2005 Project Abstract
For the Period Ending June 30, 2008

PROJECT TITLE: 3rd Crops for Water Quality – Phase 2
PROJECT MANAGER: Dean Current
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FUNDING SOURCE: Minnesota Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2005, First Special Session, Chapter 1, Article 2, Section 11, Subdivision 9(e) Third Crops for Water Quality – Phase 2

APPROPRIATION AMOUNT: $ 259,000

Overall Project Outcome and Results

The intent of this project was to accelerate the adoption of 3rd crops at a demonstration scale documenting their long term impact on water quality and storage, renewable energy supply and rural economic vitality. Demonstrations were established in the Greater Blue Earth, Chippewa, Lower Minnesota, and Rouseau River Watersheds. The work has resulted in significant findings that are being disseminated through publications and the activities of our partner, Rural Advantage.

- Landscape position has a significant impact on the success and productivity of different biomass species.
- Research on the impact of conversion from row cropping to perennial crops coupled with wetland restoration suggests that we can expect diminished flow volumes, total suspended solids, and nitrate levels. Although grass competes with woody crops, this study demonstrates the importance of soil cover as a best management practice to reduce runoff, soil erosion, and phosphorous loads during establishment of woody crops.
- Soil frost is deeper under annual crops than under perennials making soils under perennials are better able to absorb water earlier in the spring and reduce runoff from rain on snow events and from rapid snowmelt.
- Through research on the production and nutrient cycling impacts of 3rd crops, we are able to suggest species that will be productive, have important characteristics for cellulosic ethanol production, and protect environmentally sensitive areas.

The overall impact has been to generate and disseminate information that will allow us to target 3rd crop plantings for bioenergy to optimize their economic, environmental and water quality and storage benefits. The project has leveraged funding through 2013 from the private sector that will continue monitoring benefits, expand the research to answer additional questions, and provide greater detail for the development of renewable energy options in Minnesota.

Project Results Use and Dissemination

The outreach activities of this project are reported in a separate report prepared by Rural Advantage, our partner in this project. In addition to the work by Rural Advantage for audiences including farmers, natural resource professionals and citizens, the University portion of the project has provided information in the following venues and formats:

- Presentations by University researchers and students at Rural Advantage sponsored events. (approximately 12 presentations)
- Presentations at professional meetings in the US (7) and internationally (1).
- Papers and Theses prepared by University Graduate students (7).
- Projects prepared and presented by Undergraduate students (8).
- Publications by graduate students and researchers.

It is important to note that the project has used a variety of venues to disseminate information and results from project activities. Results have been disseminated to interested members of the public through a series of meetings sponsored by Rural Advantage and UMN extension as well as meetings sponsored by state agencies and initiatives (MPCA, NextGen, BWSR). In addition, research results have been disseminated through publications, presentations at scientific meetings and integrated into coursework at the University of Minnesota. This has allowed the project to reach a broad audience and have a greater impact. More detailed information can be provided on request.

LCMR 2005 Work Program Final Report

Date of Report: **August 15, 2008**
LCMR 2005 Work Program Final Report
Project Completion Date: **June 30, 2008**

I. PROJECT TITLE: 3rd Crops For Water Quality – Phase 2

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Location: *Greater Blue Earth, Chippewa, Lower Minnesota and Roseau River Watersheds*

Total Biennial Project Budget: $ 259,000 (UMN Portion)	**LCMR Appropriation:**	**$ 259,000**
	Minus amount Spent:	**$ 259,000**
	Equal Balance:	**$ 0**

Legal Citation: ML 2005, First Special Session, Chapter 1, Article 2, Section 11, Subdivision 9(e) Third Crops for Water Quality – Phase 2

Appropriation Language: Third Crops for Water Quality-Phase 2 $250,000 the first year and $250,000 the second year are from the trust fund to the commissioner of natural resources for cooperative agreements with Rural Advantage and the University of Minnesota to accelerate adoption of third crops to enhance water quality, diversify cropping systems, supply bioenergy, and provide wildlife habitat through demonstration, research, and education. This appropriation is available until June 30, 2008, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. and III. FINAL PROJECT SUMMARY:

The intent of this project was to build on the success of the previously LCMR financed project "Native Plants and 3rd Crops for Water Quality", and accelerate the adoption of 3rd crops at a demonstration scale documenting their long term impact on water quality and storage, wildlife habitat, renewable energy supply and rural economic vitality. The work has resulted in significant findings some that are being disseminated through the activities of our partner, Rural Advantage.

- The results of the research on the impact of landscape position on the success and productivity of different biomass demonstrated a marked difference in productivity of different species which depends on their landscape position and soil attributes.
- The information on soils and landscape position, along with the information generated on perennial species and their impact on water quality and storage, will help us target perennial species to positions on the landscape for optimum biomass production and environmental benefits.

- Research on the impact of conversion from row cropping to perennial crops coupled with wetland restoration suggests that we can expect diminished flow volumes, total suspended solids and nitrate levels. On a cautionary note, although grass competes with woody crops, this study demonstrates the importance of soil cover as a best management practice to reduce runoff, soil erosion, and phosphorous loads during establishment.
- Soil frost is deeper under annual crops than under perennials. Because of this, soils under perennials are better able to absorb water earlier in the spring and reduce runoff from rain on snow events and from rapid snowmelt.
- Finally, through research on the production and nutrient cycling impacts of 3rd crops, we are able to suggest species that will be productive, have important characteristics for cellulosic ethanol and protect environmentally sensitive areas.

Specific results are included in the report that follows.

IV. OUTLINE OF PROJECT RESULTS:

Cropping system-induced degradation of Minnesota waterways has had economic and ecological impacts including TMDL listings, hypoxia, habitat degradation, and drinking water impairments. This proposal, building on the success of the ongoing LCMR financed project "Native Plants and 3rd Crops for Water Quality", will accelerate the adoption of 3rd crops at a demonstration scale resulting in a long term impact on water quality and storage, wildlife habitat, renewable energy supply and rural economic vitality. The Project Team will 1) establish at least 59 acres of "working land" demonstration and research plantings; 2) determine ecological and economic benefits at field scale; and 3) accelerate the implementation of 3rd crop systems through outreach and market identification, coordination and development.

Result 1. "Establishment of 3rd Crop Plantings" Budget: $ 130,945

This result is now under a separate workplan for Rural Advantage

Result 2 – "Agronomic, Hydrologic and Economic Research" Budget: $ 259,000

Activity 1 – U of MN Agronomy and Waseca SROC (Southern Research and Outreach Center) will monitor the productivity and the water quality effects of native plant and 3rd crop systems established in 2004; the following research will be conducted:

a. Landscape position effects. Research on alternative energy crops production systems.

Several perennial biomass crops were established on a typical catena in south-central Minnesota at the southern Research and Outreach Center to evaluate the effect of landscape positions and the soil, terrain, and water attributes present at those positions on biomass production. Alfalfa (Medicago sativa L.), corn (Zea mays L.), willow (Salix spp.), cottonwood (Populus deltoides), poplar (Populus maximowiczii x P. nigra), and switchgrass (Panicum virgatum) were planted on seven landscape positions (Summit, Depositional, West Slope, Flat, South Slope, Southwest Slope, North Slope; Figure 1) in 2005 and biomass production was measured in 2006 and 2007. Soil N, P, K, pH, and Profile Darkness Index (PDI) were soil attributes analyzed for effects on biomass production (Table 1 and 2). Aspect, elevation, slope, specific catchment, compound terrain index, plan curvature, and profile curvature were the terrain attributes observed and analyzed for effects on biomass production. A Bayesian data analysis revealed that differences in biomass accumulation were present between species within single sites, and within single species grown at different sites. Analysis of soil and terrain attributes showed that different terrain and soil attributes were related to biomass yield for each species.

Species Variation by Landscape Position

Alfalfa. Two-year total alfalfa biomass ranged from 15137 to 31270 kg ha-1. Alfalfa yield at the Depositional and West slope landscape positions were lower than yields at all other positions (Table 3). Yields were lower in 2007 than in 2006 due to stand age. Poor alfalfa yield at the Depositional position can be partially attributed to water pooling and ice sheeting that killed significant portions of the stand.

Corn Stover. Two-year total corn stover yield varied from 9600 to 17231 kg ha-1 and yield at the flat landscape position was lower than yield at all other positions. Stover yield in 2007 was similar to that in 2006. Corn grain yield ranged from 15427 to 22867 kg ha-1 including yields at the Depositional and Flat positions that were lower than yields at all other positions. Corn stover yields were lower in Depositional and Flat landscape positions that were frequently wet as shown by their terrain and soil attributes. Low corn grain yields in the Depositional, Flat, and SE Slope landscape positions were in-line with previous corn research results. Corn grain yield in 2007 was lower than in 2006; this yield effect is typical of a continuous corn rotation.

Willow. Final willow tree stem diameter measurements taken after the end of plant growth in 2007 were converted to biomass estimates using the allometric equation fitting process. SX67 willow had yields at the Depositional, Flat, SE Slope and North facing Slope that were significantly higher than yields at the Summit and S Slope, ranging from 18,386-36,701 kg ha-1. 9882-41 willow had biomass yields ranged from 9,631-25,013 kg ha-1 and dry biomass yield at the Depositional and Flat positions that were higher than yields at all other sites while yield at the South Slope position was lower than for all other positions. Both willow clones produced larger stems and thus more biomass in the Depositional and Flat landscape positions, which are areas that the CTI and specific catchment terrain attributes and the PDI soil attributes suggest, retain more water for longer periods of time than do any of the other sites.

Poplar and Cottonwood. NM6 poplar biomass ranged from 26,468-34028 kg ha-1 with yield at the Depositional position being lower than at all other positions. D125F cottonwood yields were similar across all positions.

Switchgrass. Two-year total switchgrass biomass yield ranged from 9,338-17,263 kg ha-1 including yields at the Summit and West Slope positions that were higher than yield at any other position and a 2007 yield that was higher than 2006.

Species Variation within each Landscape Position

Summit. Biomass yields at the summit landscape position varied from 16,549 to 36,817 kg ha-1. Alfalfa, D125F cottonwood, and NM6 poplar yielded more 2-year total biomass than all other species at the Summit (Table 4).

Depositional. The Depositional landscape position biomass yields ranged from 9,338 to 36,701 kg ha-1. SX67 willow yielded more biomass than all other species, while alfalfa, corn grain, corn stover, and switchgrass yielded less total biomass than all other species at the Depositional position. High SX67 biomass yields at this position display the ability of some willow trees to not only tolerate saturated soils but to thrive. Conversely, alfalfa, corn, and switchgrass yields are low at the depositional position, as expected, since they are more suited to dry soils rather than the soil conditions present at this landscape position (Tables 2 and 3). The high willow/low alfalfa-corn-switchgrass biomass yields can be explained in part by the Specific Catchment, CTI and PDI values for the landscape position, which indicate saturated soil conditions for most or all of the growing season.

