Final Technical Report

Project Title: *Economic and Environmental Assessment of Switchgrass Production on High-Fertility Soil and an Assessment of Anaerobic Digests as an Intermediate Market for Switchgrass*

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Executive Summary

This project had two parts. Part 1 was an economic and environmental assessment of switchgrass production on high-fertility soil, and included an assessment of the effects of field irrigation with treated municipal wastewater (Studies A,C, and E in Final Agreement). Part 2 was an assessment of methods to enhance anaerobic digestion of switchgrass, and included evaluation of several other potential biomass feedstocks (Studies B and D in Final Agreement).

Results from Part 1 demonstrated that switchgrass does not compete economically against a corn and soybean rotation on highly productive soils. All four varieties of switchgrass lost money while corn and soybeans were profitable in all four years of this study. Breakeven prices for the four switchgrass varieties were calculated using production costs. The installation of a center pivot irrigation system had minimal impact on crop production and corn and soybean production remained profitable in the year the irrigator was installed. Because of drought and delays in installing the wastewater treatment plant, the irrigation system was not used until year 4 of this study. Therefore, longer term studies evaluating multiple year studies on the impact of irrigation on switchgrass are warranted. Results from irrigating with treated municipal wastewater showed no negative impact on soil quality.

Results from Part 2 demonstrated that anaerobic digestion (AD) of switchgrass could be significantly enhanced using low heat (100^{o}C) and mild caustic pretreatment without fine-grinding. Heat for pretreatment could be available from biogas-based combined heat and power (CHP) systems. In bench-top digesters simulating municipal wastewater treatment AD, methane production of coarse-ground switchgrass increased over 20-fold with pretreatment compared to untreated switchgrass. Bench-top studies simulating dairy-based AD also found high specific methane yield, but even untreated switchgrass digested reasonably well, indicating the value of AD micro-organisms acclimated to lignocellulosic feedstock. Similar results were found for corn stover. However, oak and maple leaves – representing common urban yard waste – were more resistant to digestion even with pretreatment. More pretreatment research is required before yard waste could become a significant feedstock for the low/medium-solids digesters common to municipal wastewater or livestock operations.

Accomplishments in Comparison to Project Objectives

Part 1 – Switchgrass on High Fertility Soil and Effluent Irrigation

The objectives of Part 1 can be summarized as follows:

1. Evaluate the feasibility for establishing and producing switchgrass at production scale on high fertility soils in comparison to the economic sustainability of A) an established corn and soybean rotation and B) switchgrass grown on marginal soils.
2. Evaluate the impact of center pivot irrigator installation on soil and crops.
3. Assess the value of future research on irrigation of switchgrass with municipal wastewater effluent.

4. Evaluate the feasibility for establishing and producing switchgrass at production scale on high fertility soils in comparison to the economic sustainability of an established corn and soybean rotation.
5. Evaluate the impact (agronomic, environmental, and economic) of irrigation of switchgrass with municipal wastewater effluent.
6. Evaluate the effectiveness of alternative fertility treatments on switchgrass grown on high-fertility soil.
7. Provide outreach to encourage Illinois farmers to grow switchgrass using recommended best management practices (BMP).

The accomplishments of Part 1 are included in Appendix 1. Key findings are summarized below.

1. Switchgrass plots were successfully established in the first year of the study and harvested in years 2-4. Corn and soybean rotations were grown in years 2-4. Corn and soybean production was profitable for all three years. For corn to be profitable during year 3 it did require the inclusion of the USDA Crop Revenue Charge payment. Swithgrass showed a negative return during each year of the study. The greatest loss was during the first year when it was being established. Yields were likely limited during year 3 from a severe drought and winter kill during the following winter may have also limited biomass production in year 4.
2. For switchgrass to compete with corn and soybean production on highly productive soils in Illinois either switchgrass yields will need to increase by more than 100% or the price would need to increase substantially.
3. Installation of the center pivot irrigation system had a minimal impact crop production.
4. Crops were irrigated during year 4 of the study. Soil samples were analyzed pre and post irrigation and the partially treated waste water was analyzed. Results showed no short-term effect on soil quality. Longer-term studies evaluating the impact of irrigation on soil and water quality and its impact on yield are recommended.

Part 2 - Pretreatment of Switchgrass and other Lignocellulosic Biomass for Anaerobic Digestion

The objectives of Part 2 can be summarized as follows:

1. Evaluate the effectiveness of switchgrass pretreatment on digestibility and methane production in bench-scale digesters. Pretreatment will utilize prolonged low-temperature heating - taking advantage of inexpensive waste heat available from CHP systems – plus dilute sodium hydroxide. Other factors to be evaluated include switchgrass particle size, ensiling, mixing, rinsing after pretreatment, alternative pretreatment chemicals, higher temperature and pressure, and digester feedstock (municipal sewage solids vs manure).

2. Evaluate the effectiveness of optimal pretreatment and digestion conditions found above on other potential large-scale, lignocellulosic biomass sources including corn stover and urban landscape waste.
3. Evaluate the potential for switchgrass and the other biomass sources evaluated above to be utilized economically in existing anaerobic digesters.
4. Identify the most promising areas of future research, including application of biomass pretreatment in larger-scale digesters.

The accomplishments of Part 2 are presented in three manuscripts, two published and one submitted for publication. These are listed as publications 1-3 in the Publications section later in this report. However, the most important results can be summarized as follows:

1. Batch and continuous-feed digestion studies demonstrated that low-heat (100^{o}C) and mild alkaline conditions can significantly improve digestion and methane production from coarse-ground switchgrass and corn stover without operational problems related to mixing or floating debris even under conditions of minimal mixing (typical of farm-based plug flow digesters). However, oak and maple leaves, typical of urban landscape waste in the Midwest, did not show significant improvement.
2. Acclimation of digester micro-organisms may be a valuable tool in improving the digestion of biomass feedstocks. Methane yield from untreated, coarse-ground switchgrass was more than 20-fold greater when seed culture was obtained from a dairy digester as compared to a municipal wastewater digester.
3. Declining prices for natural gas and generally low prices for power purchase agreements are the most important factors limiting the economic value of co-digestion of switchgrass, corn stover, and other lignocellulosic biomass sources. These factors limit the revenue potential of increased biogas production if the biogas is to be used to generate electricity in CHP units. Alternative uses for biogas – such as vehicle fuel, methanol production, or other high-value products – could increase revenue, but would also increase costs of pretreatment since CHP waste heat would no longer be available.
4. Costs for switchgrass, corn stover, and other energy crops or agricultural residues could decline with the advent of more productive varieties and improved harvesting technology. However, given the currently low revenue potential from biogas, the most promising lignocellulosic feedstocks may be wastes, such as urban landscape wastes, that could provide “tipping fee” revenue in addition to biogas. Effective pretreatment methods for these wastes, allowing them to be co-digested in existing, liquid-state digesters, represents a potentially valuable path for future research. The potential for acclimating digester micro-organisms to such wastes should be explored.
5. A side benefit of the research on thermo-chemical pretreatment was the discovery of a method for using gypsum to replace sulfuric acid in ammonia wastewater stripping/recovery technology. The method allows recovery of dilute ammonia (<3,000 ppm) in the stripping exhaust and production of ammonium sulfate fertilizer without the use of sulfuric acid. This method could be used to supplement revenues for anaerobic digesters and reduce the environmental impact of digester effluent.

Project Activities

Part 1 – Switchgrass on High Fertility Soil and Effluent Irrigation

For switchgrass production to be adopted on highly fertile soils in Illinois it must compete economically with corn and soybean production. This study provided an economic comparison of growing four different varieties of switchgrass to that of a corn/soybean rotation on highly productive soils in Illinois. Switchgrass plots were established and yields and an economic assessment comparing switchgrass production to that of a corn/soybean rotation were evaluated. Additionally, the impact of installing an irrigation system and the impact of irrigation on soil quality was evaluated.

While the study was conducted for four years, a severe drought during the summer of 2012 coupled with winter kill to the switchgrass plots may have severely limited yields during years 3 and 4. Irrigation during the summer of 2012 would have likely enhanced switchgrass yields. However, because of the drought, water evaporation from the reservoir with partially treated waste water prevented irrigation until the summer of 2013.

While utilizing partially treated wastewater may be beneficial to crop production, its impact on soil and water quality must be evaluated. Soil samples collected during year 4 before and after irrigation showed no impact on soil quality and samples of the partially treated wastewater did not indicate any immediate threat to soil and water quality. Additional studies will clearly need to be conducted to evaluate the long-term impact of using partially treated wastewater on soil quality.

The only objective that was not accomplished from Part 1 of this study was to conduct two field days in years 2 & 3 following irrigation to evaluate the impact of irrigation on biomass production and soil land water quality. This objective was not completed because of the delay in completion of the wastewater treatment facility and the delay in filling the reservoir due to evaporation during the drought as stated above.

Details of the data collected and analysis can be found in Appendix 1.

Part 2 - Pretreatment of Switchgrass and other Lignocellulosic Biomass for Anaerobic Digestion

During the planning and early implementation of this project (2007-2008), natural gas and petroleum prices were high and anticipated to remain so. These factors were expected to drive demand for cellulosic ethanol. The "chicken-or-egg" dilemma for cellulosic ethanol is that it is difficult to support production of energy crops, such as switchgrass, without ethanol plants ready to purchase those crops; yet it is difficult to raise the capital to build cellulosic ethanol plants without existing energy crop acreage. This research was intended to help circumvent this dilemma by exploring an alternative, interim market for switchgrass and other energy crops: existing anaerobic digesters. If the energy crops could be co-digested in existing digesters, increasing biogas production, revenues could potentially support increasing energy crop acreage in the near term. Over time, energy crop availability could encourage cellulosic ethanol plant construction, and anaerobic digesters could potentially move to biomass less suitable to ethanol production, such as urban landscape waste.

