An Assessment of Potential Agricultural Nonpoint Sources of Water Quality Impairment in the Rathbun Lake Watershed

Switchgrass for Biomass Effects on Water Quality Within the Lake Rathbun Watershed

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Introduction

Rathbun Lake is a 44.51 km^2 reservoir located on the Chariton River within Wayne county in southeast Iowa. Constructed in the 1970's by the Army Corps of Engineers for the purpose of providing flood protection, Rathbun Lake has become a valuable resource to the economy of southeast Iowa as a place of recreation to outdoor enthusiasts, and provides a reliable source of drinking water to more than 60,000 residents in Iowa and Missouri. Due to its location inside a watershed that is used primarily for row crop agriculture, the water quality of the lake is threatened by herbicide and nutrient runoff, and its use as a flood impoundment is hindered by siltation rates three times higher than predicted (data from Army Corps of Engineers). In an effort to improve water quality, alternative land uses are being studied. One practice being evaluated is the production of switchgrass (*Panicum virgatum*) for biomass. The capacity for switchgrass to control the loss of sediment, nutrients and agricultural chemicals in the Lake Rathbun Watershed has not been previously evaluated. The objective of this study was to quantitatively assess the water quality impacts of managing and producing switchgrass for biomass in this area.

Materials and Methods

Three fields outside the town of Millerton in Wayne County, Iowa were selected for consistent soil type and slope (5 – 7%) and availability of water supply used for rainfall simulation. Sediment runoff and runoff water quality were examined utilizing a linear rainfall simulator; use of simulated rainfall for similar research has proven valuable in comparable objectives (Eghball et al. 2000, Laflen et al. 1978).

The study consisted of six replicates each of the following three treatments: newly planted switchgrass following soybeans (**NSG**), established mature switchgrass of thirteen years (**OSG**), and no-till corn following soybeans (**NTC**).

Soils for test areas, identified and delineated by NRCS, are those of the Clarinda series- a fine, montmorillonitic, noncalcareous, mesic, sloping, Typic Argiaquoll. Climate of the area is sub-humid mid-continental with an average rainfall of 820.42 millimeters per year.

The experiment type was a fixed design and the analysis of the results a two-way pairwise statistical t-test for differences. Statistical analysis was computed using SAS (Statistical Analysis Software) version 8.0. Differences were measured at a 95% significance level.

Test plots were constructed of steel strips 15.24 centimeters high and of varying lengths to create an open-ended box 4.88m x 0.61m. These strips were hammered into the soil eight centimeters deep to prevent water accumulated under rainfall simulation from escaping the plot. Each plot was positioned parallel to a slope of 5%-7%. The open end was positioned on the down slope, where a collector was placed to obtain the runoff samples. Insertion of the collector was done carefully so as to minimize soil disturbance inside the plot. Any gaps between the front edge of the collector and the base of the plot were closed by packing of fine textured B-horizon material. For ease of sampling, a pit of approximately three feet in depth, three feet in length, and two feet in width, was dug below the end of the collector. Drainage from the end of the plot was facilitated by installing a trench from the pit to the base of the slope.

Selected crop management practices for the respective treatments are listed in Table 1 below.

Table 1. Management Summary

Treatment	**Fertilizer Application**	**Pesticide Application**	**Seeding/Planting**
NSG	0-0-60 112.08 kg/ha	1.68 kg/ha Atrazine 1.75 L/ha 2,4-D	Cave n' Rock frost seeded 11.21 kg/ha pls *Airflow*^{TM} broadcast seeder
Date Applied	Feb 11, 2000	Apr 21, 2000	Feb 11, 2000
OSG	*Heartland Lysine Fertilizer*^{TM} (HLF) 1961.45 kg/ha	1.68 kg/ha Atrazine 1.75 L/ha 2,4-D	————
Date Applied	Apr 21, 2000	Apr 21, 2000	
NTC	18-46-0 112.08 kg/ha	4.68 L/ha *Bicep*^{TM}	116 day *Mycogen*^{TM} 69,187 plants/ha
	Anhydrous NH_3 246.58 kg/ha		
Date Applied	Nov 15, 1999	May 29, 2000	May 29, 2000
	May 20, 2000		