West Facing Hillslope. Biomass yields at the W Slope landscape ranged from 16,577 to 29,868 kg ha-1. The single-stemmed trees (D125F cottonwood and NM6 poplar) yielded significantly more biomass at the W Slope than all other species.

Flat. D125F cottonwood yielded more biomass than all other species, while corn grain, corn stover, and switchgrass yields were lower than those of all other species. The conditions present at the Flat landscape position are not optimal for the types of corn hybrids grown in the Midwest. The highly positive Specific Catchment, highly negative CTI and highly positive PDI values for the landscape position suggest lengthy periods of wet, highly saturated soils which are not conducive to the production of large corn plants yielding high stover amounts or high corn grain yields.

South Facing Hillslope. The South facing Slope landscape position had a two-year biomass yield range of 9,631 to 36,002 kg ha-1. Alfalfa, corn grain, D125F cottonwood, NM6 poplar, and SX67 willow yielded more biomass than corn stover, switchgrass, and 9882-41 willow did. Biomass totals of the four higher-yielding species did not differ from each other, nor did the biomass totals for the four lower-yielding species.

Southwest Facing Hillslope. Biomass yield totals at the SW Slope landscape position ranged from 11,948 to 37,589 kg ha-1. Alfalfa, D125F cottonwood, NM6 poplar, and SX67 willow yielded significantly more two-year total biomass than corn grain, corn stover, switchgrass, and 9882-41 willow. Low corn grain and corn stover yields can be explained in part by the low specific catchment and low PDI values, indicating low levels of available soil moisture. The high SX67 willow yield is not consistent with landscape positions with low available soil water levels, so other conditions may have been present to allow the willow clone to have high biomass production (localized available soil water, positive soil fertility conditions that overcame negative soil water conditions, etc.).

North Facing Hillslope. Finally, biomass yields at the N Slope ranged from 14,195 to 32,256 kg ha-1. NM6 poplar yielded more biomass than all other species at the landscape position.

Table 1. Terrain attributes of seven ALPS landscape positions.

Landscape Position	Aspect	Elevation (m)	Percent Slope	Specific Catchment (m^2)†	Compound Terrain Index‡	Plan Curvature §	Profile Curvature¶
Summit	E	317	0.5	51.33	0	4.06	0.088
Depositional	E	314	0.5	9090.90	-7.9657	0.45	-0.05
West Slope	SW	316-317	1.5	256.52	1.7095	-0.25	-0.02
Flat	NW	314	0.5	1114.81	-4.4594	0	-0.02
South Slope	S	315-316	1.5	87.14	0	6	0.116
SW Slope	SW	313-315	4	342.60	0.7924	0	0.007
North Slope	N	314-315	3	301.81	1.6309	1.25	-0.001

† Specific Catchment = [upslope area (m^2) / width of contour]; determines relative water saturation and runoff.
‡Compound Terrain Index = Unitless LOG calculation where the (LOG base = slope) and the number being LOG transformed = the flow accumulation (not shown in this table; number of square meters flowing to the point of interest).
§ Plan Curvature = Curvature of the surface perpendicular to the direction of slope; positive values indicate convexity, negative values indicate concavity.
¶ Profile Curvature = Curvature of the surface in the direction of slope; positive values indicate convexity, negative values indicate concavity.

Table 2. Soil attributes of seven ALPS landscape positions.

Landscape Position	Soil Type	Nitrate (ppm)	Bray Phosphorus (ppm)	Potassium (ppm)	Water pH	Profile Darkness Index†
Summit	Clarion Loam	6.6	17	140	5.5	7.125
Depositional	Webster Clarion Loam	2.6	40	177	6.8	23.333
W Slope	Webster Clarion Loam	3.7	17	150	5.6	7.333
Flat	Webster Clarion Loam	2.5	36	188	6.6	16.167
S Slope	Clarion Loam	10.4	20	154	5.3	8.429
SW Slope	Clarion Loam	5.8	11	161	5.6	3.071
N Slope	Webster Clarion Loam	4.6	18	152	5.5	5.625

†Profile Darkness Index (PDI) = (A horizon thickness (cm) / ((Munsell value + Munsell chroma)+1)) (Thompson and Bell, 1996)

Table 3. Two-year total biomass yields for seven biomass species at 7 landscape positions.

Landscape Position	Alfalfa	Corn Stover	Corn Grain	SX67 Willow	9882-41 Willow	D125F Cottonwood	NM6 Poplar	Switch grass
	kg ha^{-1}							
Summit	**29924$_a$**[†]	**16549$_a$**	**22867$_a$**	**18386$_b$**	**17450$_b$**	**36817$_a$**	**33630$_a$**	**17263$_a$**
Depositional	**15137$_b$**	**13911$_a$**	**15427$_b$**	**36701$_a$**	**25013$_a$**	**30594$_a$**	**26468$_b$**	**9338$_b$**
W Slope	**26749$_a$**	**17231$_a$**	**21022$_a$**	**-**	**16973$_b$**	**29166$_a$**	**29868$_a$**	**16577$_a$**
Flat	**30490$_a$**	**9600$_b$**	**13859$_b$**	**29922$_a$**	**24942$_a$**	**33113$_a$**	**30635$_a$**	**14929$_a$**
S Slope	**28431$_a$**	**15144$_a$**	**21460$_a$**	**17286$_b$**	**9631$_b$**	**36002$_a$**	**28237$_a$**	**13072$_b$**
SE Slope	**31270$_a$**	**14987$_a$**	**17637$_b$**	**27857$_a$**	**14257$_b$**	**37589$_a$**	**34028$_a$**	**11948$_b$**
N Slope	**30503$_a$**	**16667$_a$**	**21688$_a$**	**26334$_b$**	**22588$_b$**	**23989$_a$**	**32256$_a$**	**14195$_b$**

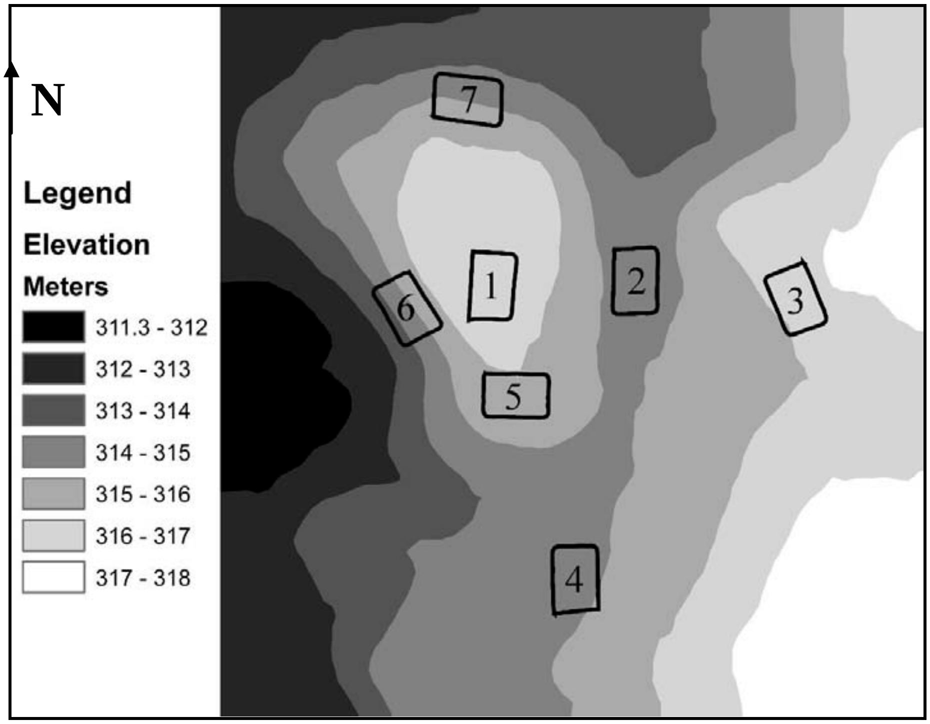
[†] values within a column that contain a common symbol do not have significantly different 95% confidence intervals.

Table 4. Two-year total biomass yields between all species within each individual landscape position.

Species	Summit	Depositional	W Slope	Flat	S Slope	SE Slope	N Slope
	kg ha^{-1}						
Alfalfa	**29924$_b$**[†]	**15137$_b$**	**26749$_b$**	**30490$_b$**	**28431$_a$**	**31270$_a$**	**30503$_b$**
Corn Stover	**16549$_b$**	**13911$_b$**	**17231$_b$**	**9600$_c$**	**15144$_b$**	**14987$_b$**	**16667$_b$**
Corn Grain	**22867$_b$**	**15427$_b$**	**21022$_b$**	**13859$_c$**	**21460$_a$**	**17637$_b$**	**21688$_b$**
SX67 Willow	**18386$_b$**	**36701$_a$**	-	**29922$_b$**	**17286$_b$**	**27857$_a$**	**26334$_b$**
9882-41 Willow	**17450$_b$**	**25013$_b$**	**16973$_b$**	**24942$_b$**	**9631$_b$**	**14257$_b$**	**22588$_b$**
D125F Cottonwood	**36817$_a$**	**30594$_b$**	**29166$_a$**	**33113$_a$**	**36002$_a$**	**37589$_a$**	**23989$_b$**
NM6 Poplar	**33630$_a$**	**26468$_b$**	**29868$_a$**	**30635$_b$**	**28237$_a$**	**34028$_a$**	**32256$_a$**
Switchgrass	**17263$_b$**	**9338$_c$**	**16577$_b$**	**14929$_b$**	**13072$_b$**	**11948$_b$**	**14195$_b$**

[†] values within a column that contain a common symbol do not have significantly different 95% confidence intervals.

Fig. 1. Experimental site layout and site numbering at Waseca, MN.



1-Summit, 2-Depositional, 3-West Slope, 4-Flat, 5-South Slope, 6-SW Slope, 7-North Slope

b) Perennial Cropping Effects on Runoff and Associated Water Quality

Results from the runoff plots at SROC, Waseca, are reported separately for periods when perennial crops were being established (first two years) in contrast to periods in which perennial crops were becoming physiologically mature (> two years). Two repetitions of five crops (willow, Illinois bundleflower, corn/soybean rotation, hybrid hazelnut with turfgrass cover, and perennial flax) were initially established in 2004 as runoff plots (Colson, 2006). By 2007, the willow crop was mature and was harvested in November, 2007. Also, in 2007 two additional runoff plots were established to investigate seven cropping practices: corn/soybean, corn/corn, corn/corn with rye ground cover, alfalfa, native grass/legume mix, False Indigo + sod, and willow on bare soil. Because willow and hazel were planted as cuttings, for the first two years (2004-05) willow plots were essentially bare soil, and the hazel plots were essentially sodgrass; thus, data from these plots did not represent the response of mature willow and hazel.