Subsequently, economic recession reduced energy prices and restricted capital markets, slowing cellulosic ethanol development. Widespread adoption of hydraulic fracturing technology further reduced natural gas prices, limiting potential revenue to anaerobic digesters from increased biogas production. While these changes have extended the timeframe for transition to renewable fuel sources, the basic premise for this study – that anaerobic digestion could serve as a valuable market for lignocellulosic biomass – continues to hold true.

Because lignocellulosic material is inherently resistant to microbial degradation, the focus of Part 2 of this research was effective and economical pretreatment that could enhance digestion and methane production. Extensive batch and continuous-feed bench-top studies were planned around the most promising pretreatment approach based on literature available at the start of this study: alkaline pretreatment using conditions of mild heat (100^{o}C). A key advantage of this pretreatment method is that waste heat from combined heat and power (CHP) units – commonly used with anaerobic digestion – could be used to provide the heat needed for pretreatment. This could be done with little energy penalty since the hot feedstock would help maintain digester temperature.

Research activities progressed largely as planned, with the bulk of activities focused on batch and continuous-feed bench-top studies of various biomass feedstocks, pretreatment conditions, seed cultures, and digestion conditions. One significant unanticipated insight from exploring the chemistry underlying the thermochemical pretreatments evaluated in the study was a method for using gypsum as a substitute for sulfuric acid in ammonia wastewater stripping/recovery technology.

Details of results and conclusions from Part 2 can be found in manuscripts 1-3 listed under Products below.

Products

A. Publications
   1. Guang Jin, Thomas Bierma & Paul Walker (2012): Biogas production from switchgrass under experimental conditions simulating U.S. digester operations, Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 47:3, 470-478.
   2. Guang Jin , Tom Bierma & Paul M. Walker (2014) Low-heat, mild alkaline pretreatment of switchgrass for anaerobic digestion, Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 49:5, 565-574.
   3. Guang Jin & Tom Bierma (Submitted) Low-heat, mild alkaline pretreatment of bioomass for dairy anaerobic co-digestion, Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes.

B. Technologies/Techniques

The technique developed for anaerobic sampling of bench-top digesters is unique to the best of our knowledge. The method is described in each of our publications (publications 1-3 above).

C. Inventions/Patent Applications/Licensing Agreements

Provisional Patent: A Method for the Capture of Ammonia and Production of Ammonium Sulfate Fertilizer from Gas with Low Concentrations of Ammonia and Carbon Dioxide, Thomas Bierma and Guang Jin, Illinois State University

Appendix 1
Results for Part 1 by Study Objective

1. Analysis of yield and cost of establishing and producing switchgrass on high fertility soil in comparison to an established corn and soybean rotation for all crop years.

An economic analysis has been completed for the first four years of production, year one (the establishment year for switchgrass) and production years two, three and four.

Forty acres of switchgrass, 160 acres of corn and 120 acres of soybean were seeded into a 320 acre high productivity field located in northeast McLean County. Figure 1 depicts the shape of the field site, location of the switchgrass plots relative to the fields containing the corn and the soybean rotation and the location of the two 160 acre center pivot irrigators. Figure 2 shows the experimental design for the switchgrass plots. The 40 acres was divided into 12 – 3.3 acre plots. The primary soil types within this 320 acre field are 171 B Catlin silt loan (2 to 5% slope) 38.1%, 223 B2 Varna silt loam (2 to 4% slope) 22.7%, 232 A Ashkum silty clay loam (4 to 6% slope) 23.9% and 614 B Chenoa silty clay loam (2 to 5% slope) 9.8%. The drainage class for these soils is moderately well drained to poorly drained and the frequency for flooding and ponding is none. Switchgrass was sowed into 12 – 3.3 acre plots using four varieties replicated 3 times without vegetative boundaries around each plot, thereby making one continuous 40 acre field of switchgrass. Four cultivars of switchgrass were evaluated. Cave-In-Rock and Blade 2101 are upland types and Kanlow and Blade 1102 are lowland types.

Figure 1. Field Shape Planted Into Switchgrass, Corn and Soybean

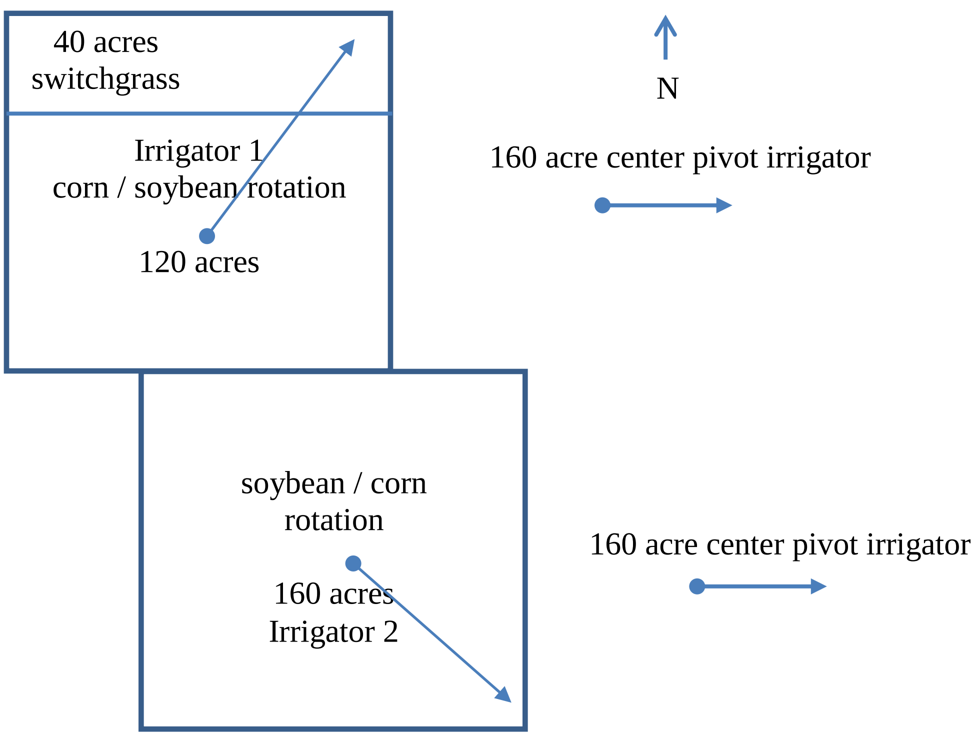
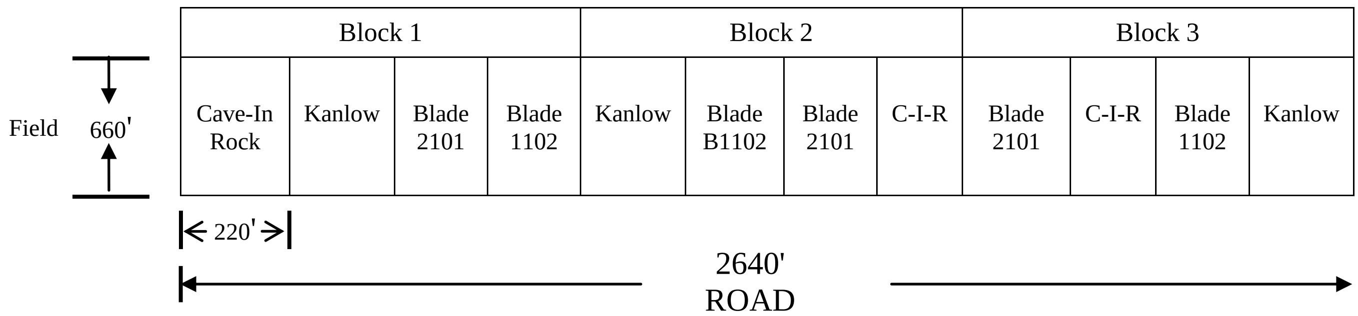


Figure 2. Forty Acre Field Planted Into Twelve 3.33 Acre Switchgrass Plots



The following is a summary of the data collected during the four years of switchgrass establishment.

Costs for field operations were taken from the University of Illinois Machinery Cost Estimates published in the April 2010 Farm Business Management www.farmdoc.uiuc.edu. Prevailing local rent ($:acre) of $205:acre was used and the source was McLean County Extension, Average Land Rent for McLean County. Table 1 shows individual management operation costs used to calculate expenses.

The cost:acre, income:acre and net return:acre for corn, soybean and switchgrass production was calculated using actual production costs. Table 1 compares the profit/loss per acre for producing corn, soybean and switchgrass during the first year of establishing switchgrass. Soybeans generated more dollars in net return per acre ($331.46) than corn ($274.84) but both corn and soybeans far exceeded switchgrass in net return:acre. There was insufficient switchgrass growth to harvest and still provide sufficient vegetation to prevent winter kill. Therefore, there was no return per acre for switchgrass during the first year of establishment. This suggests that the $452.49 cost:acre to establish switchgrass must be recovered during the second year of production or should be amoritorized over several years of future production. Assuming interest on debt is 4% and the cost of establishing switchgrass in year one is amortized over 4 years; each of the first four years of switchgrass harvest must pay $124.66:acre $498.64 total cost of establishing the stand in addition to other annual costs of production/harvest/marketing.