The rainfall simulator was a linear type with downward sweeping nozzles, provided by the USDA-ARS National Soil Tilth Laboratory at Purdue University in West Lafayette, Indiana (see Figure 1 below). Rate of rainfall during the study was approximately 54 mm/hr. Water was provided by Rathbun Regional Rural Water, and was tested prior to use by Minnesota Valley Testing Labs (**MVTL**) in Nevada, Iowa. Samples were evaluated for selected chemical impurities that could affect water quality testing or enhance soil erosion through dispersion. Tests conducted included specific conductance, pH, nitrate, total and ortho-phosphorus, total Kjeldahl nitrogen, total residual chlorine, calcium, magnesium, and sodium. Results from these tests indicated that measured parameters would have little affect on soil erosion and water quality measurements.

Figure 1. Linear Rainfall Simulator.

Sediment and water quality sampling during rainfall simulations began at the start of consistent runoff flow from the collector at the end of each plot. Sampling was conducted at five-minute intervals for 15 seconds. Each 15-second sample was intended to represent the runoff/erosion that occurred within that five-minute interval. The total run time for each simulation was 80 minutes to reach a steady state of runoff. 0.95 liter polypropylene bottles were used to collect runoff for sediment and water quality analysis. A single bottle was used to collect runoff for water contaminant testing (samples collected for 15 seconds at five minute intervals) for the duration of each run and emptied after each interval into a clean five-gallon pail to collect a flow-weighted average. At the end of each simulation the pail was stirred, then separated into bottles for lab testing. Samples for water quality testing were collected during Periods 1 and 2 using the same procedures (see Figure 2 below). Period 1 samples were collected in May 2000 starting with NPS and ending with OSG. Period 2 samples were collected from late June starting with NTC and ending in late July with NPS. Drought conditions during the early summer slowed the growth of the new switchgrass and prevented its emergence in some places within the test area. Testing sequence for the treatments in Period 1 and Period 2 was determined by random draw.

Figure 2. Sample Collection.

Runoff samples for contaminant analysis were packed on ice prior to transport to MVTL. Samples were stored no longer than 36 hours following collection. Each sample was evaluated for nitrate + nitrite, total Kjeldahl nitrogen, and total phosphorus, as well as atrazine (Aatrex), metolachlor (Dual), and alachlor (Lasso) pesticides. Test methods used for each and the reference to those methods are outlined in Table 2 below.

Table 2. Water Analysis Methods.

Analyte	Method	Reference
Nitrate + Nitrite	4500N03E	Franson et al.
Total Phosphorus	365.2	EPA
Total Kjeldahl Nitrogen	4500NH3E	Franson et al.
Alachlor	3510	EPA
Atrazine	8081	EPA
Metolachlor	8141A	EPA

Runoff samples to measure sediment and water were brought to ISU for analysis, with the following procedure used: Dry sample bottles were weighed prior to collection. Each full weight bottle (containing water and sediment) was weighed, water was removed by siphoning, then the bottles with sediment were oven dried at 100 degrees C to remove residual moisture prior to weighing. Calculations were as follows: Weight of water = (full bottle weight – empty bottle pre-weight) – oven dried sediment bottle weight. Water weight then was converted to liters. Weight of sediment = (oven dried sediment bottle weight – empty bottle pre-weight). Sediment concentration = (sediment weight) / (volume of water) for each bottle.

<u>Results – Period 1</u>

The results for Period 1 are summarized in Table 3 below. NTC contributed significantly higher concentrations of sediment, nitrate/nitrite, and total phosphorus than NSG and OSG. NTC was also significantly higher than NSG for TKN, but contributed less than half the concentration of TKN compared to OSG. NTC contributed about the same concentration of atrazine as OSG, and both were significantly less than NSG. NTC contributed significantly more metolachlor than did NSG. Trace amounts of metolachlor were also found in runoff from OSG, and small concentrations of alachlor were found in all treatments.

NSG contributed significantly more sediment, total P, and atrazine than OSG, and the mean was numerically higher for nitrate/nitrite, although this was not significantly different. TKN was nearly 5 times greater for OSG than for NSG; this difference was highly significant.

Table 3. Period 1 t-statistics test for differences.