In the first year of establishment (2004), hybrid hazelnut - sodgrass (HN) and perennial flax (PF) had lower runoff (table 5), total suspended solids (TSS), and phosphorus than soybean and hybrid willow (HW) plots. Nitrate loadings were nearly equal during the runoff events for soybean, Illionois bundleflower (IBF), HN and PF, but less than HW. Water Quality summary tables are presented in Appendix 2-1.

With less than 10% ground cover, the HW plots responded similarly to soybean plots during spring and early summer storms. In contrast, the sodgrass cover on the HN plots had a major influence on runoff and nutrient loss. Although grass competes with woody crop seedlings, this study demonstrates the importance of soil cover as a best management practice to reduce runoff, soil erosion, and phosphorus loads during establishment.

Table 5 Total precipitation and runoff (mm) from runoff plots under hybrid willow (HW), corn-soy rotation (CSR), hybrid hazelnut – sod (HN), and perennial flax (PF) during the establishment period, 2004 and 2005 at the SROC, Waseca.

Year	**Total Precip. (mm)**	**HW RO (mm)**	**CSR RO (mm)**	**IBF RO (mm)**	**HN RO (mm)**	**PF RO (mm)**
2004	1025	21.4	23.3	21.8	104	88
2005	850	12,7	11.0	11.0	30	40

By 2007, all perennial crops on the runoff plots were well established. In November, 2007 the willow plots were harvested, therefore, there was no overstory on the willow plots for April-May 2008. Ranking of runoff from highest to lowest for 2007 indicated: Hybrid willow – bare soil (HW) > corn/corn (C/C) & corn/soy (CSR) > alfalfa (A) & native grass/legume (NG/L) > false indigo-sod (FI-sod). During the spring period before annual crops were growing, runoff from CSR, C/C, and HW –bare soil were far greater than runoff from A, NG/L and FI-sod. This spring period represents the period that normally has the highest levels of streamflow and flooding in the region, suggesting that perennial crops with good ground cover can effectively diminish surface runoff and potentially peak flows during the spring runoff period.

Table 6. Summary of April – October 2007 and April May 2008 surface runoff from perennial and annual crop systems, runoff plots at the University of Minnesota SROC, Waseca.

Month	Year	Rainfall	Runoff (L/Ha)						
		mm (in)	Corn/Soy	Corn/Corn	Corn/Corn+Rye	Alfalfa	Native Grass/Legume	False Indigo+sod	*Willow
April	2007	48 (1.9)	3214	4449	458	577	986	470	7871
May	2007	86 (3.4)	1558	2262	2045	1486	1301	740	5999
June	2007	107 (4.2)	46432	37940	7989	5958	2129	1022	28679
July	2007	59 (2.3)	1650	1380	1288	913	854	489	12565
Aug	2007	273 (10.8)	10972	20495	6449	2067	3944	2263	114400
Sept	2007	119 (4.7)	8036	11454	2815	746	2406	1523	34729
Oct	2007	144 (5.7)	26405	34835	2798	661	1459	826	29349
Total	2007	835 (32.9)	98266	112816	23841	12408	13079	7334	227910
April	2008	106 (4.2)	828	1663	1055	992	789	768	1018
May	2008	99 (3.9)	3575	4478	1984	2309	2603	1593	4174
Total	2008	205 (8.1)	4404	6141	3039	3301	3391	2361	5192

* Willow data adjusted for plot size

Water quality data are summarized for the establishment period and for the 2007-2008 periods in Appendix 2. During the establishment period, P and NO-3 loadings were greatest for the hybrid willow, soybean and Illinois Bundle flower and least for the hybrid hazelnut – sod and perennial flax plots (table 7). As with the runoff results during the establishment period, perennial crops with exposed soil and the least biomass produced the highest P and NO-3 losses from the plots.

Table 7. Total P and No-3 loadings from runoff plots of perennial and annual crops at the SROC, Waseca for the establishment period, 2004 and 2005.

Total Phosphorus Load: Average kg/ha from total of rainfall events measured					
Year	**Willows**	**Soybean**	**IBF**	**Hazels**	**Perennial Flax**
2004	12.18	3.47	2.23	0.39	0.96
2005	5.96	1.44	1.36	0.06	0.12
NO3- Load: Average kg/ha from total of rainfall events measured					
2004	1.307	0.439	0.52	0.413	0.733
2005	2.85	2.68	2.31	0.21	0.41

Total suspended sediment (TSS) measurements were taken for major runoff events in 2004 and, similar to the results for P and NO-3, showed that sediment losses were greatest for the willow-bare soil plots followed by soybean and Illinois bundleflower with the least sediment losses from the hazelnut-sod and perennial flax plots (table 8).

Table 8 Total suspended sediment (TSS) loading averages from annual and perennial crop runoff plots during the first year of establishment at the SROC, Waseca.

	Average TSS loadings in kg/ha per treatment				
Event Date	Willow	Soybean	Illinois bundleflower	Hazelnut	Perennial flax
2-Mar-04	21	N/A	57	55	16
9-Jun-04	1750	297	441	N/A	58
11-Jul-04	3017	1194	348	96	248
22-Aug-04	160	97	10	9	0
15-Sep-04	1968	204	257	11	128
7-Oct-04	498	192	0	0	11
Total	7414	1983	1112	171	461

Water quality results for the period 2007-spring 2008 are summarized in Appendix A (tables 4A , 5A and 6A). TSS from willow on bare soil, corn/soy and corn/corn were two orders of magnitude higher than the alfalfa, native grass/legume and false indigo – sod plots (table 2-4A). Less dramatic but similar responses were observed for NO-3 and total P (tables 5A and 6A). Willow will require more research to determine rooting depth and the surface soil properties under willow (with no ground cover).

c) Perennial Cropping System Effects on Tile Drainage

Monitoring of tile drain plots began in 2004 and continued into 2008; by 2007, all perennial crops except hybrid poplar were at a stage of maturity. Mean annual drainage measured as tile flow is summarized for each crop in table 7 for the period 2004- June, 2008. Mean monthly tile flows are summarized in Appendix B.

Drainage grouped into an "early" period (April-June) showed an increase in the amount of significantly different flows (= 0.10) as the study progressed from 2004-2006 (Appendix B – from Clipper 2007). Few differences existed among crops in early 2004 , when all differences in drainage involved IBF-BB (lowest flow) compared to perennial systems (table 2B). During early 2005, drainage for four of the six perennial cropping systems (alfalfa, IBF-BB, turf, willow) was significantly lower than from corn (tables 1B & 2B). For 2004 and 2005, alfalfa and IBF-BB were both lower than flax and HP. For early 2006, significant differences were found between soybean and all perennial systems, suggesting that all perennial crops were well established by the third year of the study.

Drainage grouped into a "late" period (July-September) revealed no trends from 2004-2006 (table 3B). Significant differences in drainage were found for late 2004, among which alfalfa and IBF-BB were both significantly lower than from flax and willow. Minimal drainage during late 2005 showed few significant differences . Drainage for late 2006 consisted of mostly zero flows (data not included).

Table 9. Mean annual tile drainage for perennial and annual crops at SROC, Waseca from 2004-early 2008.

Annual Tile Flow 2005-2008 (L/Plot)												
			ppt(mm)	**Corn/Soybean**	**Corn/Corn+Rye**	**Alfalfa**	**Prairie Grass/Legume**	**Perenn Flax**	**False Indigo/Sod**	**Willow**	**Poplar**
	2005		1138	38178	30652	13849	11321	26762	17973	13279	25957
	2006		980	52164	27687	9304	22801	24808	15275	26383	45076
	2007		1364	70969	58867	24269	48958	73548	25824	4051	17589
6/30	2008		483	27600	14322	10520	7505	25602	16825	8207	19514

Drainage vs. Precipitation

The relationship between tile drainage and precipitation (Q/P) for all cropping systems during 2004-2006 is depicted in Figures 2 – 4 (Clipper 2007). During the establishment year (2004), March and April had below normal precipitation resulting in nearly zero Q/P for all cropping systems in April. Q/P increased May-June with increasing precipitation and declined in July 2004 with increasing evapotranspiration (ET) from cropping systems. Q/P continued to decline for all crops through August, and then increased in September due to the combination of reduced ET and above average precipitation. IBF-BB exhibited the lowest Q/P for May, June and September with values of 0.02, 0.04 and 0.02 respectively. Note that for 2005 and particularly 2006 (Figures 3 and 4) the annual crops (corn and soybean, respectively) exhibited high Q/P ratios in contrast to perennial crops.

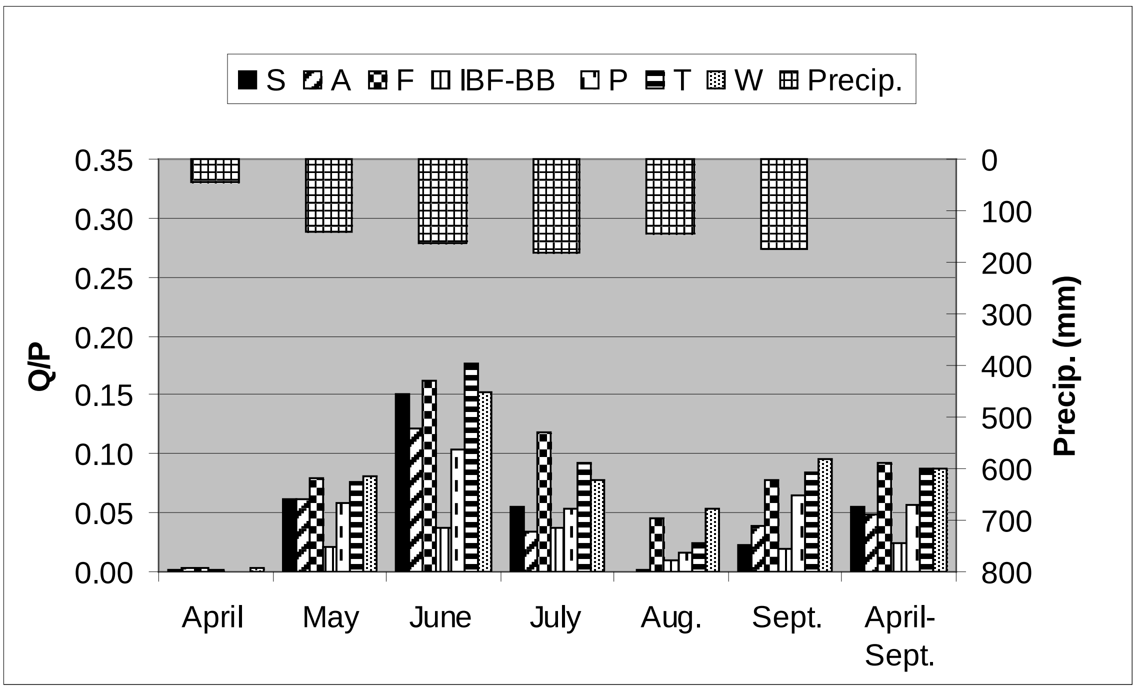


Figure 2. Ratio of monthly and seasonal tile flow to precipitation (Q/P) as influenced by cropping system in 2004 (Clipper 2007). S = Soybean, A = Alfalfa, F = Flax, IBF-BB = Illinois Bundleflower – Big Bluestem, P = Poplar, T = Turf, W = Willow

Table 10. Snow data from the SROC weather station for 2003-2004 winter season (Clipper 2007).

