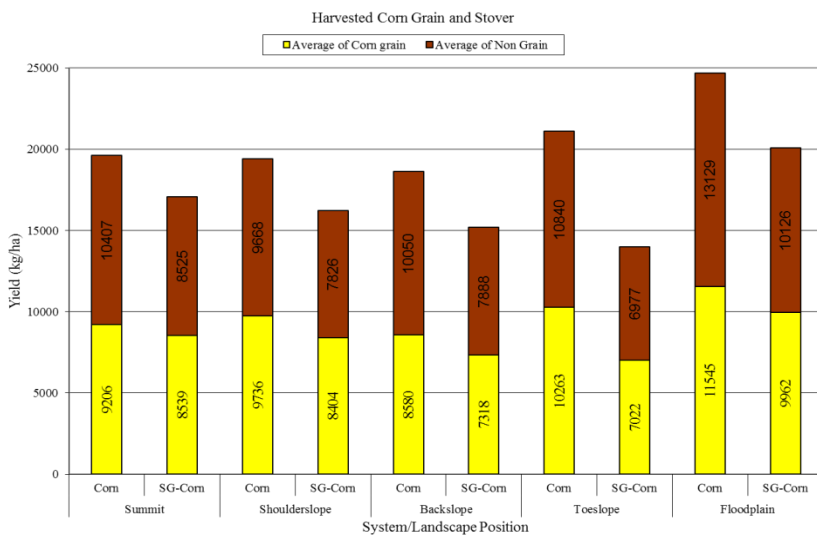


Fig. 1. Proportion of grain and non-grain in total dry biomass in 2009 corn treatments.

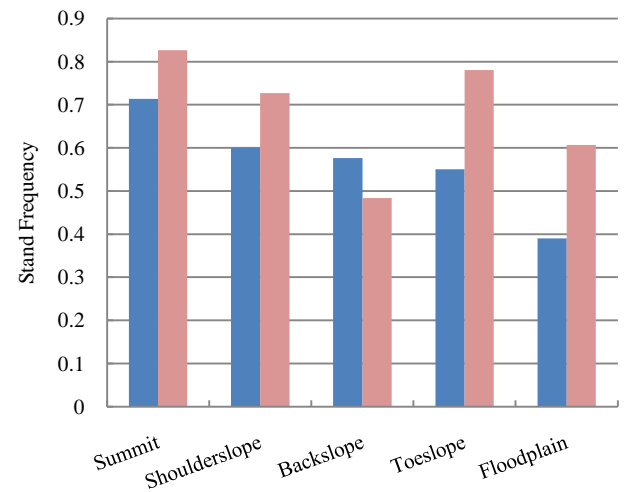


Fig.2. Switchgrass stand frequencies following establishment in corn

Treatment	Grain		Stover	
	Yield (Mg-ha <sup>-1</sup> )	Moisture (%)	Yield (Mg-ha <sup>-1</sup> )	Moisture (%)
Control	11.6 a	31.6 a	10.8 a	51.9 a
'Kanlow'	9.6 b	30.7 a	8.3 b	48.4 a
'CIR'	9.7 b	32.1 a	8.2 b	50.0 a
Position				
Summit	10.3 a	27.2 b	9.1 ab	34.4 b
Shoulder	10.4 a	31.1 a	8.4 b	49.3 a
Backslope	9.1 a	32.5 a	8.6 ab	52.2 a
Toeslope	9.5 a	33.5 a	8.2 b	54.4 a
Floodplain	12.3 a	32.9 a	11.1 a	60.4 a

Table 1. Summary of corn grain and stover yields and harvest moistures in 2009 at Uthe Farm, Boone County, IA.