Means		Sediment (g/L)	NO_3+NO_2 (mg/L)	Total P (mg/L)	TKN (mg/L)	Atrazine (mg/L)	Metolachlor (mg/L)	Alachlor (mg/L)
NTC		4.08	7.97	1.35	8.80	0.16	0.0713	0.0005
NSG		1.49	4.32	0.96	4.12	0.40	0.0230	0.0005
OSG		0.33	1.78	0.56	19.95	0.18	0.0008	0.0005
Contrasts								
NTC vs OSG	t value	12.38	3.21	4.78	-7.54	-0.81	7.85	…………
	p value	< 0.0001	0.0058	0.0002	< 0.0001	0.4300	< 0.0001	…………
NSG vs OSG	t value	3.73	1.32	2.39	-10.71	7.05	2.48	…………
	p value	0.0002	0.2038	0.0305	< 0.0001	< 0.0001	0.0257	…………
NSG vs NTC	t value	-8.56	-1.89	-2.39	-3.17	7.86	-5.38	…………
	p value	< 0.0001	0.0776	0.0305	0.0064	< 0.0001	< 0.0001	…………

Results – Period 2

The results for Period 2 samples are summarized in Table 4 below. Statistically significant decreases in runoff levels of sediment and total phosphorus occurred from NTC to NSG to OSG. The same numerical trends were noted for nitrate/nitrite, TKN, and metolachlor; however, differences between NSG and OSG were not statistically significant for nitrate/nitrite, atrazine, or metolachlor. Differences in atrazine levels between NTC and NSG, and between NTC and OSG, were statistically significant. The difference in TKN levels between NSG and NTC approached significance at $p = 0.0611$. Traces of alachlor were detected in all samples, although it was not utilized in the crop management program for this experiment. Possible reasons for this will be discussed later.

Table 4. Period 2 t-statistics test for differences.

Means		Sediment (g/L)	NO_3+NO_2 (mg/L)	Total P (mg/L)	TKN (mg/L)	Atrazine (mg/L)	Metolachlor (mg/L)	Alachlor (mg/L)
NTC		4.23	13.47	1.23	7.57	0.13	0.0429	0.0010
NSG		1.95	2.58	0.89	5.37	0.01	0.0011	0.0005
OSG		0.17	0.50	0.14	2.95	0.02	0.0005	0.0005
Contrasts								
NTC vs OSG	t value	15.21	5.59	9.63	4.25	10.95	13.67	∞
	p value	< 0.0001	< 0.0001	< 0.0001	0.0007	< 0.0001	< 0.0001	< 0.0001
NSG vs OSG	t value	6.71	0.90	6.64	2.22	-0.68	0.21	∞
	p value	< 0.0001	0.3834	< 0.0001	0.0419	0.5072	0.8368	< 0.0001
NSG vs NTC	t value	-8.54	-4.69	-2.98	-2.02	-11.63	-13.46	∞
	p value	< 0.0001	0.0003	0.0093	0.0611	< 0.0001	< 0.0001	< 0.0001

Results – Comparison Between Periods 1 and 2

The comparisons of mean values for Periods 1 and 2 are summarized in Table 5, and statistical analysis for these comparisons are summarized in Table 6 below. No statistical differences were noted for sediment loss between Periods 1 and 2. Nitrate+nitrite levels were significantly higher in Period 2 NTC than in Period 1, but no differences between Periods were noted for nitrate+nitrite levels from NSG or OSG. No differences between Periods were noted for phosphorus levels from NTC or NSG. OSG phosphorus was significantly reduced from Period 1 to Period 2. TKN from OSG was considerably higher in Period 1 than in Period 2 ($p < 0.0001$), but no differences between Periods were noted for NTC or NSG. There was a significant drop in atrazine levels from OSG from Period 1 to

Period 2; an even larger decrease was noted for NSG ($p < 0.0001$). No difference between Periods was noted for atrazine from NTC. Both NTC and NSG showed significant decreases in metolachlor levels from Period 1 to Period 2. No difference between Periods was noted in metolachlor levels from OSG. Traces of alachlor were detected in all samples, but levels were too low to be considered important.

Table 5. Period 1 and Period 2 means.