Table 1. Expenses, Income, Net Return For Switchgrass Year 1

Management Operations	Cost: Per Acre ($)	Income: ($)	Net Return: Acre ($)
Mowing (corn stalks)	13.20		
Field Cultivator (2 times at $8.80, Spring)	17.60		
Culti-Pack	8.80		
Planting (Brillion Seeder)	11.40		
Mowing (2 times at $13.20, July and Aug)	26.40		
2,4-D Herbicide Application	5.50		
Rent	205.00		
Seed (Blade 1102)	237.50		
Seed (Blade 2100)	133.00		
Seed (Cave-In-Rock)	123.50		
Seed (Kanlow)	171.00		
Totals Based on Seed Variety			
Total Per Acre (Blade 1102)	525.40	0	-525.40
Total Per Acre (Blade 2100)	420.90	0	-420.90
Total Per Acre (Cave-In Rock)	411.40	0	-411.40
Total Per Acre (Kanlow)	458.90	0	-458.90
Mean Per Acre (for all varieties included)	452.49	0	-452.49

Using the $124.66:acre actual cost to establish switchgrass we can estimate the return per acre for years two, three, and four; assuming the cost to mow switchgrass is $18:acre and the cost to bale 1,500 pound switchgrass bales is $12:bale. The cost of production per acre when harvesting 3 ton, 4 ton, 6 ton or 8 ton of switchgrass is $190.66, $206.66, $238.66 or $270.66, respectively. The break even cost per ton to produce switchgrass is estimated at $63.55, $51.67, $39.78 or $33.83 when the yields are 3 ton, 4 ton, 6 ton or 8 ton:acre. For 1,500 pound big round or big square bales these values correspond to $47.66 (3T:ac), $38.75 (4T:ac), $29.83 (6T:ac) or $25.37 (8T:ac) per bale cost of production, assuming FOB in the field (i.e. no charge for hauling is included). If 1,500 pound switchgrass bales sell for $40 each, producing 3T:ac loses $30.64 per acre; 4T:ac nets $6.67 per acre; 6T:ac nets $81.36 per acre; and 8T:ac nets $156.05 per acre. Currently big round straw bales are selling for $60:ton in the McLean County, Illinois area. During the year of establishing switchgrass, switchgrass production on high fertility soil does not appear to compete with either corn or soybean production (Table 2). In order to return the same net dollars per acre as soybean ($331.46) or corn ($274.84) Table 3 shows the estimated (predicted) value for switchgrass per ton. Even at 8 ton:acre yield switchgrass must receive $18.19 to $24.26 per ton more than for what straw was currently selling ($50:ton).

Table 2. Overall Analysis Per Acre - Year 1, Establishment of Switchgrass

Column 1	Switchgrass	Soybeans	Corn
Expenses/Acre	$452.49	$294.94	$565.88
Income/Acre	$0.00	$626.40	$840.72
Profit/Acre	-$452.49	$331.46	$274.84

Table 3. Value of Switchgrass ($:Ton) To Return The Same Net Dollars Per Acre As Corn Or Soybean Production Based On Year 1 Production

	3T:ac	4T:ac	6T:ac	8T:ac
Equivalent to Soybean (net return = $331.46:ac)	174.04	134.54	95.02	74.26
Equivalent to Corn (net return = $274.84:ac)	155.16	120.38	85.59	68.19

Tables 4 and 5 contain the expenses and income per acre respectively for switchgrass for years 2-4 of production. The rent charge for year 3 rose $75:acre to $280:acre. Fertilizers were added at rates that would replace nutrient loss from harvested biomass. The value of wheat straw bales for comparative pricing of mature baled switchgrass was $80:ton for year 3 and $60 in year 4. Baling cost:acre was reduced in year 3 due to decrease in yield (tons:acre) of switchgrass because of drought. However, total expenses per acre increased for year 3 and 4 over year 2 because of the increased rent charge. Yield of switchgrass decreased almost 1,400 pounds:acre in year 3 from year 2and rebounded slightly in year 4. Income per acre increased for year 3 and 4 over year 2 even though yield (tons:acre) of switchgrass decreased due to increased value of straw (switchgrass) bales. Because the switchgrass is mature in late fall when harvested and its nutritional value is similar to wheat straw, the local price (McLean County, IL) of wheat straw was used to calculate a comparative value of switchgrass. Table 6 provides a summary of the net loss per acre for switchgrass during years 1, 2 and 3. The greatest loss per acre occurred for year 1, the establishment year, when no switchgrass was harvested. Economic losses realized in years 2 and 3 were similar but less than in year 1. Overall, $893.23 was lost per acre in producing switchgrass (Table 6). To break even when switchgrass is valued at $80:ton, the yield per acre would have to be approximately 14.2 tons, greatly exceeding the yields observed in this study. While it was expected that swithcgrass yields would increase during years 3 and 4, it appears that the drought during year 3 and winter damage to the swithgrass stand prior to year 4 limited yields during these years.

Table 4. Mean, Expenses, Dollars Per Acre For Switchgrass Years 2 -4

Item	Year 2	Year 3	Year 4
Rent	205.00	280.00	280
Burned	0.00	—	—
70 lbs. of N/acre – Broadcast application	4.30	4.30	4.30
70 lbs. of N/acre – Urea Cost (46-0-0)	0.45	0.45	0.45
Atrizine (1qt/acre) – Application	4.30	—	—
Atrizine (1qt/acre) – Atrazine	4.00	—	—
Mowing	20.70	20.70	20.70
Raking	9.50	9.50	9.50
Hauling Hay	14.11	11.40	12.50
Round Baling Hay	54.21	43.80	46.75
Total Expenses	316.57	370.15	373.65

Table 5. Mean Income Dollars Per Acre for Switchgrass years 2-4

	Year 2			Year 3			Year 4		
Variety	Tons/ acre	$/Ton	Gross Income	Tons/ acre	$/Ton	Gross Income	Tons/ acre	$/Ton	Gross Income
Blade 1102	4.2	50.00	208.00	3.1	80.00	248.00	2.8	60.00	168.00
Blade 2101	4.0	50.00	200.50	3.0	80.00	240.00	4.3	60.00	258.00
Cave-In-Rock	2.9	50.00	143.00	2.5	80.00	200.00	3.9	60.00	234.00
Kanlow	3.8	50.00	191.00	3.5	80.00	280.00	3.0	60.00	180.00
Average	3.7	50.00	185.63	3.02	80.00	242.00	3.51	60.00	210.00

Table 6. Average Profit / Loss in Dollars Per Acre For all Switchgrass Varieties Years 1-4

Year	1	2	3	4	Total
Expenses ($)	454.49	316.57	370.15	373.65	1,512.86
Income ($)	0.00	185.63	242.00	210.00	637.63
Loss ($)	-452.49	-130.94	-128.15	-163.65	-875.23

Tables 7, 8 and 9 show the expenses, income and profit/loss obtained in years 2 - 4 for corn production. Rent, seed, fertilizer and crop revenue coverage / hail insurance expenses were higher in year 3 and 4 than in year 2. Primary tillage, combining and grain hauling costs were lower for year 3 compared to year 2 and 4, primarily due to reduced corn yield (bushel:acre).

Consequently, production expenses were higher in year 3 and 4 than in year 2. Despite higher value per bushel, $6.59 vs. $5.71, for no. 2 yellow corn grain during year 3 compared to year 2, less income per acre was generated for year 3 than for year 2 because significantly less corn grain per acre was harvested and although yield increased in year 4, the lower selling price per bushel reduced its profit (Table 9). Without the USDA Crop Revenue Charge (CRC) payment, corn production lost $185.66:acre during year 3. When the CRC payment (guaranteed 148 bu:ac yield minus the 87.2 bu:ac harvested value at $7.50:bu) of $455.85:acre is included corn production realized $270.19 net profit for year 3 (Table 9) compared to $502.78 in year 2.

Table 7. Expenses (Dollars Per Acre) For Corn Years 2-4

Item	Year 2	Year 3	Year 4
Rent	205.00	280.00	280.00
Chisel Plow	12.80	—	—
Filed Cultivator	8.80	8.80	8.80
Planting (No-till Drill)	14.60	14.60	14.60
Seed	106.73	110.00	114.00
36-92-120	50.27	143.08	144.09
Durango Herbicide Application	22.35	25.77	26.02
Lexar Application	18.83	22.64	23.16
Side Dressed 156 # N	52.22	89.87	91.56
CRC & Hail Insurance	—	13.10	13.10
Combine	35.80	35.80	35.80
Grain Cart	8.80	8.80	8.80
Grain Hauling (0.09/Bushel)	16.70	7.85	19.57
Total Expenses	552.90	760.31	779.50

Table 8. Income (Dollars Per Acre) For Corn Years 2 - 4

Item	Year 2	Year 3	Year 4
Price / Bushel ($)	5.71	6.59	4.41
Bushels / Acre	184.9	87.2[a]	217.4
Subtotal		574.65	
CRC Payment[b]		455.85	
Income / Acre	1,055.68	1,030.50	958.73

[a]Actual yield
[b]USDA Crop Revenue Coverage guaranteed yield was 148 bu:acre, therefore the 60.78 bu:acre difference guaranteed at $7.50:bu = $455.85.

Table 9. Profit / Loss (Dollars Per Acre) For Corn Years 2 And 3

Item	Year 2	Year 3	Year 4
Expense	552.90	760.31	779.50
Income	1,055.68	1,030.50	958.73
Profit	502.78	270.19[a]	179.23

[a]Without CRC, the loss per acre was -$185.66

Tables 10, 11 and 12 contain the expenses, income and profit values, respectively, of soybean production for years 2 - 4. Rent, herbicide, seed, CRC and hail insurance expenses were higher in year 3 and 4 than in year 2. Only grain hauling was less expensive during year 3 than in year 2 and 4 due to lower yields. Primarily due to increased rent, cost of production per acre for soybean was higher in year 3 and 4 than in year 2. Gross income per acre was higher in year 3 compared to year 2 even though yield per acre was significantly lower due to increased value per bushel of soybean, comparing $15.62:bu in year 3 to $11.70:bu in year 2. However, net profit per acre was similar comparing $384.33 to $387.72 for year 2 and year 3, respectively. Due to the decrease in selling price of soybeans in year 5 the profit decreased compared to years 2 and 3.