2003-2004			
Month	**Peak Snowpack (mm)**	**Snowfall (mm)**	**Snowfall 30-year Normal† (mm)**
November	25.4	76.2	213.4
December	177.8	297.2	269.2
January	152.4	175.3	332.7
February	330.2	403.9	200.7
March	152.4	157.5	256.5

† 1971-2000

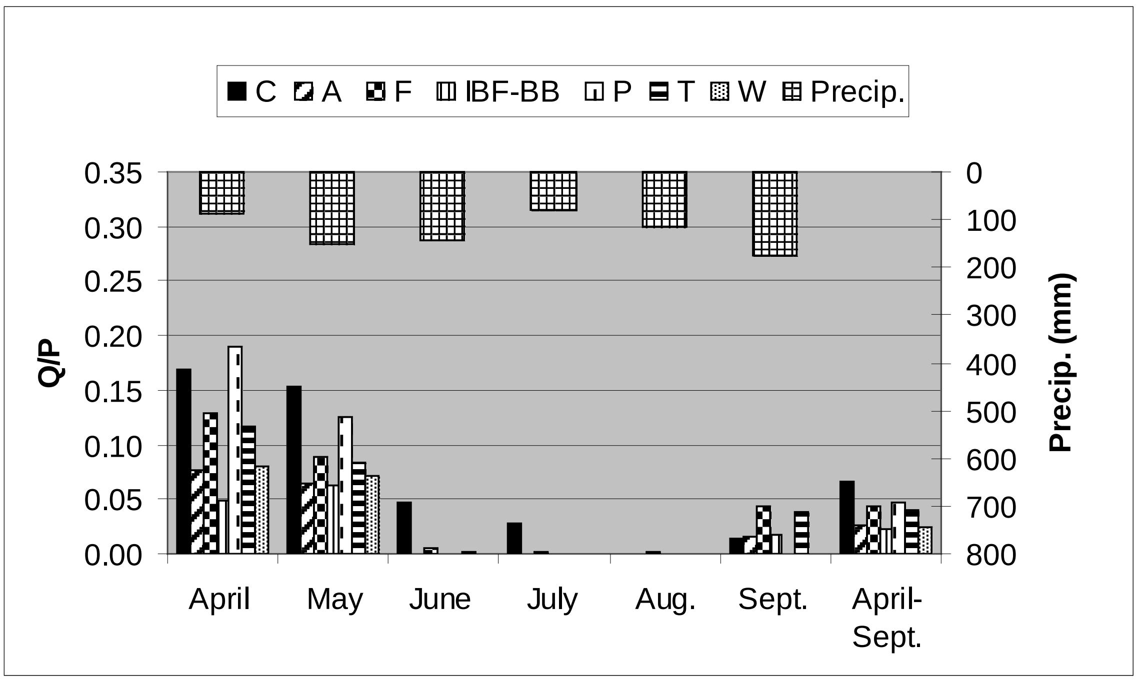


Figure 3 Ratio of monthly and seasonal tile flow to precipitation (Q/P) as influenced by cropping system in 2005 (Clipper 2007). C = Corn, A = Alfalfa, F = Flax, IBF-BB = Illinois Bundleflower – Big Bluestem, P = Poplar, T = Turf, W = Willow

Table 11 Snow data from the SROC weather station for 2004-2005 winter season.

2004-2005			
Month	**Peak Snowpack (mm)**	**Snowfall (mm)**	**Snowfall 30-year Normal† (mm)**
November	25.4	55.9	213.4
December	25.4	25.4	269.2
January	127.0	188.0	332.7
February	101.6	271.8	200.7
March	304.8	360.7	256.5

† 1971-2000

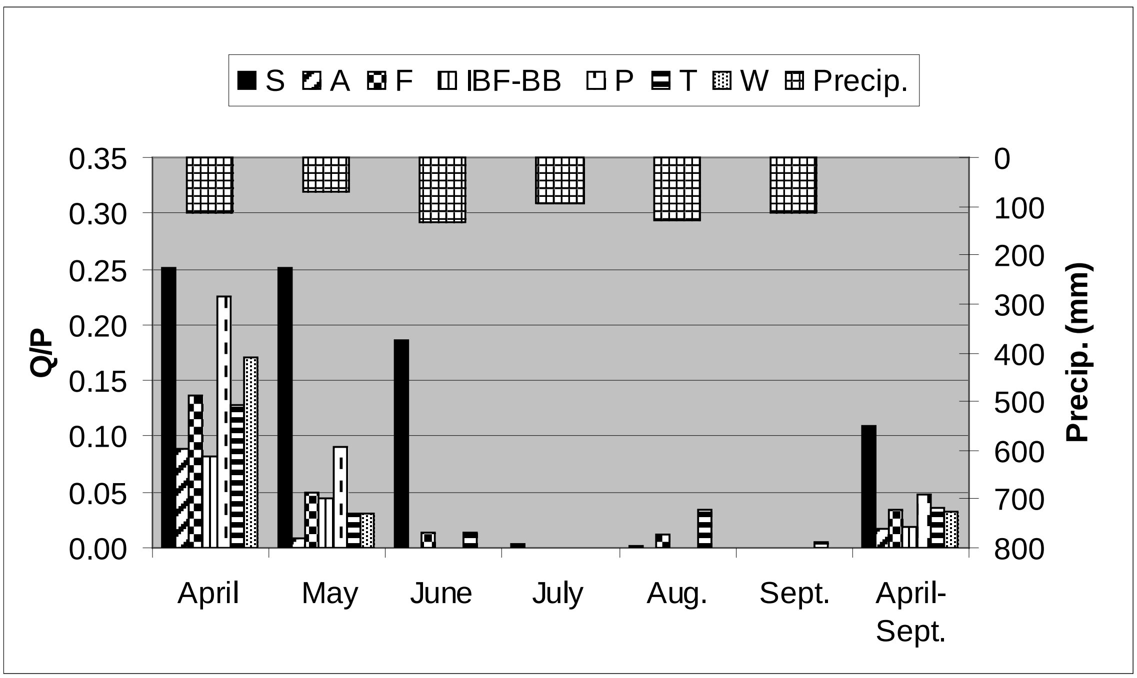


Figure 4. Ratio of monthly and seasonal tile flow to precipitation (Q/P) as influenced by cropping system in 2006. S = Soybean, A = Alfalfa, F = Flax, IBF-BB = Illinois Bundleflower – Big Bluestem, P = Poplar, T = Turf, W = Willow

Tile Drainage Water Quality

A major concern with tile drainage is nitrate nitrogen. Given that subsurface tile drains would not be expected to transport significant quantities of sediment (early sampling showed negligible TSS) and associated particulate P, the emphasis with tile drains centers on NO-3 (table 12). In 2005, high levels of NO-3 were measured from corn, willow and poplar plots, with the tree crops showing the residual effects of previous fertilizer applications. Following 2005 nitrate levels were consistently higher in annual crops than alfalfa and the woody crops (FI/sod, willow and poplar). Intermediate levels were measured in the native grass/legume and perennial flax plots.

Table 12. NO-3 loss in Kg/Ha from tile drainage under perennial and annual crops at SROC, Waseca from 2005-2008.

			ppt(mm)	Corn/Soybean	Corn/Corn+Rye	Alfalfa	Prairie Grass/Legume	Perenn Flax	False Indigo/Sod	Willow	Poplar
				Kg/Ha							
	2005		1138	13.6	M	1.6	2.9	4.4	1.1	8.7	11.3
	2006		980	11	3.7	1.2	2.5	2.3	0.6	N/A	N/A
	2007		1364	9	10.7	1.8	6.3	8.5	1.4	1.8	1.6
6/30	2008		483	5	0.9	0.6	0.4	2.3	0.5	1.9	0.3

Soil Moisture & Soil Frost under Annual and Perennial Crops

Differences in soil moisture among crops were examined on runoff plots, in landscape position studies, and in the tile drainage plots to determine total soil moisture use for the soil profile to a depth of 130 cm and to determine if differences occurred with increasing depth (Bryne, 2008). Soil moisture differences among crops indicated:

(1) During the 2004 – 2005 establishment period for perennials, annual soil moisture in the runoff plots did not differ among crops. The rooting depth and above ground biomass of perennial crops were not sufficiently different from annual crops during the first and second year following establishment.

(2) In the tile drainage plots soil moisture did not differ among crop types the first year. Soil moisture decreased at the deepest layers on the tile drainage plots, a result of the proximity to the tile drains.

(3) In the hillslope locations soil moisture varied considerably in the surface layer of both the mature hybrid poplar and corn-soybean. Differences were observed with

increasing depth. In 2004, soil moisture under the mature poplar was consistently lower than that under corn. In 2005, the field was planted in soy, and the soil under poplar was significantly drier only in April, May and June, but no significant differences were observed in July or August.

(4) Soil moisture measurements from 2006 and 2007 indicate that the mature woody species are depleting soil moisture at higher levels than during the first two years of establishment. Higher levels of transpiration explain these increases in soil water consumption (Hinck, 2008).

Soil Frost

Soil frost was measured with frost tubes on three sites at the SROC beginning in the 2004-05 winter (Byrne, 2008). The first two, which were the mature poplar grove and experimental plots underlain by tile drainage, were also monitored for soil moisture. The third site was landscape position plots. Data for 2006 – 2008 are summarized in Appendix 4.