Means	Sediment (g/L)		NO_3+NO_2 (mg/L)		Total P (mg/L)		TKN (mg/L)		Atrazine (mg/L)		Metolachlor (mg/L)		Alachlor (mg/L)	
	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2
NTC	4.08	4.23	7.97	13.47	1.35	1.23	8.80	7.57	0.16	0.13	0.0713	0.0429	0.0005	0.0010
NSG	1.49	1.95	4.32	2.58	0.96	0.89	4.12	5.37	0.40	0.01	0.0230	0.0011	0.0005	0.0005
OSG	0.33	0.17	1.78	0.50	0.56	0.14	19.95	2.95	0.18	0.02	0.0008	0.0005	0.0005	0.0005

Table 6. Period 1 vs. Period 2 t-statistics test for differences.

Treatment / Period		Sediment (g/L)	NO_3+NO_2 (mg/L)	Total P (mg/L)	TKN (mg/L)	Atrazine (mg/L)	Metolachlor (mg/L)	Alachlor (mg/L)
NTC P1 vs NTC P2	t value	-0.52	-2.58	0.88	0.95	0.98	4.23	∞
	p value	0.6011	0.0151	0.3858	0.3494	0.3365	0.0002	< 0.0001
NSG P1 vs NSG P2	t value	-1.61	0.81	0.46	-0.96	16.68	3.26	……..
	p value	0.1072	0.4227	0.6505	0.3431	< 0.0001	0.0028	……..
OSG P1 vs OSG P2	t value	0.53	0.60	2.95	13.10	6.91	0.05	∞
	p value	0.5933	0.5518	0.0062	< 0.0001	< 0.0001	0.9607	< 0.0001

Discussion

Sediment

NTC consistently contributed the most sediment of the treatments in Periods 1 and 2. It is likely that this can be attributed to soil disturbance and diminished soil structure from ammonia application in the spring. NSG was broadcast seeded (as opposed to rows in NTC); the diverse pattern of plants helped to decrease water velocities and subsequent erosion as the water flow was forced to move around more stems, resulting in less sediment loss. OSG contributed the least amount of sediment in the runoff for several reasons. The established canopy of old growth (Period 1) and new growth to further fill in the canopy (Period 2) served to intercept the energy contained in raindrops before it could reach the soil surface and cause soil detachment. Raindrops that fell past the canopy were met by a thick vegetative mat of residue at the soil surface. Residues also served as temporary dams to slow water velocities and cause re-deposition of soil particles eroded earlier in the flow. The irregular surface caused by the residues also created depressions that served as catchments to contain water and slow its release. Amounts of sediment eroded during Periods 1 and 2 were not statistically different within treatments – neither period was a greater contributor than the other.

Samples gathered from each treatment during simulation were 15-second sub-samples of the total erosion occurring during each five-minute interval, expressed in grams soil / liter water. The following calculations were made to determine soil loss in metric tons / hectare. Individual values for grams of sediment collected in each 15-second sub-sample were multiplied by twenty (twenty 15-second intervals = five minutes), then each calculated 5-minute soil loss was added together to estimate total soil loss in each treatment for the 80-minute rainfall simulation period. Soil loss across all six replications were summed. The total surface area of all six plots was 17.82 m^2 for each treatment. Calculations for total soil loss were as follows: metric tons/hectare = (grams total soil loss in each treatment) x (1 kg/1000g) x (1/17.82m^2) x (10,000m^2/1ha) x (1 metric ton/1000 kg). These results are summarized in Table 7 below.

Table 7. Period 1 & 2 sediment loss in metric tons/hectare.

Treatment	**Period 1**	**Period 2**
NTC	0.87	1.46
NSG	0.50	1.08
OSG	0.11	0.08

Sediment loss from OSG plots was less than 13% of that for NTC for both periods.