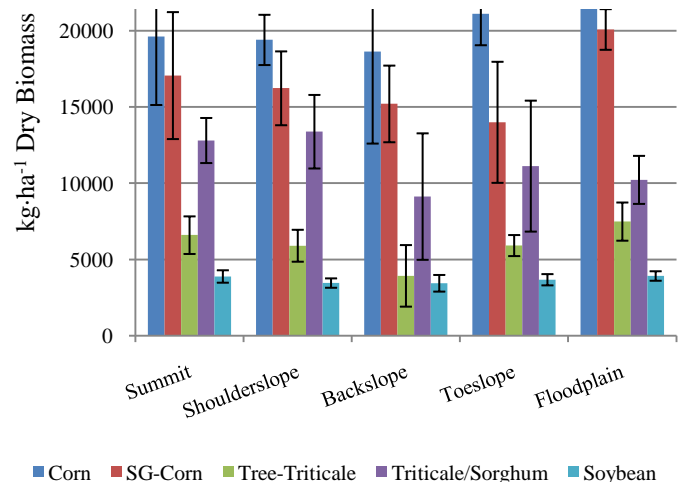
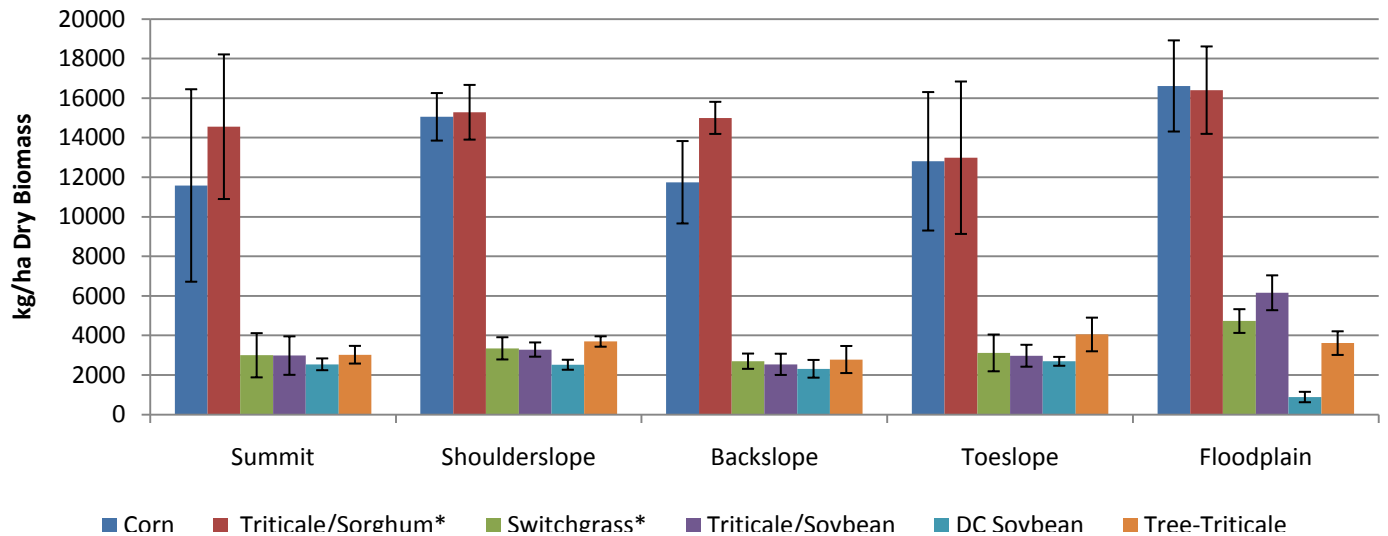


Fig. 3 2009 total dry biomass by treatment and landscape position. Error bars represent treatment standard deviation from landscape position average.



**Figure 4.** 2010 total dry biomass by treatment and landscape position. Error bars represent treatment standard deviation from landscape position average.  
 \*Average of two varieties of switchgrass and sorghum