During the winter of 2004-05, all plots had soil frost below 50cm depth (Bryne 2008). Concrete-type soil frost was found under all crop types, and soil frost was out of the soil at about the same time under all crop types. These results are likely explained by the lack of snow during November, December and early January and cold temperatures. With minimal snow cover during the coldest part of the winter, snow conditions were essentially identical in all sample locations, making similar soil frost penetration not unexpected.

From the data presented in Appendix 4, the following conclusions can be reached. Annual crops are largely bare soil during the winter months, as wind scours snow from fields unless there is crop stubble. Except for years with low snowfall (2006), lower snow depths occur largely in open fields compared to areas with perennial vegetation. Deeper snow is associated with shallower frost depth; therefore, the major influence that perennial crops have on soil frost is though their effects on trapping and retaining snow cover (Figures 5 and 6).

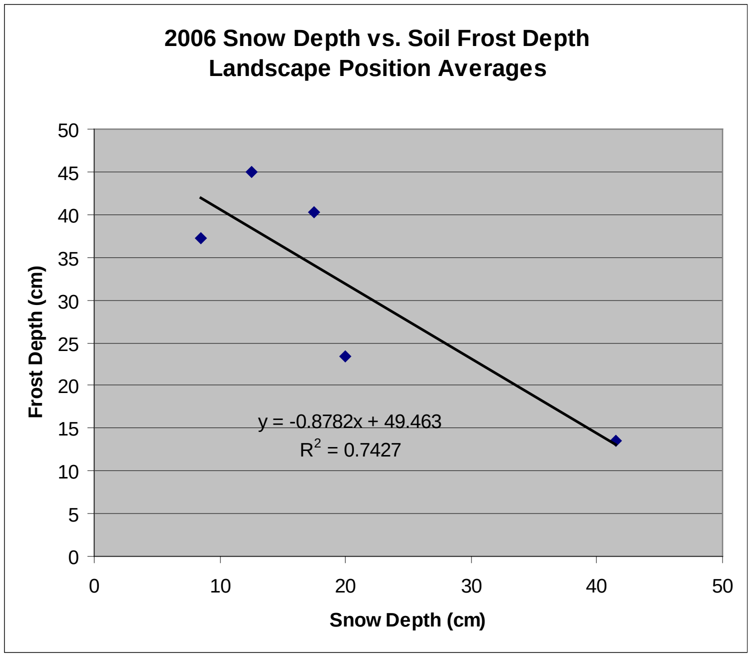


Figure 5 Relationship between snow depth and soil frost depth on landscape plots at SROC, Waseca for 2006.

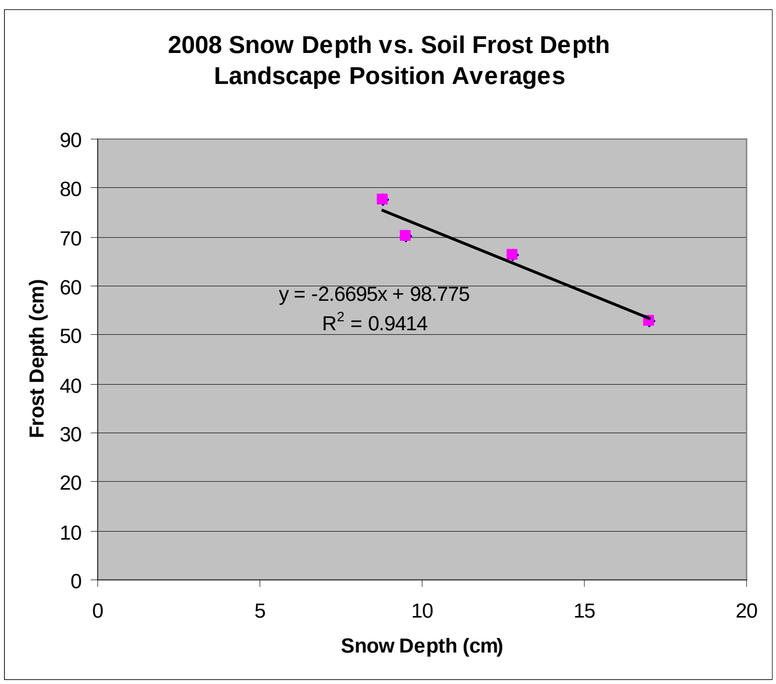


Figure 6 Relationship between snow depth and soil frost depth on landscape plots at SROC, Waseca for 2008

<u>Activity 2</u> – Hydrologic and water quality impacts. CINRAM and Forest Resources will use a paired watershed approach and measure the impacts (including TMDL impacts) of converting to a 3rd crop system as compared to traditional annual cropping systems.

Nested watersheds, tributaries to Elm Creek in the Blue Earth Basin, have been monitored since 2005 (Lenhart 2008). Monitoring sites were selected in the Kittleson watershed (W- designation in Figure 7) so that water flow from small watersheds that consist of mostly corn-soybean fields can be compared with the greater watershed that includes a mix of perennial vegetation, wetland area, and annual crops (Figure 7). The SHEEK watershed, with monitoring sites designated as S1 and S2 in Figure 7, was selected to represent larger watersheds that consist of significant portions of perennial vegetation and wetland complexes.

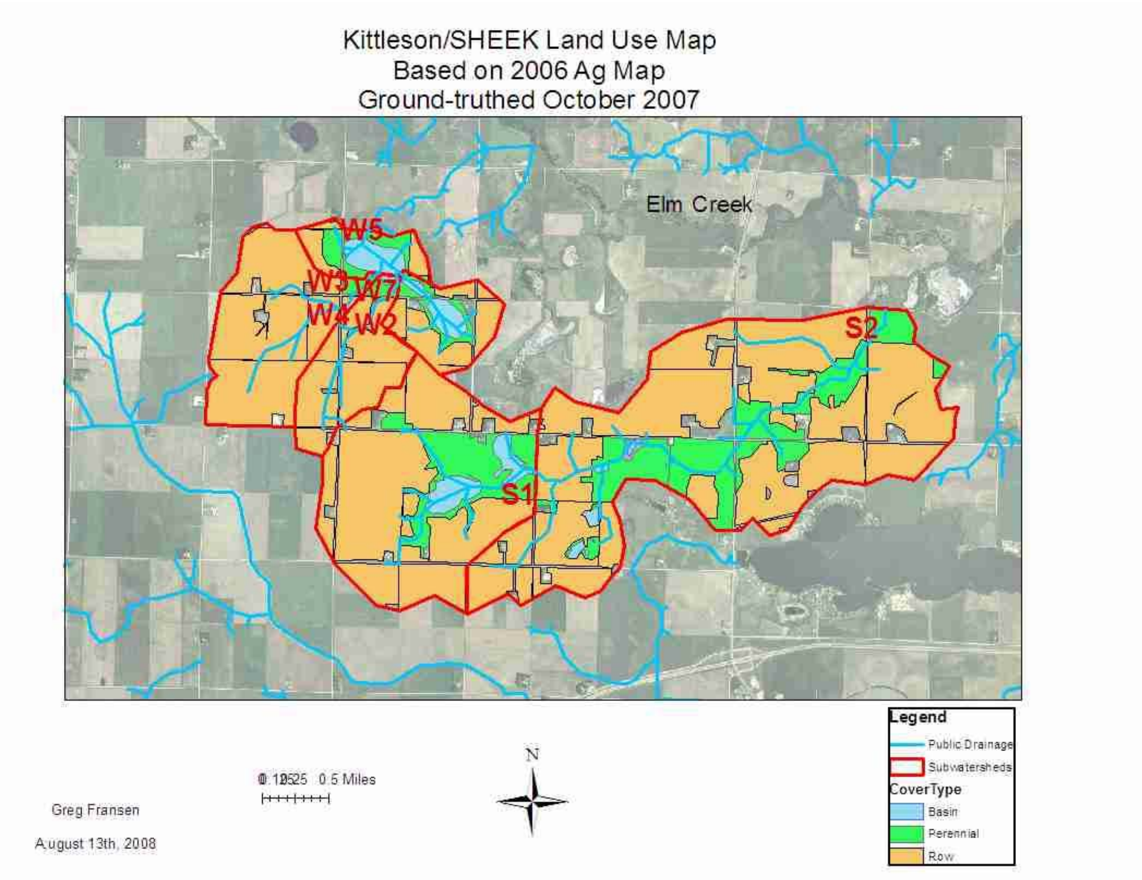


Figure 7. Monitoring sites for the Kittleson and SHEEK watersheds in the Elm Creek watershed of the Blue Earth Basin, Minnesota.

During the 2007 season, vegetative cover was classified using using ArcGIS, based on the 2006 National Ag Mosaic photographs, then verified by ground truthing. Ground cover was classified into 4 categories: "Perennial" (pasture, alfalfa, emergent wetland vegetation, buffer strips, and CRP grassland), "Row Crop" (corn and soybeans), "Lake/Wetland" (permanent to semipermanent surface water) and "Other" (farmstead and road). The results of the classification are shown in Table 13. The subwatersheds drained by the West and East branches of Judicial Ditch 73-2 had the highest proportion of row crop and the lowest proportion of perennial vegetation, while the subwatersheds drained by Judicial Ditch 37 had the highest proportion of perennial vegetation and the lowest proportion of row crop.

Table 13 Nested watersheds and their vegetative cover conditions associated with the monitoring locations in the Elm Creek watershed of the Blue Earth Basin, MN.

SUB-WATER -SHED	MONITORING STATIONS	SUBWATER-SHED SIZE (HECTARES)	DRAINAGE AREA-WETLAND RATIO	PEREN-NIAL PERCEN TAGE	ROW CROP PERCEN TAGE	LAKE/W ETLAND PERCEN TAGE	OTHER COVER PERCEN TAGE
Ditch 73-2 west branch	W3 (tile) W4 (surface)	289	N/A	2.5	92.4	0.0	5.1
Ditch 73-2 east branch	W7 (tile) W2 (surface)	164	81.2	4.1	86.9	1.2	7.8
Ditch 73-2 wetland	W5	651	14.5	9.3	77.7	6.9	6.1
Ditch 37 wetland	S1	560	15.9	17.6	69.4	6.3	6.7
Ditch 37 watershed outlet	S2	1654	37.9	19.1	70.4	2.6	7.9

Total flows were measured by area-velocity probes and dataloggers at stations W2, W3, W4, W7, and S2. At stations W5 and S1, water levels at the water control structures were measured by pressure transducer probes and dataloggers, and flows were determined by applying stage-discharge formulas for the control structures.