Nitrate + Nitrite

In Period 1, NTC resulted in 3.65 mg/L more nitrate+nitrite in the runoff than OSG. It can be said with reasonable confidence that most of this is nitrate. Nitrite does not typically accumulate unless the soil is undergoing denitrification under waterlogged conditions, or is calcareous and in localized areas where NH_4^+ containing or forming fertilizers such as anhydrous ammonia are being used. The increased nitrate level is very likely attributable to the greater amount of soil erosion in this treatment. As soil was detached and transported in the runoff, it carried with it nitrogen remaining from unincorporated dry 18-46-0 fertilizer spread during the fall of 1999 and anhydrous ammonia knifed in the month before planting. OSG contributed far less nitrogen to the nitrate+nitrite levels due to reduced erosion. No statistical differences were observed between NSG and OSG, or between NSG and NTC.

In Period 2, NTC produced more nitrate+nitrite than OSG and NSG; likely due to increased erosion. Period 2 NTC had greater nitrate+nitrite loss than Period 1 NTC, probably attributable to increased soil microbial activity from warmer temperatures that resulted in conversion of nitrogen into plant available forms. No statistical differences were observed between NSG and OSG.

Mean concentrations (in mg / L) of nitrate+nitrite for each treatment period were multiplied by the calculated total water loss (from sediment analysis) to estimate mean total nitrate+nitrite loss from all plots within each treatment. The following calculations were used to convert this result (expressed in mg) to kg / ha: kg/hectare = (milligrams nitrate+nitrite) x (1 kg/1,000,000mg) x (1/17.82m^2) x (10,000m^2/1ha). These results are summarized in Table 8 below.

Table 8. Nitrate+Nitrite loss in runoff expressed as kilograms per hectare.

Treatment	**Period 1**	**Period 2**
NTC	1.83	5.08
NSG	1.62	1.52
OSG	0.76	0.28

Total Kjeldahl Nitrogen

TKN was evaluated to estimate how much organic nitrogen was present in runoff. In Period 1, OSG had considerably more TKN than both NTC and NSG. The accumulation of large amounts of TKN in runoff from OSG cannot be explained by erosion, because OSG had the least amount of sediment loss in Period 1. High levels of TKN could originate from organic soil nitrogen compounds such as proteins, amino acids, amino sugars, and other compounds produced by large numbers of active heterotrophic microorganisms (a far larger population than would be found in NTC and NSG) breaking down the abundant amount of organic matter in the soil. Higher erosion rates in NTC can account for higher TKN than in NSG in Period 1. In period 2, TKN was far lower in runoff from OSG than from NTC. Droughty conditions during Period 2 simulations could account for this difference; soil water uptake would have been far greater in the extensive root systems of OSG, resulting in more severe soil desiccation and decreased microbe activity. No statistical differences were noted when comparing levels of TKN from NSG and NTC. Results for TKN in kg/ha were estimated using calculations identical to nitrate+nitrite, and are summarized in Table 9 below.

Table 9. Total Kjeldahl Nitrogen loss in runoff expressed as kilograms per hectare.

Treatment	**Period 1**	**Period 2**
NTC	2.02	2.85
NSG	1.55	3.15
OSG	8.50	1.63

Total Phosphorus

Neither NSG nor OSG received fertilizers containing phosphorus, while NTC received 112 kg/ha of 18-46-0 dry fertilizer in November 1999. In Period 1 NTC contributed more total phosphorus in runoff than NSG and OSG. Period 2 analysis demonstrated the same results with NTC contributing the most total phosphorus in the runoff, followed by NSG and OSG. NTC experienced greater sediment loss, much of which contained phosphorus. The same theory applies to NSG vs OSG. No significant differences were noted between Periods 1 and 2 for NTC and NSG within treatment. There was a significantly lower total P loss from OSG in Period 2 vs Period 1. Total phosphorus loss was estimated using the same calculations as for nitrate+nitrite and TKN, and are summarized in Table 10 below.

Table 10. Total Phosphorus loss in runoff expressed in kilograms per hectare.

Treatment	**Period 1**	**Period 2**
NTC	0.31	0.46
NSG	0.36	0.52
OSG	0.24	0.08

Atrazine

High levels of atrazine were detected in runoff from NTC in both periods, although none was applied as part of the crop management for this experiment. Its appearance can only be identified as residual herbicide remaining in the soil from previous years. NSG and OSG were treated with the same amount of atrazine, 1.68 kg/ha during the spring, following planting. Higher levels of atrazine contamination in runoff can be attributed to greater erosion in NSG compared to OSG.