Table 10. Expenses (Dollars andAcre) For Soybeans Years 2 And 3

Item	Year 2	Year 3	Year 4
Rent ($)	205.00	280.00	280.00
Burndown Herbicide Durango and 2, 4-D	12.79	14.94	15.27
Seed	24.62	54.14	54.14
Planting (No-till Drill)	14.60	14.60	14.60
Power Max and Fusilidae dx Applied	13.31	13.66	16.88
CRC & Hail Insurance	—	13.32	13.32
Combine	31.40	31.40	31.40
Grain Cart	7.40	7.40	7.40
Grain Hauling ($0.09/Bushel)	5.38	4.74	5.10
Expenses ($;acre)	314.50	434.20	438.11

Table 11. Income (Dollars Per Acre) For Soybeans Years 2 And 3

Item	Year 2	Year 3	Year 4
Price / Bushel	11.70	15.62	12.70
Bushels / Acre	59.70	52.60	56.7
Income / Acre	698.84	821.92	720.09

Table 12. Profit / Loss (Dollars Per acre) For Soybeans Years 2 And 3

Item	Year 2	Year 3	Year 4
Expense	314.50	434.20	438.11
Income	698.84	821.92	720.09
Profit	384.34	387.72	281.98

Table 13 provides a comparative economic summary for years 2 - 4 between corn, soybean and switchgrass production. Soybeans had the greatest profit per acre during the three years averaging $351.35 per acre followed by corn at $317.40. However, if there is a bright spot for switchgrass production, it is that during a drought year without CRC, corn grain production can lose more money per acre than switchgrass production (Table 14).

Table 13. Overall Analysis Year 2 - 4 ($:acre)

Item	Switchgrass	Soybeans	Corn
Expense / Acre	353.46	395.60	697.57
Income / Acre	212.54	746.95	1,014.97
Profit / Acre	-140.91	351.35	317.40

Table 14. Overall Analysis Year 3 ($:acre)

Item	Switchgrass	Soybeans	Corn	Corn W.O. CRC
Expense / Acre	370.15	434.20	760.31	760.31
Income / Acre	242.00	821.92	1,030.50	574.65
Profit / Acre	-128.15	387.72	270.19	-185.66

In addition to evaluating switchgrass production collectively across the four varieties, yield production, nutrient composition, and cost of production and net return analyses were compared between varieties. The four varieties compared were Blade 1102, Blade 2101, Cave-In-Rock and Kanlow. Table 15 (a, b, c, d) shows the cost of establishing each variety in year 1. Since the same soil preparation, fertilization and planting practices were used to establish each variety the only difference in establishment cost was the cost of the seed. Cave-In-Rock seed cost the least per pound and Blade 1102 was the most expensive per pound of seed. Yield, reflected as tons of dry matter produced per acre, was lowest for Cave-In-Rock during both years 2 and 3. Blade 1102 produced more biomass in year 2 than either Blade 2101 or Kanlow, with Blade 2101 and Kanlow having similar yields. During year 3 Kanlow out yielded the other three varieties with Blade 1102 and Blade 2101 having similar dry matter production. In year 4 Blade 2101 had the greatest yield followed by Cave-In-Rock. Return per acre ($ per acre) was negative, reflecting a net loss in each year for each of the four varieties. Due to lower biomass production per acre, despite lower seed cost, Cave-In-Rock lost the most money per acre in each year of production (years 2 and 3). Blade 2101 lost the least money during production years 2-4 due to higher biomass yields. However, because of higher seed cost, Blade 1102 lost the most money over the three year period. The higher yielding Blade 1102 could not produce enough biomass in the first year following the establishment year nor in the second production year (year 3) under drought conditions to pay for the increased seed cost.

Table 15a. Blade 1102 Prorated Switchgrass Analysis ($ per acre)

	Yr. 1 (2010)	**Yr. 2 (2011)**	**Yr. 3 (2012)**	**Yr. 4 (2013)**	**4 Yr. Total**	**4 Yr. Average**
Expense ($)	525.40	324.22	370.15	378.29	1,598.06	399.52
Income ($)	0.00	208.00	248.00	168.00	624.00	156.00
Profit / Loss ($)	-525.40	-116.22	-122.15	-210.29	-974.06	-243.52
Tons / Acre Required to Break Even @ $50/T	10.51	6.48	7.40	7.57	31.96	7.99
Tons / Acre Required to Break Even @ $80/T	6.57	4.05	4.63	4.73	19.98	5.00
Dollars/Ton Required to Break Even at Actual Yield	—	77.19	119.40	145.50	342.09[a]	114.03[a]

[a]Tons of switchgrass required in each of years 2, 3, and 4.

Table 15b. Blade 2101 Prorated Switchgrass Analysis ($ per acre)

	Yr. 1 (2010)	**Yr. 2 (2011)**	**Yr. 3 (2012)**	**Yr. 4 (2013)**	**4 Yr. Total**	**4 Yr. Average**
Expense ($)	420.90	321.76	370.15	379.77	1,492.58	373.15
Income ($)	0.00	200.05	240.00	258.00	698.50	174.63
Profit / Loss ($)	-420.90	-121.71	-130.15	-121.77	-794.53	-198.63
Tons / Acre Required to Break Even @ $50/T	8.42	6.44	7.40	7.60	29.86	7.47
Tons / Acre Required to Break Even @ $80/T	5.26	4.02	4.63	4.75	18.66	4.67
Dollars/Ton Required to Break Even at Actual Yield	—	80.44	123.38	97.38	301.20[a]	100.40[a]

[a]Tons of switchgrass required in each of years 2, 3, and 4.

Table 15c. Cave-In-Rock Prorated Switchgrass Analysis ($ per acre)

	Yr. 1 (2010)	**Yr. 2 (2011)**	**Yr. 3 (2012)**	**Yr. 4 (2013)**	**4 Yr. Total**	**4 Yr. Average**
Expense ($)	411.40	300.30	360.95	372.15	1,444.80	361.20
Income ($)	0.00	143.00	200.00	234.00	577.00	144.25
Profit / Loss ($)	0.00	-157.30	-160.95	-138.15	-456.40	-114.10
Tons / Acre Required to Break Even @ $50/T	8.23	6.01	7.22	7.44	28.90	7.23
Tons / Acre Required to Break Even @ $80/T	5.14	3.75	4.51	4.65	18.05	4.51
Dollars/Ton Required to Break Even at Actual Yield	—	103.55	144.38	103.38	351.31[a]	117.10[a]

[a]Tons of switchgrass required in each of years 2, 3, and 4.

Table 15d. Kanlow Prorated Switchgrass Analysis ($ per acre)

	Yr. 1 (2010)	**Yr. 2 (2011)**	**Yr. 3 (2012)**	**Yr. 4 (2013)**	**4 Yr. Total**	**4 Yr. Average**
Expense ($)	458.90	318.70	379.35	387.70	1,544.65	386.16
Income ($)	0.00	191.00	280.00	180.00	651.00	162.75
Profit / Loss ($)	0.00	-127.70	-99.35	-207.70	-434.75	-108.69
Tons / Acre Required to Break Even @ $50/T	9.18	6.37	7.59	7.75	30.89	7.72
Tons / Acre Required to Break Even @ $80/T	5.74	3.98	4.74	4.85	19.31	4.83
Dollars/Ton Required to Break Even at Actual Yield	—	81.72	108.39	143.59	333.70[a]	111.23a

[a]Tons of switchgrass required in each of years 2, 3, and 4.

During this study, Blade 2101 had the greatest biomass yield followed by Blade 2101. Due to higher seed cost, Blade 1102 lost the most total dollars and had the highest average loss per acre per year. Blade 2011 lost the second greatest amount of dollars per acre. Kanlow lost the least amount of dollars per acre followed closely Cave-In-Rock.

The price of wheat straw (used as the equivalent value for switchgrass) in the local area (McLean County, Illinois) was $50 per ton in year 2, $80 per ton in year 3, and $60 per ton in year 4. The mean cost of production per acre across all four varieties for was $378.22 and the mean biomass yield for years 2-4 was 3.51 tons of dry matter per acre. Accordingly, the breakeven price per ton was calculated as $110.69 per ton or 4.78 tons per acre of biomass production if the price was $80:ton and 7.60 tons per acre of biomass if the price was $50:ton.

2. **Analysis of yield and cost of establishing and producing switchgrass on high fertility soil in comparison to switchgrass grown on marginal soils for all crop years.**

Switchgrass production on high fertility soils during the first four years of production did not compete with a corn-soybean rotation. Other studies that suggest switchgrass can be profitable have utilized projected yields and theoretical costs. This study utilized actual production costs and actual yield values to calculate the economic comparisons. Varvel et al. (2008) compared corn and switchgrass production on marginal soils in Nebraska and observed biomass yields between corn and switchgrass. They calculated that switchgrass biomass has more potential for ethanol production than corn biomass due to higher ethanol yield:ton of biomass. They, also, observed that removing one half of the corn stover each year decreased corn grain yield over time. Combining the income generated from corn grain production with the corn biomass harvest in their study agrees with the results of the ISU study; corn grain production returns more net dollars:acre than switchgrass production.

In another study, Fike et al. (2006) found lowland cultivars such as Kanlow were higher yielding than upland cultivars such as Cave-In-Rock. They also observed that varieties such as Kanlow are more sensitive to temperatures compared to varieties such as Cave-In-Rock. These reports agree with the observations of the study reported here (Table 5) where Kanlow out yielded Cave-In-Rock slightly over the three years, 3.3 tons/a for Kanlow to 3.0 t/a for Cave-In-Rock. The Kanlow yield was lower in year 4 and may have been due to winter during the winter following year 3 of production.

Khanna et al. (2008) reported to average yield of switchgrass in Illinois was 9.4t/ha (3.8 t/acre) similar to the yield obtained during year 2 of this study (3.7 t/acre) but higher than the yield harvested in year 3 (3.02 t/acre) and 4 (3.2 t/acre). The decrease in yields during year 3 was likely due to the drought and the lower yield in year 4 may have been from winter kill. Khanna and coworkers conclusion was that the breakeven cost for switchgrass is too high to result in a profit without government policies designed to provide incentives to offset potential economic losses. Their conclusion is supported by the results reported here. The yields reported in these two studies are similar to the average yield and highest yield of 6.5 mg/ha (2.6 t/acre) and 8.5 mg/ha (3.4 t/acre) reported by Lemus et al. (2006). In another study, Epplin (1996) estimated the costs to establish, produce and deliver switchgrass to an energy plant. His computer model found these costs per Mg equal to $37.08 (equivalent to $33.71 per ton of switchgrass) which is considerably less than the $85.56 per ton in year two and $122.57 per ton in year three observed in the study reported here. The results of this study are similar to the conclusions cited by Moore and Helmer (2013) who found continuous corn production more profitable when biomass production was valued at $16.50 per ton. In their study switchgrass became profitable when biomass was valued at $49.50. These investigators reported three ways in which switchgrass production could be profitable: through increased yields, by creating more biomass demand for energy production or with support from government payment incentives, none of which are likely to occur within the near future.