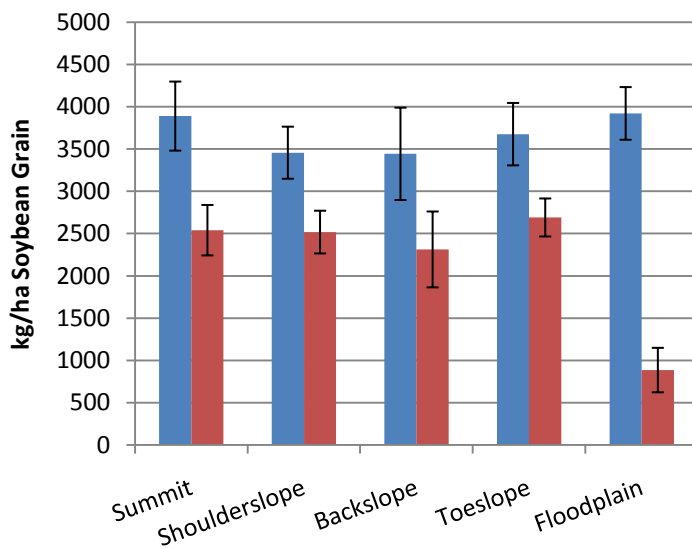


Fig. .5 Soybean grain yields years 2009 and 2010

In 2010, corn yield was reduced in all landscape positions. The triticale sorghum double crop had the highest average yield in all positions except the floodplain. Standard deviations of yield vary between landscape position and cropping system shown above as error bars (Fig.4). Switchgrass yield was lower than expected overall with differences between varieties (data not shown).

A comparison of full season soybean and late planted double crop following triticale are shown in in Fig.5. Yield reductions were greatest in the floodplain position which experienced flooding in August 2010. In both years the greatest variation and lowest yield was the backslope position. Floodplain soybeans were not of marketable quality with staining and underdeveloped seeds.

### Current Season

Expectations for 2011 are continuous corn yields stabilizing or continue to decrease slightly. The three year rotation includes corn this year which will make an interesting comparison. Switchgrass stands are in their second full season following establishment so an increase in above ground biomass is likely. The triticale-sorghum double crop system is no longer using multiple varieties and sorghum yields may increase slightly from values shown above. Triticale will no longer be used in an alley crop as a cover for tree establishment, with expected 2011 yield slightly lower than previous years.

**Trees and Triticale at the Uthe Farm**  
William L. Headlee and Richard B. Hall

**Prologue – Why hybrid aspen and triticale?**

- Wood is a preferred feedstock for producing pyrolysis bio-oils, and a good source of cellulose for ethanol production.
- Established trees provide many environmental services.
- Hybrid aspen has yielded 100+ dry tons/ac for 10-yr-old stands in Iowa<sup>1</sup>.
- Intercropping with triticale for first 3-4 years should improve timing of biomass availability and financial returns.

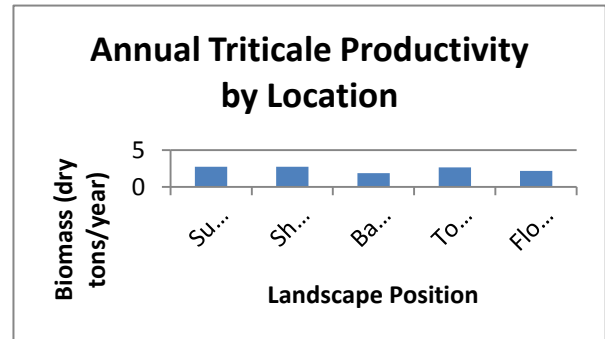


**Double Cropping for Energy Production**

- Maximum tree stem heights the second year ranged from 2.6 to 3.1 meters (8.5-10.2 ft).
- Tree productivity is highest on the toeslope (where moisture, fertility and soil quality are good) and is lowest on the backslope; excessive water and animal damage limit productivity on the floodplain.
- Root, stem, and total biomass were all increased by fertilization tablets added in the planting hole. The maximum fertilizer rate tested was 40 grams per tree (about 8 lbs N per acre).
- Triticale in the intercropped area yielded



from 1.75 to 3 tons per acre, depending on the landscape position. Yields were lowest at the backslope and highest at the summit.



**Epilogue – Where could this lead?**

- Contour belts of trees on steep erodible land with traditional crops in between.
- Harvested aspens re-sprout and should give even faster productivity in the subsequent sprouting cycles.
- Young sprout stands can be harvested with forage choppers.
- Trials of converting such tree stands back to row crops look promising.



**Re-Sprout Stand:** 120,000 stems/ac in late July after harvesting 1<sup>st</sup>-cycle trees in March

<sup>1</sup> Goerndt, M.E. and C. Mize. 2008. Short-rotation woody biomass as a crop on marginal lands in Iowa. North. J. Appl. For. 25(2):82-86.