Summary of results from 2005-2006

The effectiveness of the wetland-perennial vegetation complexes in reducing peak flows, sediment, phosphorous and nitrogen loads was assessed by Lenhart (2008) for 2005-2006 immediately following restoration of the wetlands (Figure 7). Between 70-90% of annual inflow to the wetlands is sub-surface tile flow that averaged 17 to 19 mg/l of nitrate-nitrogen (NO3-N). Infrequent, but flashy surface runoff from two corn-soybean subwatersheds exceeded 740 and 100 mg/L of total suspended solids (TSS), respectively, and total phosphorous (TP) concentrations of over 1 mg/L. The two wetland complexes, referred to as SHEEK and Kittleson, effectively reduced peak flows, TSS and nitrogen but had mixed effectiveness for phosphorous removal. Peak flows of up to 1.5 m3/second (cms) were reduced by 85%, while small storms, less than 50 mm, were reduced nearly 100%. TSS removal exceeded 90% by both wetlands; due to a larger storage volume to drainage area ratio, the SHEEK wetland was more effective at reducing TSS and nitrogen, exporting only 3-7% of the NO3-N and less than 50% of the TSS exported by the Kittleson wetland. NO3-N outflow was nearly zero from mid June through October of 2005-2006 for both wetlands. The restored wetlands were less effective in removing phosphorous, as wetland outflow ranged from 0.125 to 0.230 mg/l.

This is considered to be due to high residual phosphorous levels in soils underlying the restored wetlands and to wind re-suspension of sediment and internal biogeochemical reactions. Reduction of flow volume may be the single most effective way to reduce nutrient loading downstream. A combination of wetland and grassland restoration and replacement of annual crops with perennial crops on portions of watersheds offers a means of reducing spring soil moisture and runoff in the MRB.

Results 2006 - 2007

During the 2006 and 2007 seasons, the datalogger at station W5 was erroneously set to overwrite its data every 2 days. Because it was downloaded to a computer approximately every 10 days, a general profile was seen, and missing data was filled in by using a water budget method (inputs – outputs = change in storage). Monitoring dates are shown in Table 14. Because the subsurface tile line of the west branch of ditch 73-2 began to leak and subsequently "blew out" during the 2006 season, flows at station W3 are underreported for both 2006 and 2007. Because of equipment failure leading to loss of 2006 data up until July 15th, and 2007 data up until May 18th, S2 flows are also underreported.

Response coefficients were obtained by dividing total flow volume by the volume of precipitation that fell during the monitoring period of each station, and are presented as unit-less ratios. In table 2.8, W2+W7 and W3+W4 represent the sums of surface and subsurface flows for the east and west (respectively) branches of JD 73-2.

Table 14. Flow response of subwatershed monitoring sites to precipitation at the Kittleson and SHEEK watersheds in the Elm Creek watershed, Minnesota.

	2006 Season April 1st – October 31st			**2007 Season April 1st –October 31st**		
Station	Volume (thousands of cubic meters)	Response coefficient	Dates monitored	Volume (thousands of cubic meters)	Response coefficient	Dates monitored
W2	85.0	.0816	3/2-11/10	6.1	.0066	4/5-11/17
W3	67.2	.0369	3/2-11/1	45.3	.0274	4/5-11/17
W4	51.5	.0279	3/2-11/1	263.4	.1591	4/5-11/17
W5	917.4	.2206	3/21-9/26	686.0	.1841	4/1-11/17
W7	257.9	.2474	3/2-11/10	94.0	.1006	4/5-11/17
S1	896.6	.2508	3/21-11/29	400.2	.1249	4/6-11/17
S2*	306.7	.0639	7/5-11/29	267.2	.0853	5/18-11/17
W3+W4	118.7	.0643		308.7	.1864	
W2+W7	342.9	.3289		100.1	.1072	

Table 15 Loading and flow weighted mean concentrations at the Kittleson and SHEEK watershed monitoring locations in the Elm Creek watershed, Minnesota.

2006 Season								
Station	TSS		NO3		TP		OP	
	Load (kg)	fwmc (mg/L)	Load (kg)	fwmc (mg/L)	Load (kg)	fwmc (mg/L)	Load (kg)	fwmc (mg/L)
W2	347.2	4.08	917.6	10.79	16.4	0.193	13.7	0.091
W3	87	1.29	1356	20.16	1.9	0.028	1.5	0.014
W4	1449	28.13	1123	21.8	17	0.330	14.8	0.133
W5	8298	9.05	2753	3.00	135.8	0.148	42.9	0.047
W7	5.1	0.020	5477	21.23	8.4	0.033	7.6	0.029
S1	4610	5.14	104.5	0.12	106.6	0.119	52.3	0.100
S2	1134	3.70	1234	4.02	71	0.231	60.8	0.198
W3+W4	1536	12.93	2479	20.87	18.9	0.159	16.3	0.147
W2+W7	352.3	1.03	6395	18.64	24.8	0.072	21.3	0.062
2007 Season								
Station	TSS		NO3		TP		OP	
	Load (kg)	fwmc (mg/L)	Load (kg)	fwmc (mg/L)	Load (kg)	fwmc (mg/L)	Load (kg)	fwmc (mg/L)
W2	No samples taken							
W3	255.7	5.25	840.1	17.24	1.0	0.021	0.9	0.018
W4	7144	27.12	2590	9.83	50.9	0.193	28.5	0.108
W5	17080	23.52	2733	3.76	203.9	0.281	28.6	0.039
W7	107.2	1.11	1517	15.73	2.2	0.023	2.2	0.023
S1	6999	16.96	110.9	0.27	47.9	0.116	18.4	0.045
S2	2494	8.33	1888	6.31	51.6	0.172	38.8	0.130
W3+W4	7400	23.71	3430	10.99	51.9	0.166	29.4	0.094
W2+W7	107.2	1.11	1517	15.73	2.2	0.023	2.2	0.023

Total loading in the 2005, 2006 and 2007 seasons was calculated for each monitoring station using the FLUX model (Walker, 1996). Briefly, daily flow data were used along with periodic water quality samples to predict daily concentrations and volume flows. The sum of the daily flows times their concentration is total loading and results are presented in Figures 8-11.

Subsurface drainage tile flows (stations W3 and W7) carried high loads of nitrate, but relatively low concentrations and loads of TSS, orthophosphate and total phosphorus. However, when the integrated subwatershed response is considered, surface channel flows measured at stations W2 and W4 contributed large amounts of TSS and total phosphorus. The Kittleson wetland (station W5) acted as a sink for nitrate in both seasons, conveying less than its total loading to Elm Creek. This effect is typical for wetlands with relatively long water retention times, during which nitrate is converted to nitrogen gas by microbes under anaerobic conditions, and lost to the atmosphere through degassing. In contrast, in two of three years the Kittleson wetland acted as a source for TSS, orthophosphate, and total phosphorus, exporting more than it took in for both the

2006 and 2007 season. The excess TSS and total phosphorus probably resulted from wind-aided re-suspension of bottom sediments to which phosphorus was attached, while the source of orthophosphate may have been phosphorus bound to oxidized iron in bottom sediments. During the summer, warming water promotes decomposition of organic material in deeper wetland waters, depleting oxygen in the waters overlying bottom sediments. Under warm, anaerobic water conditions, microbes reduce the iron, resulting in a release of phosphorus, which is bound less tightly to the reduced form of iron than the oxidized.

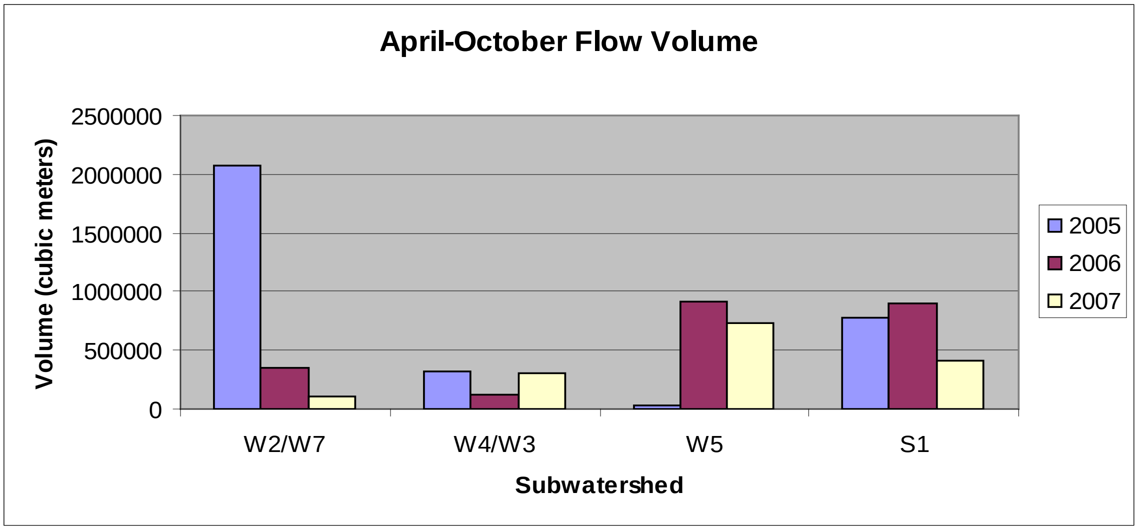
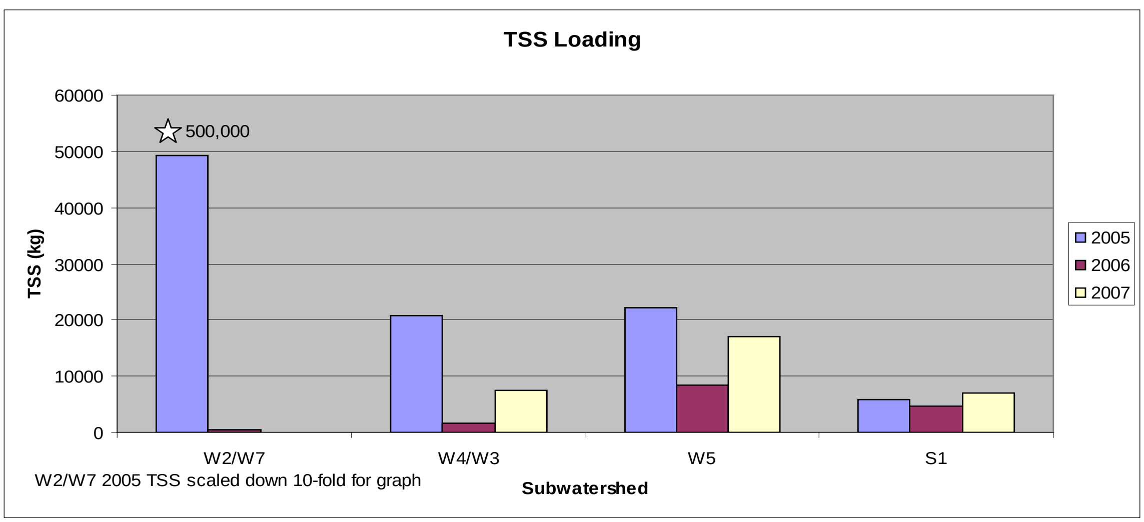


Figure 8 Flow volumes for monitoring sites on the Kittleson and SHEEK watersheds, tributaries to the Elm creek watershed, Minnesota from 2005-2007.