3. Analysis of the impact of center pivot irrigator installation on soils and crops.

Center pivot irrigation had a minimal impact on soil and crop yields. Soil bulk density increased immediately after installation, but within a year were back to similar values as the surrounding soils. While yields may have decrease slightly in the areas impacted by installation, the overall impact on yield in the 3.3 acre plots was minimal.
Localized increases in bulk density under corn and soybean cropping systems can be corrected with either fall or spring tillage. Fields under switchgrass will reduce compaction naturally through root growth and during the winter months when the soil undergoes freeze thaw cycles that are common to the Midwest.

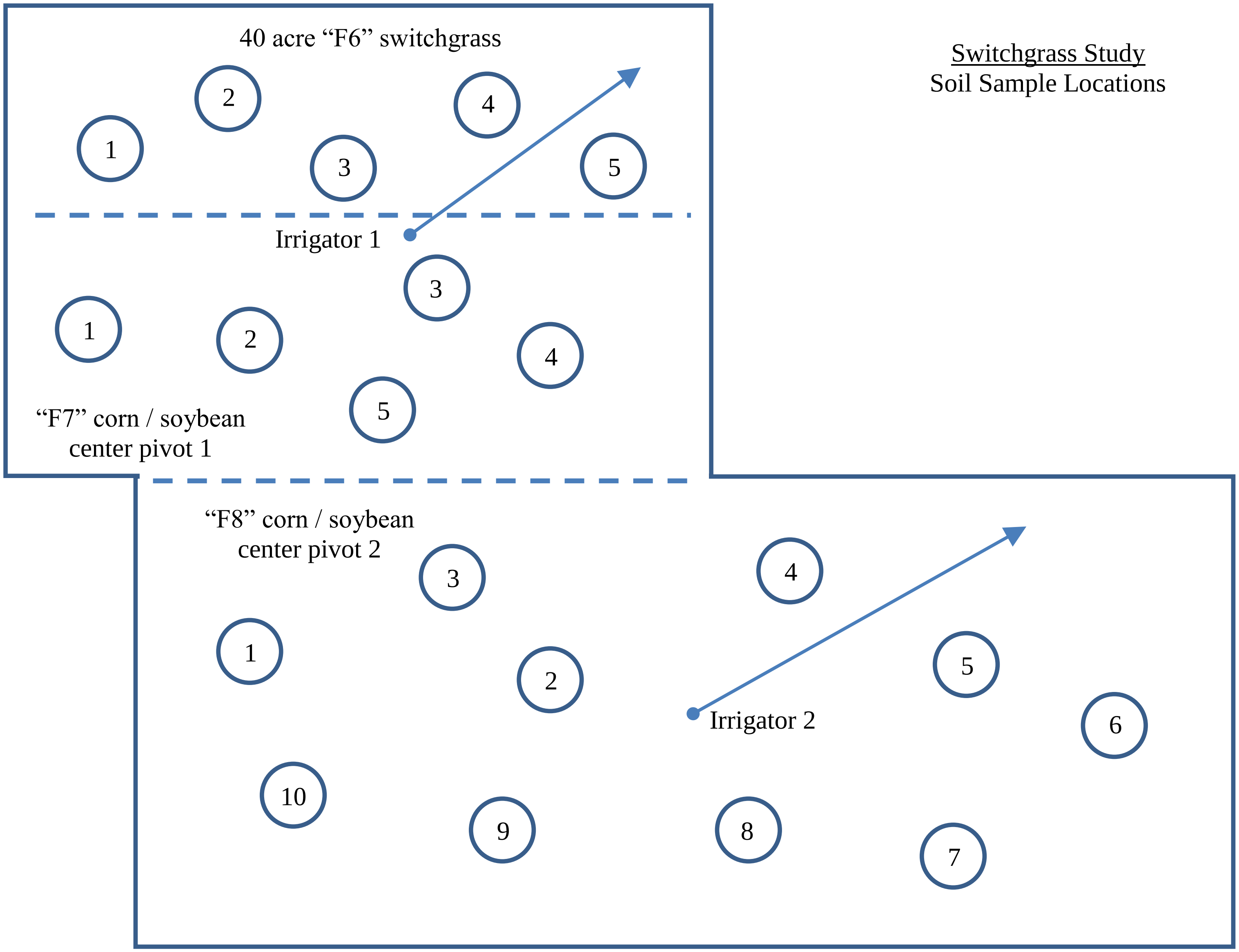
4. A determination of the value of future research on irrigation of switchgrass with municipal wastewater treatment effluent.

Future research on the impact of irrigation of switchgrass with municipal wasterwater treatment effluent should be continued. This study was not able to evaluate the long term benefits of the effects of irrigation on yields or the filtering ability of switchgrass to reduce runoff and leaching from this management system. During the drought year of 2012 the switchgrass could have benefitted from irrigation and it is very likely yields would have increased if irrigation could have been used to relieve the drought stress incurred during that growing season. The increased yield could have reduced the loss associated with growing switchgrass. Additionally, fertilizer could easily be added to water used to irrigate switchgrass. The fertilizers could be added during times of high crop demand which could optimize uptake and potentially minimize runoff and leaching. These practices could also increase switchgrass yield, which could make switchgrass more competitive economically compared to a corn and soybean rotation.

5. A determination of the impact (agronomic, environmental, and economic) of irrigation of switchgrass with municipal wastewater effluent.

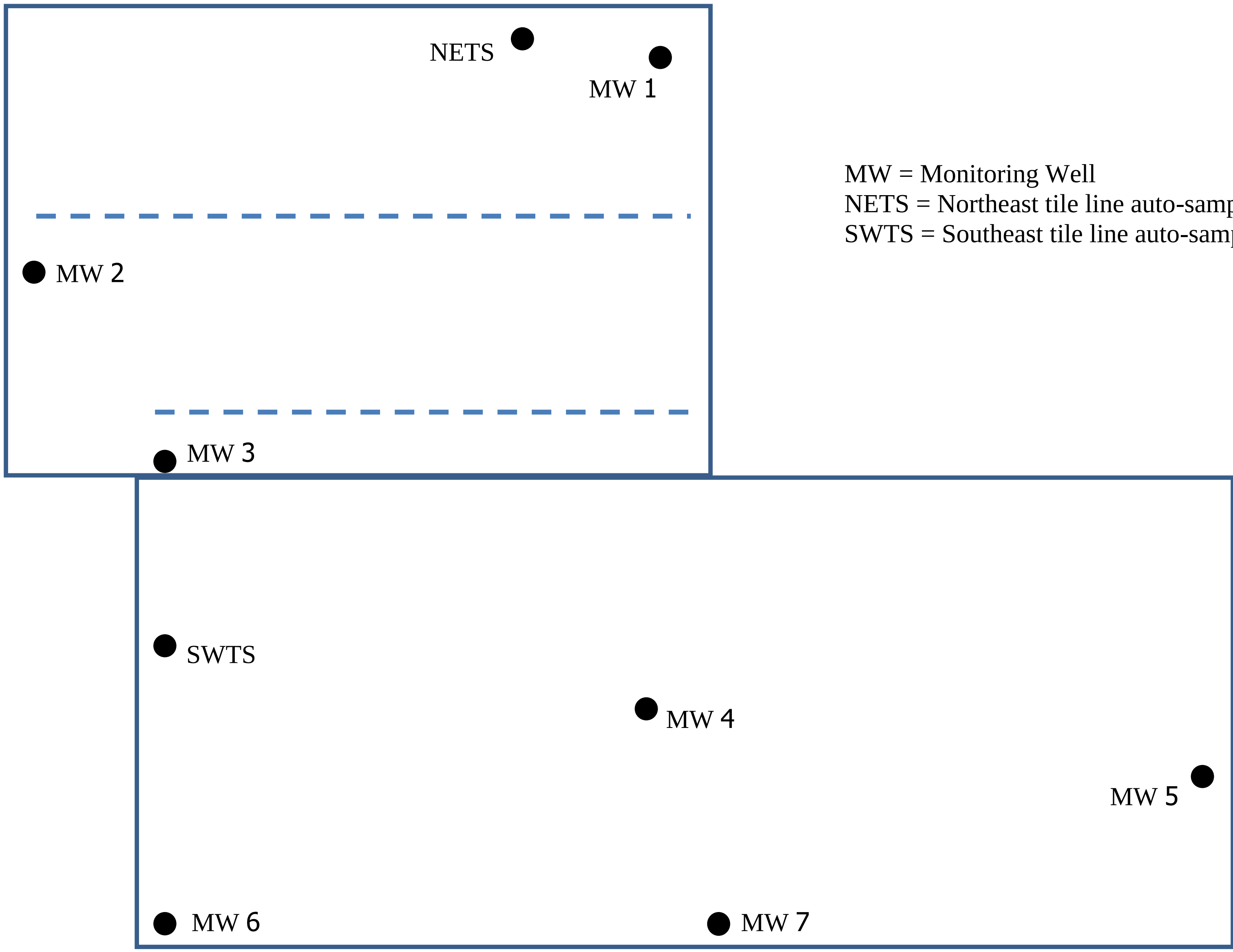
Soil samples and ground water samples were collected prior to irrigating with partially treated municipal waste water (PTMW) when sampling began in 2010. The purpose of collecting soil samples and ground water samples prior to irrigating with PTMW was to estimate pre-existing nutrient, heavy metal and pathogen indicator microorganism concentrations. Figure 3 shows the approximate locations for soil sample collection. Figure 4 depicts the locations of the tile line sampling locations and the ground water monitoring wells. Table 16 shows the water sample parameters measured. Heavy metal analyses were below detection limits. Fecal coliform was detected in only one well. Detection of fecal coliforms was not expected as the land area utilized for this study has no history of livestock manure application (previous 30 years) nor of a previous farmstead location. However, Kelley et al. (1999) reported that environmental factors (season of the year, soil moisture, soil temperature, etc.) can have more effect on the presence of pathogen indicator microorganism populations than the soil amendment. Therefore, detection of fecal coliform in one well may be a random occurrence. Nitrate – N, chloride salts and sulfates were detected in both of the tile lines and in the monitoring wells. As expected, soil samples collected prior to irrigation using PTMW contained detectable levels of ammonium nitrate and nitrate – N. Detectable levels of several heavy metals were observed, also (Table 17), but all levels were below the EPA maximum allowable limits.