Atrazine levels in NSG and OSG during Period 2 were considerably lower than Period 1; however, atrazine levels in runoff from NTC stayed about the same from Period 1 to Period 2. The atrazine in the NTC plot was likely well-absorbed residual chemical from previous year’s crop(s), and would have been less vulnerable to being washed away during a rainfall event than the applications that were sprayed over the top of the NSG and OSG plots after planting. NSG experienced higher atrazine loss than OSG, probably due to greater sediment loss. Atrazine loss in kg/ha was estimated as for nitrate+nitrite, etc., and is summarized in Table 11 below.

Table 11. Atrazine loss in runoff expressed in kilograms per hectare.

Treatment	**Period 1**	**Period 2**
NTC	0.04	0.05
NSG	0.15	0.01
OSG	0.08	0.01

Metolachlor

Metolachlor was applied to NTC at a rate of 4.68 L/ha in May 2000. NSG and OSG were not treated with metolachlor for this experiment; however; trace amounts were found in their runoff. It is possible that metolachlor was already present in the NSG plots, as soybeans were grown in these plots the year before. The reason for its occurrence in the OSG plots is not known. The amount of metolachlor in runoff from NTC can be considered quite high, as the EPA health advisory rating for this contaminant for lifetime exposure is 0.10mg/L. The high levels in Period 1 runoff for NTC can be attributed to high erosion rates compared to NSG and OSG. Levels in Period 2 NTC were lower than for Period 1, due primarily to herbicide lost to runoff, but not due to a difference in the amount of sediment loss. Sediment loss was not statistically different between Period 1 and Period 2 NTC plots. Metolachlor loss in kg/ha was estimated as for nitrate+nitrite, etc., and is summarized in Table 12 below.

Table 12. Metolachlor loss in runoff expressed in kilograms per hectare.

Treatment	**Period 1**	**Period 2**
NTC	0.02	0.02
NSG	0.01	0.0006
OSG	0.0003	0.0003

Alachlor

No alachlor was applied to plots during this study. Its presence may be due to residual amounts remaining in the soil from past crop management practices. Due to the lower recording limits of 0.0005 mg/L in the lab equipment, no measure below this limit could be made and the differences between treatments could not be measured if present. Period 2 NTC was the only treatment to contribute a higher level of alachlor. Due to lack of variability within treatments for each period, t-values could not be utilized, and p-values were used instead. Period 1 values for each treatment were the same, due to the recording limits stated above. In Period 2 NTC contributed 200% more alachlor in runoff than in other treatments; however, this amount was well below the EPA drinking water standard of 0.002 mg/L, therefore it is not considered a significant threat to water quality. The reason for the increase in alachlor level from NTC from Period 1 to Period 2 is not known. Alachlor loss in kg/ha was estimated as for nitrate+nitrite, etc., and is summarized in Table 13 below.

Table 13. Alachlor loss in runoff expressed in kilograms per hectare.

Treatment	**Period 1**	**Period 2**
NTC	0.0001	0.0004
NSG	0.0002	0.0003
OSG	0.0002	0.0003

Conclusions

In both Periods, switchgrass (new and established) were beneficial in reducing sediment loss, inorganic nitrogen loss (measured as nitrate+nitrite), total phosphorus loss, and metolachlor contamination in runoff when compared to NTC. OSG contributed significantly more organic nitrogen to runoff than either of the other treatments in the early sampling period. This was not the case for sampling period 2, which was associated with complete canopy cover by the switchgrass and drought conditions. Atrazine was not used on NTC, therefore the low levels recorded were probably due to residual chemical, and were not considered important to water quality. Atrazine contamination in Period 1 runoff was reduced from NSG to OSG. For most parameters, NSG was less effective at preventing nutrient loss or herbicide contamination; however, NSG provided significant improvements over NTC for sediment loss, total phosphorus, TKN during adequate moisture conditions, and metolachlor. Strong trends for improvement were also noted for inorganic nitrogen loss and TKN loss during drought conditions for NSG over NTC. This is convincing evidence that such benefits will be observed very quickly following establishment of a new stand of switchgrass, and that stands of mature switchgrass offer the best protection from sediment and nutrient loss and herbicide contamination of runoff that may threaten water quality.

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