Note for graphs: For the 2005 W2/W7 TSS, the bar is reduced by 10x in order to make the scale of the graph more legible for the other values.

Figure 9 Total suspended solids (TSS) for monitoring sites on the Kittleson and SHEEK watersheds, tributaries to the Elm creek watershed, Minnesota from 2005-2007.

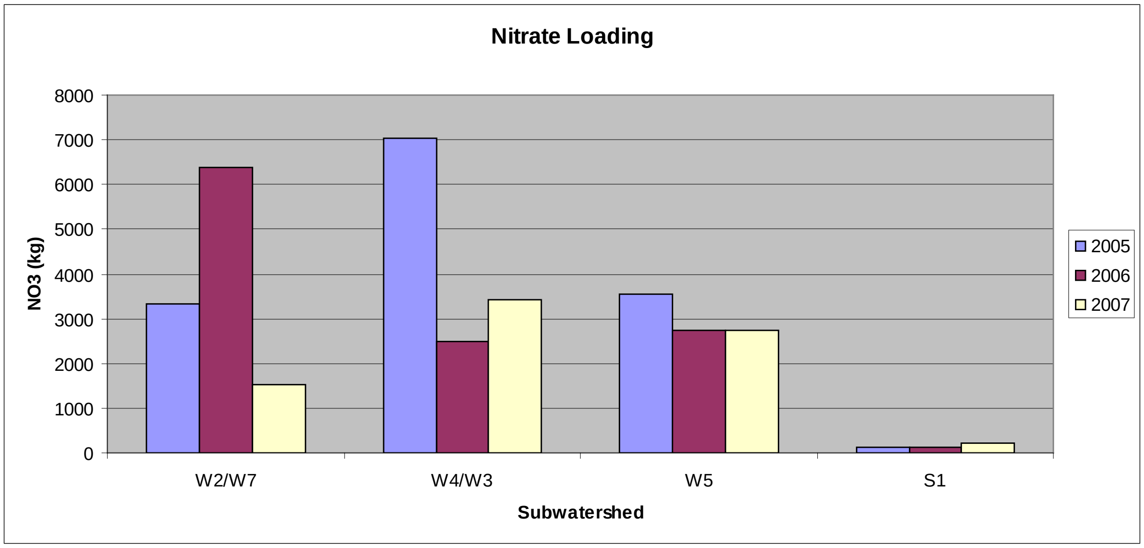


Figure 10 Nitrate loading for monitoring sites on the Kittleson and SHEEK watersheds, tributaries to the Elm creek watershed, Minnesota from 2005-2007.

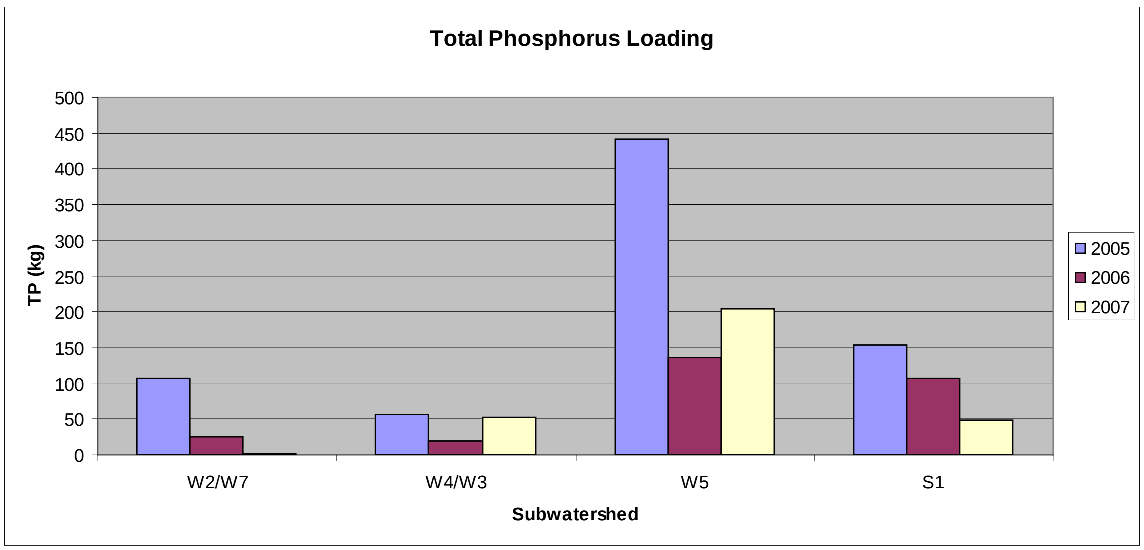


Figure 11 Total phosphorus loading for monitoring sites on the Kittleson and SHEEK watersheds, tributaries to the Elm creek watershed, Minnesota from 2005-2007.

Summary of Results from LCMR Funded Research and Associated Research Leveraged with LCMR Funding

Hydrologic changes with shifts toward corn-soybean systems and intensive tile drainage in the Minnesota River Basin

- Annual streamflow, baseflow and average annual peak flows have increased with corresponding increases in corn-soybean cropping and tile drainage. Stormflow discharge, baseflow and 7-day low flows have increased in the Lesueur and Cottonwood Rivers over the period 1939-2007, with baseflow and 7-day low flow levels being higher for the more intensively drained Lesueur than the Cottonwood (Ennaanay, 2006). The Cottonwood and Lesueuer watersheds as of 2006 were 84% agricultural land use of which 92% was in 2-yr corn-soybean rotation, and had artificial drainage density (largely tile drains) of 25 m/ha and 75 m/ha. Similar results from streamflow records have been reported in Iowa (Schilling and Libra, 2003; Schilling and Wolter, 2005).

Hydrologic differences between perennial and annual crops in the Minnesota River Basin

  - Streamflow simulations with the Hydrologic Simulation Program – Fortran (HSPF) model of the Cottonwood River indicated that conversions of corn-soybean to hybrid poplar (potential bioenergy crop) and accompanying restoration of wetlands in the wettest soils would generally reduce streamflows and importantly, reduce peakflows associated with 1.25 to 2.2 return periods, which represent bank-full flows (Ennaanay, 2006).
  - In comparing the hydrologic and water quality differences among corn-soybean rotation cropping and perennial crops (alfalfa, native grasses/legume mixes, perennial flax, false indigo, willow, and hybrid poplar) there is a varying period before perennial crops become established; in the case of woody plants there is at least a two-year period before plants begin to fully occupy the sites. As a result, runoff, sediment and nutrient loading from the respective crops vary accordingly.
  - As perennial crops become mature, runoff and drainage diminish in contrast to annual crops which do not become established normally until mid-late June. The spring period normally has the highest levels of streamflow and flooding in the region, suggesting that perennial crops with good ground cover can effectively diminish surface runoff and potentially peak flows during the spring runoff period.

- Ground cover crops are critically important in reducing surface runoff and sediment loads from tree plots, particularly during the first two years of establishment. In the case of willows, in which the soils were maintained bare of any understory, surface runoff, sediment and associated nutrient loads were excessive and higher than the annual crops. Where a rye ground cover was established under corn, sod was grown between willow and false indigo, or where alfalfa and native grass/legume mixes were well established, there were significant reductions in surface runoff , TSS, NO_3, and P in contrast to corn/soybean or corn/corn cropping systems.

- Comparisons of evapotranspiration (ET) among annual and perennial crops indicated that (1) perennial crops of willow, alfalfa and an Illinois bundle flower – big bluestem mix exhibited higher daily ET in April-May (1 – 3 mm/day), before corn/soybeans were actively transpiring, and (2) corn-soybean crops averaged higher daily ET in July (3.3 – 5 mm/day) than the perennial crops (1 – 1.8 mm/day) during the peak of the crop growing period (Hinck, 2008). Soil moisture during the summer and into early fall was found to be reduced under mature poplar in contrast to corn-soybean crops.
- Soil frost is deeper under annual crops than perennial crops. Perennial crops increase and retaining snow deposition which explains this response. Reduced soil frost depth and reductions in concrete type frost in late winter – early spring can help reduce runoff from rain-on-snow events and from rapid snowmelt.
- Tile drainage under annual and perennial crops is reduced as plants mature. For mature perennial crops, there are reductions in tile flow in the April-early June and over the entire April – September period in contrast to corn-soybean crops. Furthermore, nitrate loads are considerable lower from tile flow under perennial crops than corn-soybean crops.
- Nested watershed responses indicate that wetland-perennial vegetation complexes that intercept tile flow and surface runoff from corn-soybean fields result in reduced peak flows from intense rainfall events and reduced nitrate loading to downstream receiving water bodies. Restored wetlands, however, appear to be less effective at mitigating phosphorus loading that originates from agricultural practices. The reason for the higher levels of P being released from restored wetland may in part be due to high levels of residual P in the soils (previously farmed). Wind also mixes the bottom sediment and creates higher TSS and P values – a response that is currently being investigated further. In addition, work is on-going to explain P responses from these wetlands. Our research suggests that as the percentage of perennial crops and wetland area increases on a watershed, flow volumes, peaks, TSS and nitrate levels diminish.

<u>Activity 3</u> -- U of MN Agronomy and Waseca SROC will conduct the following research on 3rd crops grown in environmentally sensitive areas and evaluate new 3rd crop germplasm for use in landscape plantings

a. Establishment, production, and nutrient cycling impacts of woody and herbaceous 3rd crops in environmentally sensitive environments:

Native perennial herbaceous prairie species have emerged as leading bio-energy crops with the potential to produce high biomass yields as well as provide environmental benefits. Switchgrass has been targeted as having the greatest potential and research is underway to increase biomass yield and energy production through improved crop management and plant breeding. However, research has shown that when switchgrass is managed as a bio-energy crop in monocultures, plant density and yield tends to decline after three to four years.