Figure 3. Soil Sample Locations



<u>Switchgrass Study</u>
Soil Sample Locations

Figure 4. Location of Groundwater Monitoring Wells



MW = Monitoring Well
NETS = Northeast tile line auto-sampler
SWTS = Southeast tile line auto-sampler

Table 16. Selected Characteristics Of Monitoring Well And Tile Water Samples Collected Prior To Irrigation (mg/L) In Year 4

February 4, 2013

Collection Site	Chloride	NO_3 - N	NO_2 - N	N H_3 - N	SO_4	pH[1]	TDS[2]	FC[3]	As	Cd	Pb	Hg	Ni	Se
Well 1	22.0	4.60	< 0.15	< 0.10	19	7.00	400	< 10						
Well 2	39.0	0.76	< 0.15	< 0.10	260	6.80	870	< 10						
Well 3	12.0	0.07	< 0.15	< 0.10	160	6.90	560	< 10						
Well 4	17.0	8.00	< 0.15	0.21	1,000	6.70	2,000	< 10						
Well 5	16.0	0.74	< 0.15	< 0.10	170	6.80	650	< 10						
Well 6	7.5	< 0.02	< 0.15	< 0.10	60	7.00	400	< 10						
Well 7	14.0	5.00	< 0.15	< 0.10	32	7.00	400	< 10						
Sub-Mean	18.2	2.74	BDL	BDL	243	6.9	703	BDL						

June 25, 2013

Collection Site	Chloride	NO_3 - N	NO_2 - N	N H_3 - N	SO_4	pH[1]	TDS[2]	FC[3]	As	Cd	Pb	Hg	Ni	Se
Well 1	20.0	42.0	< 0.15	< 0.10	15	7.91	460	<10	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Well 2	35.0	1.6	< 0.15	< 0.10	200	7.74	790	<10	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Well 3	11.0	0.07	< 0.15	< 0.10	140	8.00	480	<10	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Well 4	15.0	1.7	< 0.15	< 0.10	160	7.85	580	110	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Well 5	23.0	32.0	< 0.15	< 0.10	35	7.98	370	<10	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Well 6	7.3	0.11	< 0.15	< 0.12	54	7.90	300	<10	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Well 7	11.0	6.2	< 0.15	< 0.10	29	7.71	320	<10	< 0.02	<0.002	<0.01	<0.0002	<0.01	<0.01
Sub-Mean	17.5	12.0	BDL	BDL	90	7.87	514	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Tile 1	9.7	23	< 0.15	< 0.10	8.6	7.90	300	<10	BDL	BDL	BDL	BDL	BDL	BDL
Tile 2	10.0	22	< 0.15	< 0.10	9.0	7.80	310	<10	BDL	BDL	BDL	BDL	BDL	BDL
Sub-Mean	9.9	23	BDL	BDL	8.8	7.85	305	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Mean	15.2	12.6	BDL	BDL	113.9	7.5	507	12.2	BDL	BDL	BDL	BDL	BDL	BDL

[1]pH measured in pH units
[2]TDS = Total dissolved solids
[3]FC = Fecal Coliforms measured in Colony Farming Units (CFU/100ml)

Table 17. Heavy Metal And Nitrogen (mg/kg) Analysis Of Soil Samples Collected Prior To Irrigation (Spring 2012) In Year 3

Sample	**Ammonium Nitrate**	**NO_3 - N**	**Se**	**As**	**B**	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Pb**	**Ni**	**Zn**
1[a]	1,441.0	5.0	< 2.0	4.6		1.0	11.0				17.0	14.0	
2[a]	1,545.8	2.0	< 2.0	< 3.0	1.1	12.0				14.0	19.0		
3[a]	1,493.4	3.0	< 2.0	< 3.0	1.1	12.0				14.0	18.0		
4[a]	1,572.0	3.0	< 2.0	< 3.0	0.99	11.0				14.0	16.0		
5[a]	1,441.0	3.0	< 1.9	< 2.8	0.94	11.0				14.0	17.0		
Sub-mean[a]	1,498.6	3.2	BDL[d]	BDL	0.81	9.4	BDL	BDL	BDL	11.2	17.4	BDL	BDL
1[b]	1,179.0	14.0	< 1.9	< 2.8	0.95	11.0				13.0	17.0		
2[b]	1,126.6	8.0	< 2.0	3.4	1.0	1.2				15.0	15.0		
3[b]	917.0	11.0	< 2.0	3.7	0.98	1.0				17.0	16.0		
4[b]	1,257.6	13.0	<2.0	3.9	1.0	1.0				17.0	15.0		
5[b]	1,179.0	9.0	< 2.0	5.2	1.0	11.0				16.0	16.0		
Sub-mean[b]	1,131.8	11.0	BDL	3.2	0.99	5.0	BDL	BDL	BDL	15.6	15.8	BDL	BDL
1[c]	995.6	26.0	< 2.0	3.0	1.0	12.0				13.0	16.0		
2[c]	1,021.8	10.0	2.9	3.3	1.1	12.0				15.0	15.0		
3[c]	1,205.2	26.0	< 2.0	< 3.0	1.1	13.0				15.0	16.0		
4[c]	1,126.6	11.0	< 1.9	> 2.8	1.1	13.0				13.0	17.0		
5[c]	1,283.8	9.0	< 2.0	4.9	1.1	12.0	BDL	BDL	BDL	13.0	19.0	BDL	BDL
Sub-mean[c]	1,126.6	16.4	BDL	BDL	1.1	12.4	BDL	BDL	BDL	13.8	16.6	BDL	BDL
Total mean	1,252.3	10.2	BDL	BDL	0.97	8.9	BDL	BDL	BDL	13.5	16.6	BDL	BDL

[a]Samples collected from soil growing switchgrass under center pivot one.
[b]Samples collected from soil growing corn/soybean under center pivot one.
[c]Samples collected from soil growing corn/soybean under center pivot two.
[d]BDL = Below detection limit.

Table 18a. Selected Characteristics Of Soil Samples Collected Prior To Irrigation

			Pounds Per Acre				Percent	Metal Concentrations (mg/kg)							Percent Saturation					Meq/ 100g
Sample	**Water pH**	**Buffer pH**	**Phos-phorus**	**Potassium**	**Calcium**	**Mag-nesium**	**Organic Matter**	**Sulfur**	**Zinc**	**Manganese**	**Boron**	**Iron**	**Copper**	**Sodium**	**Ca**	**Mg**	**K**	**H**	**Na**	**CEC**
1 - 1[a]	6.0	6.6	44	234	4,762	579	3.5	9.2	1.5	10.8	0.41	38.6	.89	11.9	65.6	13.3	1.7	19.4		18.1
1 - 2[a]	5.5	6.1	40	228	5,069	691	4.1	9.8	1.1	7.2	0.42	35.8	.82	8.0	56.5	12.8	1.3	29.3		22.4
1 - 3[a]	5.7	6.3	36	224	6,035	1,100	4.4	10.7	1.1	3.3	0.48	22.8	1.07	14.1	56.2	17.1	1.1	25.6		26.8
1 - 4[a]	6.2	6.7	89	298	6,245	1,028	4.5	11.0	1.7	6.7	0.48	28.6	1.19	9.7	64.2	17.6	1.6	16.6		24.3
1 - 5[a]	6.4	6.9	33	241	5,636	897	4.0	9.9	1.1	8.7	0.46	32.6	.92	10.5	68.9	18.3	1.5	11.3		20.5
Sub-mean[a]	6.0	6.6	40	234	5,636	898	4.1	9.9	1.1	7.2	0.46	32.6	.92	10.5	64.2	17.1	1.5	19.4		22.4
2 - 1[a]	6.2	6.8	54	252	5,158	723	3.2	9.7	1.6	17.1	0.55	53.0	1.04	8.6	65.8	15.4	1.7	17.0	0.19	19.6
2 - 2[a]	5.5	6.1	29	256	5,485	923	3.6	10.1	1.3	10.7	0.88	42.6	1.23	11.6	54.3	15.2	1.3	29.0	0.20	25.3
2 – 3[a]	5.7	6.4	62	371	6,679	1,152	3.5	11.8	1.7	4.6	0.45	46.6	1.80	11.3	56.7	16.3	1.6	25.2	0.17	29.4
2 – 4[a]	5.8	6.5	33	230	5,399	1,085	3.2	10.1	1.4	12.9	0.53	27.6	1.15	10.5	55.5	18.6	1.2	24.5	0.19	24.3
2 - 5[a]	5.9	6.6	38	250	5,456	933	3.4	9.5	1.7	10.9	0.48	44.4	1.16	9.8	58.8	16.8	1.4	22.9	0.18	23.2
Sub-mean[a]	5.8	6.4	43	272	5,635	843	3.4	10.2	1.5	11.2	0.57	42.8	1.28	10.4	58.2	16.5	1.4	23.7	0.19	24.4
Total mean[a]	5.9	6.5	42	253	5,636	871	3.8	10.1	1.3	9.2	0.52	37.7	1.10	10.5	61.2	16.8	1.5	21.6	0.19	23.4

[a]Samples collected from soil growing switchgrass under center pivot one.

1 = Samples collected spring of 2010 (year 1).

2 = Samples collected spring of 2012 (year 3).

Table 18b. Selected Characteristics Of Soil Samples Collected Prior To Irrigation

			Pounds Per Acre				Percent	Metal Concentrations (mg/kg)							Percent Saturation					Meq/ 100g
Sample	**Water pH**	**Buffer pH**	**Phos-phorus**	**Potassium**	**Calcium**	**Mag-nesium**	**Organic Matter**	**Sulfur**	**Zinc**	**Manganese**	**Boron**	**Iron**	**Copper**	**Sodium**	**Ca**	**Mg**	**K**	**H**	**Na**	**CEC**
1 - 1[b]	6.8	7.3	198	986	5,478	788	4.5	9.7	5.7	21.3	0.62	48.8	1.13	7.7	71.5	17.2	6.6	4.7		19.1
1 - 2[b]	6.3	6.8	40	278	6,977	1,216	4.1	12.8	1.8	8.2	0.57	30.6	1.34	12.6	65.8	19.1	1.3	13.7		26.5
1 - 3[b]	6.5	7.1	35	332	4,968	553	3.5	9.6	1.6	14.6	0.42	24.8	0.74	7.4	74.6	13.8	2.6	9.1		16.7
1 - 4[b]	6.0	6.6	34	235	4,548	580	3.6	9.6	1.1	12.0	0.31	26.8	0.72	11.3	64.3	13.7	1.7	20.3		17.7
1 - 5[b]	5.8	6.4	38	284	6,265	926	4.4	11.9	1.3	7.4	0.53	26.0	1.08	12.4	59.5	14.7	1.4	24.5		26.3
Sub-mean[b]	6.3	6.8	38	284	5,478	788	4.1	9.7	1.6	12.0	053	26.8	1.08	11.3	65.8	14.7	1.7	13.7		19.1
2 - 1[b]	5.9	6.6	13	215	4,260	692	2.8	8.8	1.0	14.6	0.44	24.6	0.78	9.5	59.4	16.1	1.5	22.8	0.23	17.9
2 - 2[b]	5.7	6.4	24	217	3,927	553	2.6	8.2	0.8	11.3	0.23	25.6	0.68	7.2	58.3	13.7	1.7	26.2	0.18	16.8
2 - 3[b]	5.4	6.4	69	266	3,928	459	3.2	9.1	1.4	19.3	0.22	36.4	0.82	8.4	55.5	10.8	1.9	31.6	0.21	17.7
2 - 4[b]	5.7	6.4	65	309	4,295	679	3.3	9.3	1.4	13.9	0.32	35.0	0.77	10.3	56.8	15.0	2.1	25.9	0.24	18.9
2 - 5[b]	5.8	6.5	39	238	4,530	591	3.1	9.2	1.1	19.1	0.27	26.4	0.78	9.9	60.7	13.2	1.6	24.2	0.23	18.7
Sub-mean[b]	5.7	6.5	42	249	4,188	595	3.0	8.9	1.1	15.6	0.29	29.6	0.77	9.1	58.1	13.8	1.8	26.1	0.22	18.0
Total mean[b]	6.0	6.7	40	267	4,833	692	3.6	9.3	1.4	13.8	0.41	28.2	0.93	10.2	62.0	14.3	1.8	19.9	0.22	18.6

[b]Samples collected from soil growing corn/soybean under center pivot one.

1 = Samples collected spring of 2010 (year 1).

2 = Samples collected spring of 2012 (year 3).

Table 18c. Selected Characteristics Of Soil Samples Collected Prior To Irrigation

			Pounds Per Acre				Percent	Metal Concentrations (mg/kg)							Percent Saturation					Meq/ 100g
Sample	**Water pH**	**Buffer pH**	**Phos-phorus**	**Potassium**	**Calcium**	**Mag-nesium**	**Organic Matter**	**Sulfur**	**Zinc**	**Manganese**	**Boron**	**Iron**	**Copper**	**Sodium**	**Ca**	**Mg**	**K**	**H**	**Na**	**CEC**
1 - 1[c]	6.2	6.8	21	204	4,734	564	3.5	9.0	1.3	11.6	0.36	25.4	0.76	10.5	69.1	13.7	1.5	15.7		17.1
1 - 2[c]	6.4	7.0	35	202	4,806	535	3.4	8.9	1.1	14.1	0.31	26.0	0.70	9.7	73.3	13.6	1.6	11.6		16.4
1 - 3[c]	7.7	7.5	33	320	7,356	1,045	1.4	12.8	0.9	20.0	0.29	18.3	0.63	12.3	79.4	18.8	1.8	0.0		23.2
1 - 4[c]	5.8	6.4	96	425	5,452	714	4.0	10.3	1.9	10.6	0.34	46.4	1.07	7.5	60.6	13.2	2.4	23.7		22.5
1 - 5[c]	6.0	6.7	35	215	4,863	822	3.3	9.1	0.9	15.1	0.31	23.6	0.70	9.4	61.2	17.2	1.4	20.2		19.9
1 - 6[c]	5.7	6.3	50	232	5,365	762	4.5	9.7	1.3	10.9	0.35	35.0	0.90	10.9	59.5	14.1	1.3	25.1		22.6
1 - 7[c]	6.1	6.6	47	188	4,705	567	4.4	9.2	1.1	10.2	0.34	28.2	0.69	6.9	65.9	13.9	1.4	18.8		17.8
1 - 8[c]	6.1	6.6	70	262	4,885	539	4.0	10.0	1.2	14.2	0.36	30.4	0.76	11.9	66.9	12.3	1.8	19.0		18.3
1 - 9[c]	6.5	7.0	98	373	5,910	746	4.2	10.8	2.0	6.5	0.42	40.2	1.16	7.8	71.8	15.1	2.3	10.8		20.6
1 - 10[c]	6.0	6.7	32	226	4,385	575	3.3	9.5	0.8	10.2	0.31	24.0	0.63	9.4	63.9	14.0	1.7	20.4		17.2
Sub-mean[c]	6.1	6.7	41	230	4,874	656	3.8	9.6	1.2	11.2	0.34	27.1	0.73	9.6	66.4	14.0	1.6	18.9		19.1
2 - 1[c]	5.6	6.3	21	267	4,414	756	2.8	8.2	0.9	12.0	0.23	26.6	0.67	10.8	55.2	15.7	1.7	27.2	0.24	20.0
2 - 2[c]	6.1	6.7	53	310	4,635	653	3.0	8.9	1.6	17.7	0.34	38.6	1.05	6.4	64.2	15.1	2.2	18.4	0.16	18.0
2 - 3[c]	5.3	6.3	27	226	3,698	630	2.9	8.6	1.0	15.8	0.23	30.4	0.71	8.3	49.6	14.1	1.6	34.6	0.19	18.6
2 - 4[c]	6.1	6.7	31	288	5,864	948	3.3	10.8	1.2	10.6	0.38	28.2	1.14	12.9	62.9	17.0	1.6	18.3	0.24	23.3
2 - 5[c]	6.2	6.8	61	234	5,785	739	3.3	5.3	0.9	13.1	0.32	43.0	1.04	9.7	68.0	14.5	1.4	15.9	0.20	21.3
Sub-mean[c]	5.9	6.6	39	265	4,879	745	3.1	8.4	1.1	13.8	0.30	33.4	0.92	9.6	60.0	15.3	1.7	22.9	0.21	20.2
Total mean[c]	6.0	6.7	40	248	4,877	701	3.5	9.0	1.2	12.5	0.32	30.3	0.83	9.6	63.2	14.7	1.7	20.9	0.21	19.7

[c]Samples collected from soil growing corn/soybean under center pivot two.

1 = Samples collected spring of 2010 (year 1).

2 = Samples collected spring of 2012 (year 3).

Table 19. Irrigation dates and amounts in 2013.

North Pivot - Irrigation schedule

Date	**Amount (inches)**
July 10, 2013	0.5
July 21, 2013	0.5
July 29, 2013	0.5
July 31, 2013	0.01
August 14, 2013	0.5
August 15, 2013	0.5
August 27, 2013	0.5
Total	**3.1**

South Pivot – Irrigation schedule

August 12, 2013	0.5
August 19, 2013	0.5
August 20, 2013	0.5
August 29, 2013	0.5
Total	**2.0**

Table 20. Selected Characteristics Of Partially Treated Waste Water (mg/L) used for Irrigation During Year 4[1]

Sample No.[2]	**Chloride**	**NO_3 - N**	**NO_2 - N**	**NH_3 – N**	**SO_4**	**pH**[3]	**TDS**[4]	**FC**[5]	**As**	**Cd**	**Pb**	**Hg**	**Ni**	**Se**
1	13	0.04	< 0.15	0.11	10.0	9.24	460	640	< 0.02	< 0.002	< 0.10	< 0.0002	< 0.10	< 0.12
2	68	0.04	< 0.15	< 0.10	56.0	9.24	460	45	< 0.02	< 0.002	< 0.10	< 0.0002	< 0.10	0.010
3	72	< 0.02	< 0.15	< 0.10	54.0	9.19	470	18	< 0.02	< 0.002	< 0.10	< 0.0002	< 0.10	0.011
4	65	< 0.02	< 0.15	< 0.10	48.0	9.19	500	81	< 0.02	< 0.002	< 0.10	< 0.0002	0.013	0.014
Mean	55		BDL		42.0	9.22	479	196	BDL	BDL	BDL	BDL	BDL	BDL

[1]Represents two collection dates, late July and early August, 2013.
[2]Sample 1 and 2 collected from center pivot 1 (July). Samples 3 and 4 collected from center pivot 2 (August).
[3]pH measured in pH units.
[4]TDS = Total dissolved solids.
[5]FC = Fecal coliforms measured in colony forming units (CFU/100 ml).

Table 21. Selected Characteristics Of Soil Samples Collected Following Irrigation, November 2013

				Pounds Per Acre			Percent			Metal Concentrations (mg/kg)							Percent Saturation			Meq/ 100g
Sample	**Water pH**	**Buffer pH**	**Phos-phorus**	**Potassium**	**Calcium**	**Mag-nesium**	**Organic Matter**	**Sulfur**	**Zinc**	**Manganese**	**Boron**	**Iron**	**Copper**	**Sodium**	**Ca**	**Mg**	**K**	**H**	**Na**	**CEC**
3 - 1[c]	6.3	6.9	50	381	4611	559	3.2	11.4	3.5	10.4	0.43	35.8	0.87	18.8	69.3	14.0	2.9	13.3	0.49	16.6
3 - 2[c]	6.1	6.7	36	263	4569	702	3.3	11.4	1.5	8.7	0.46	41.2	0.87	28.2	63.5	16.3	1.9	17.6	0.68	18.0
3 - 3[c]	6.2	6.8	30	249	4521	735	3.4	10.6	1.0	7.5	0.58	33.6	0.74	22.4	63.5	17.2	1.8	16.9	0.55	17.8
3 - 4[c]	5.8	6.4	35	328	4951	825	4.2	12.1	0.9	6.2	0.63	39.0	0.87	28.4	57.8	16.1	2.0	23.6	0.58	21.4
3 - 5[c]	6.1	6.6	40	316	5890	1070	4.5	13.0	1.3	3.4	0.61	32.8	1.10	22.0	60.8	18.4	1.7	18.8	0.39	24.2
Sub-mean[c]																				
4 – 1[D]	6.0	6.5	28	296	5216	1015	4.2	10.8	0.9	3.5	0.60	25.8	1.00	20.6	59.1	19.2	1.7	19.6	0.41	22.1
4 – 1[D]	6.2	6.8	26	291	4788	828	3.2	10.3	0.9	8.1	1.56	25.0	0.88	23.6	63.7	18.4	2.0	15.4	0.55	18.8
4 – 1[D]	6.3	6.9	39	319	5890	1078	3.5	13.3	1.2	6.9	0.72	27.2	1.16	25.7	64.6	19.7	1.8	13.4	0.49	22.8
4 – 1[D]	6.1	6.6	39	284	4698	817	3.6	10.3	1.2	9.3	0.58	28.4	0.97	24.1	62.2	18.0	1.9	17.3	0.56	18.9
4 – 1[D]	6.3	6.8	49	285	5599	962	4.2	11.9	1.4	5.9	0.69	30.0	1.06	20.6	65.1	18.6	1.7	14.2	0.42	21.5
Total mean[c]	6.1	6.7	37.2	301.2	5073.3	859.1	3.7	11.5	1.4	7.0	0.69	31.9	1.0	23.4	63.0	17.6	1.9	17.0	0.51	20.2

[c]Samples collected from switchgrass under center pivot one.

[D]Samples collected from corn/soybean rotation under center pivot one.

Tables 18a, 18b and 18c show selected characteristics analyzed for the soil growing switchgrass irrigated by center pivot one, the soil growing corn/soybean irrigated by center pivot one and the soil growing corn/soybean irrigated by center pivot two, respectively. As expected, similar concentrations of nutrients and similar pH values were found for each of the three land areas. These three land areas (prior to initiation of this study) had been treated as one field used to grow corn and soybean in a rotation.

The PTMW was land applied via irrigation for the first time beginning in July of year four (Table 19). Selected characteristics of the PTWM collected from the center pivots during irrigation are show in Table 20. For the most part, heavy metals and nitrogen were either below detection limits (BDL) or very low (< 0.15 mg/L), below the EPA maximum allowable limits. The fertilizer value of the PTMW is very small and would need to be supplemented to optimize biomass production. The pH of the PTMW was 9.22, which long-term could decrease the availability of selected micronutrients. Fecal coliforms were present as well as chloride salts. Soil samples collected from switchgrass and the corn and soybean rotations in November 2013 following irrigation are similar to those collected prior to irrigation.

6. An evaluation of the effect of alternative fertility treatments on switchgrass grown on high-fertility soil.

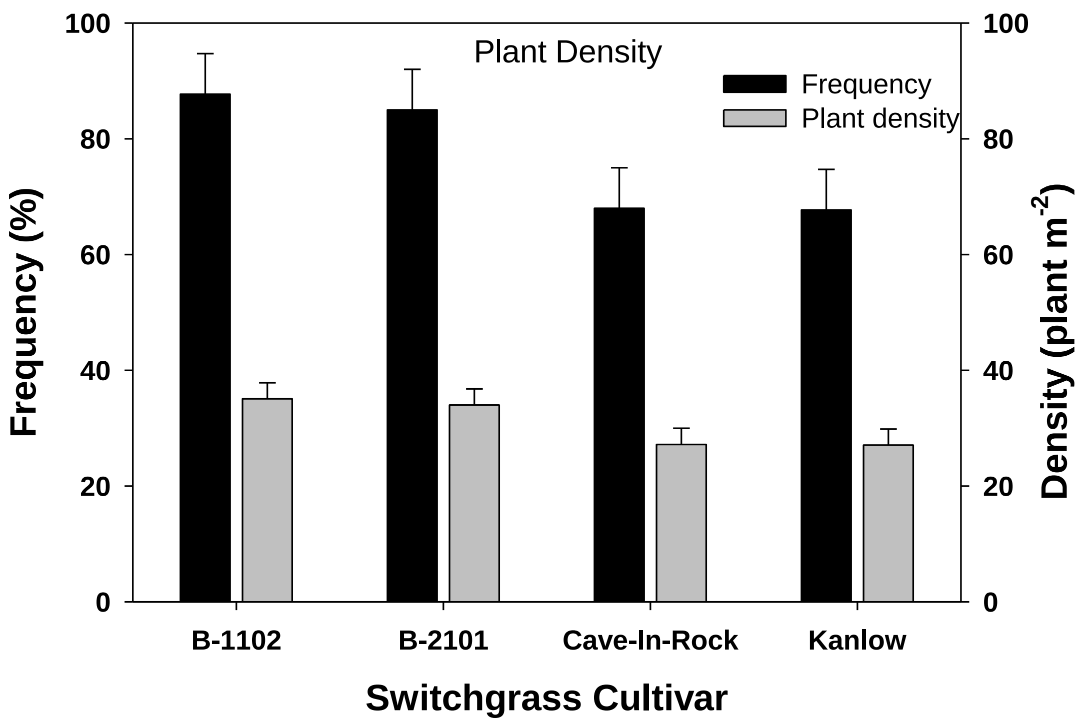
In Spring 2010, a 40-ac field near Lexington, IL was seeded into four switchgrass (*Panicum virgatum*) varieties (Cave-In-Rock, Kanlow, Blade 1102, Blade 2101) using a randomized complete block design with 3 replications as previously described (Figure 2). Cave-In-Rock and Blade 2101 are upland types and Kanlow and Blade 1102 are lowland types.
Overall during year one (2010) switchgrass frequency was good (Table 23; Figure 5) ranging from 65% coverage for Cave-In-Rock to 85.8% for Blade 1102. Of the 4 varieties, the lowland varieties had greater germination than the upland types. Vogel (1987) and Masters (1997) reported that when a frequency of occurrence of 40% or more (16 plant m-2) exists, there were no differences in biomass yield the first or second year after establishment for switchgrass and big bluestem.

Table 22. Mean ± SD Switchgrass Frequency And Plant Density

	Percent Frequency*			Plant m^{-2}		
Cultivar	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
EG 1102	87.7 (7.6)	85.8 (5.6)	89.3 (5.1)	35.1 (3.0)	35.1 (3.0)	35.7 (2.1)
EG 2101	85.0 (7.2)	77.9 (3.0)	96.3 (2.1)	34.0 (2.9)	34.0 (2.9)	38.5 (0.8)
Cave-In-Rock	68.0 (11.4)	65.0 (11.7)	84.7 (4.5)	27.2 (4.6)	27.2 (4.6)	33.9 (1.8)
Kanlow	67.7 (14.0)	82.9 (6.1)	87.3 (5.1)	27.1 (5.6)	27.1 (5.6)	34.9 (2.1)

*Percent frequency was determined by counting the number of squares containing live grasses using a grid of
25 squares m^{-2} in November or December of each year. The mean of six measurements was used to determine the mean.

Figure 5. Frequency and Plant Density of Switchgrass Seedling Measured on July 23, 2010 (year 1)



Three problems were evident in November 2010 (year1). First, giant foxtail control was inconsistent; the weed was adequately controlled in some areas, but was very abundant in other areas. Second, corn residue accumulated in low areas and reduced germination. Finally, there was severe rutting following pipe/wire installation. Proper management in 2011 (year 2) reduced the impact of these 2010 (year 1) problems.

During year 1, soil moisture, and soil and air temperature sensors were installed in one plot of each variety in Replication 2. There were no differences in temperature or in soil moisture among the cultivars during 2011 (year 2 and the first year of recording these measurements).

The 2012 (year 3) growing season began with warm temperatures in the late winter and very early spring followed by a hard freeze in April that damaged the early growth. Temperatures in Central Illinois during much of the growing season were well above normal, and precipitation was below normal through the early and mid portions of the growing season. These conditions contributed to the difficult growing conditions. Interestingly, the older, unimproved varieties, Cave-in-Rock and Kanlow, performed better than the newer EG 1102 and EG 2101 varieties during the early growing season heat and drought due to the newer types being selected for optimal growth in optimal growing conditions. Because growing conditions were not optimal during the early- and mid-2012 growing season (year 3), the growth of EG 1102 and EG 2101 was impacted more than the growth of Cave-in-Rock and Kanlow. Soil moisture and temperature at the field site were measured throughout year 3. During the later potions of the growing season, all of the grasses, especially EG 1102 and EG 2101, appeared to recover and add growth.

Overall switchgrass planting and establishment in year 1 and the year 1 to year 3 percent frequency counts were very good (Table 22) with year 3 percent frequency counts ranging from 85% coverage for Cave-In-Rock to 96% for EG 2101. While EG 2101 had greater germination and percent frequency in the field than the two lowland varieties, the researchers would recommend planting Kanlow or EG 1102 due to greater stature. This recommendation may change given the survival and performance of the four types following wastewater irrigation in the future.

7. Two Illinois switchgrass cultivation field days.

Due to the late installation of the waste water treatment plant, which caused the delay in irrigating until the 2013 growing season, the project reached the point of hosting field days in years 2 and 3 following irrigation.

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