In contrast to pure grass monocultures, polycultures of grasses and forbs generally had greater long-term productivity, stress tolerance, and ecosystem sustainability (Tilman et al. 1997, 2001). Low input high diversity (LIHD) mixtures of perennial grassland species have been shown to be nitrogen and carbon neutral bio-energy crops with superior long-term yields to monocultures (Tilman et al. 2006). While long-term studies have shown the benefits of native prairie plantings, there has been insufficient research on the short-term yield potential and initial stand development of these polycultures. On average it takes three years for prairie plantings to establish and reach a level of sustained yield and we anticipate that the relationship between diversity and productivity will strengthen with the development of the stand (personal comm. M.H.H Stevens 2008). Therefore, it is critical to evaluate the productivity and population dynamics of monocultures and polycultures during the establishment phase.

Methods:

An experiment was established in 2006 in 4 diverse environments at the University of Minnesota in St. Paul, MN (45° 0' 60" N, 93° 8' 13" W), the Southern Research and Outreach Center in Waseca, MN (44° 03' 40" N, 93° 32' 15" W), the Sand Plain Research Farm in Becker, MN (45° 23' 24" N, 93° 52' 59" W), and the Southwest Research and Outreach Center in Lamberton, MN (44° 14' 22" N, 95°17' 52" W). Soils at these locations are Waukegan silt loam (fine-silty over sandy, mixed, Typic Hapludoll), Webster clay loam (fine-loamy, mixed, mesic, Typic Haplaquoll), Hubbard loamy sand (sandy, mixed, Udorthentic Haploboroll), and Normania clay loam (fine-loamy, mixed, mesic, Aquic Haplustoll), respectively.

Twelve treatments with varying levels of species diversity (1, 4, 8, 12, or 24 species) were established in 2006 using native tallgrass prairie species (Table 16). The experimental design was a randomized complete block with six replications per location (288 plots). After a killing frost (-4.44° C) in late October 2007, the biomass yield of all plots was estimated by harvesting a 1- by 0.5-m quadrant to a height of 10 cm. The remaining biomass was then removed with a flail-type harvester. Harvested samples were weighted in the field, dried in an oven at 60° C for 48 h, separated by species, and re-weighed. An additional biomass sample, of individual plant species, was collected within the plot, weighted in the field, air- dried (~ 30° C) on drying racks, and used for carbohydrate analysis.

Results

Herbage Biomass Yield

Averaged for all treatments, herbage biomass yields were greatest ($P< .001$) at Lamberton and least at Becker. In addition, herbage biomass yield of individual species and polycultures were consistently among the highest at Lamberton and were among the lowest at Becker and St. Paul (Figure 10). As expected because of these diverse environments, a location by treatment interaction occurred.

Biomass yield differed among treatments but a grass monocultures or grass dominated polyculture were among the highest yielding treatments at each location. At Lamberton, switchgrass and Canada wildrye were the highest yielding grasses. Switchgrass was the highest yielding grass at Becker and Waseca and at St. Paul, Canada wildrye was the highest yield species. Yields of big bluestem and Indiangrass were less than for the highest yielding monoculture at each location . The grass polyculture was dominated by either Canada wild rye or switchgrass at each location and had yields similar to the dominant species when grown in monoculture.

The productivity of the polycultures containing a diversity of species and functional groups was not consistent over locations and an increase in functional and species diversity did not always provide a yield advantage. It appears that the productivity of polycultures was more of a function of the predominant species. At Lamberton, the four-species grass polyculture that was dominated by Canada wildrye had greater biomass yield than all other polycultures; the grass polyculture had 62% greater aboveground biomass than grasses grown with legumes and 86% greater aboveground biomass than grasses grown with forbs. Yield of the forb polyculture, grass-forb polyculture, and the grass-legume-forb polyculture that were all dominated by Maximillian sunflower were similar and all exceeded yield of the high diversity-24 species mixture. In contrast, at Waseca, yields of the grass polyculture were similar to those of the forb polyculture, grass-legume mixture, and grass-legume-forb mixture. As at Lamberton, Maximillian sunflower was a dominant forb but yellow coneflower-goldenrod also had a significant presence. At both, Waseca and Lamberton, the legume polyculture that was dominated by Canada milkvetch had significantly lower yields than the grass polyculture.

At St. Paul and Becker, biomass productivity was significantly less than in southern Minnesota, composition of most mixtures shifted, and relative yields of polycultures changed. The 24 species polyculture was the most productive polyculture at St. Paul. The grass ford, legume forb, and grass-legume-forb polycultures that had predominated at Lamberton because of the presence of Maximillian sunflower were relatively lower yielding here due to the greater presence of coneflower and goldenrod. Also, the grass-legume mixture that was mostly grass had yield similar to those of the grass polyculture.. At Becker, the grass polycultures and the grass-legume polycultures were higher yielding than more diverse mixtures containing grasses, forbs, and legumes.

The forb polycultures and the legume-forb polycultures that were mostly maximillan sunflower, were the lowest yielding mixtures.

The legume polyculture was consistently among the lowest yielding at each location. The highest yielding legume in our experiment was Canada milkvetch, which was so competitive that it may have led to the decline of other legume species at some locations. This fast growing legume often covered the entire plot and created a closed canopy over smaller emerging seedlings of other species. Since all legumes (four species) were planted together in treatment six and then combined with other functional groups (grasses, non-leguminous forbs, and grasses + non-leguminous forbs) we can evaluate legume productivity between treatments. At Lamberton, the legume polyculture had 18% greater aboveground biomass yield when grown in a treatment with grasses. Likewise, at Waseca the legume polyculture had 30% greater yield when grown in a polyculture as compared to a pure stand. This is most likely related to the presence of a cool season grass, Canada wildrye, which competed very well with early season annual weeds. This may have contributed to the competitive ability of legumes later in the season. At St. Paul and Becker, the overall establishment of legumes during 2007 was too low for statistical analysis.

Chemical composition

We evaluated chemical composition of six plants that predominated in monoculture and mixtures (Table 19). For example, cell wall carbohydrate production affects the ethanol yield and lignin reduces cellulose availability. For all forms of utilization, dry matter content influences the costs of transportation and also the energy used in burning. All native grasses had greater lignin, ash, and total carbohydrate concentration then the legume or forbs ($P<.001$). Canada milkvetch, a perennial legume, had the highest concentration of crude protein and lowest Klason lignin while switchgrass had the lowest crude protein and highest total carbohydrate concentration.

Carbohydrate composition and amount differed among native plant species. As expected, glucose was the predominant monosaccharide in all species while mannose had the lowest concentration. Overall, grasses had greater glucose and xylose concentrations than forbs ($P<.001$). Canada milkvetch had the lowest glucose concentration ($P<.001$), while switchgrass had higher xylose concentration than all other species except Indiangrass ($p<.001$). Overall, plants grown at Lamberton had a greater xylose concentration than plants grown at St. Paul or Becker ($P<.001$). Forbs generally had greater concentrations of mannose than grasses, although big bluestem had a greater amount than other grasses.

The variation in chemical composition of native plant species is often explained according to variation in species functional groups, as grasses and forbs have different proportions of the dominant C5 and C6 carbohydrate. However, analysis of variance showed an interaction between species and location that may further explain differences in total carbohydrates. For example, Maximilian sunflower grown at Lamberton had greater glucose and galactose concentration than Maximilian sunflower grown at either St. Paul or Becker. Likewise, Canada wildrye grown at Lamberton had greater galactans than when grown at St. Paul. Overall, biomass yield was greatest at Lamberton and lowest at Becker during the 2007 harvest. This relates to the maturity of the stand at harvest, since high yielding sites had more mature plant material than lower yielding sites during the establishment phase. Total carbohydrates were highest for switchgrass and lowest for Canada wild rye, ranging from 357 to 604 g kg-1 DM for all species. Carbohydrate yield affected estimated potential ethanol production. Switchgrass and Canada wildrye had the greatest ethanol yields (Table 20).

Table 16. List of individual species divided into plant functional groups and a list of species combination in each treatment.

Perennial grasses	**Legumes**	**Perennial Forbs**
A- Switchgrass, *Panicum virgatum*	I- Canadian milkvetch, *Astragalus canadensis*	Q- Butterfly milkweed, *Asclepias tuberosa*
B- Big bluestem, *Andropogon gerardii*	J- Wild blue indigo, *Baptisia australis*	R- Maximilian sunflower, *Helianthus maximilianii*
C- Indiangrass, *Sorghastrun nutans*	K- Purple prairie clover, *Dalea pupurea*	S- Stiff goldenrod, *Solidago rigida*
D- Canada wild rye, *Elymus canadensis*	L- Lead plant, *Amorpha canescens*	T- Yellow coneflower, *Ratibida pinnata*
E- Little bluestem, *Schizachyrium scoparium*	M- Perennial lupine, *Lupinus perennis*	U- Rough blazing star, *Liatris aspera*
F- Slender wheatgrass, *Elymus trachycaulus*	N- Partridge pea, *Chamaecrista fasciculata*	V- Wild bergamot, *Monarda fistulosa*
G- Sideoats grama, *Bouteloua curtipendula*	O- Showy tick trefoil, *Desmodium canadense*	W- Cup plant, *Silphium perfoliatum*
H- Virginia wild rye, *Elymus virginicus*	P- Roundheaded bushclover, *Lespedeza capitata*	X –Golden Alexander, *Zizia aurea*

Treatments

1-A	7- Q, R, S, T
2-B	8- A, B, C, D, I, J, K, L
3-C	9- A, B, C, D, Q, R, S, T
4-D	10- I, J, K, L, Q, R, S, T
5-A, B, C, D	11- A, B, C, D, I, J, K, L, Q, R, S, T
6- I, J, K, L	12- A through X

Table 17. Protein, ash, Klason lignin,and total carbohydrates content of six perennial tallgrass prairie species.

Species Location	Crude Protein (g kg^{-1} DM)	Ash (g kg^{-1} DM)	Klason lignin (g kg^{-1} DM)	Carbohydrates (g kg^{-1} DM)	Total of components (g kg^{-1} DM)
Switchgrass					
Lamberton	28	58	160	600	846
Waseca	29	92	166	581	868
St. Paul	94	94	145	472	805
Becker	42	58	152	573	824
Average	**48**	**76**	**155**	**556**	**836**
Big Bluestem					
Lamberton	50	83	171	568	871
Waseca	59	93	166	527	845
St. Paul	-	-	-	-	-
Becker	79	66	178	537	860
Average	**63**	**80**	**172**	**544**	**859**
Indiangrass					
Lamberton	48	96	169	565	878
Waseca	35	92	158	598	883
St. Paul	81	101	169	490	841
Becker	104	82	176	489	851
Average	**67**	**92**	**168**	**536**	**863**
Canada wild rye					
Lamberton	56	67	158	604	885
Waseca	63	95	178	539	875
St. Paul	-	-	-	-	-
Becker	113	82	158	484	837
Average	**77**	**82**	**165**	**542**	**866**
Canadian milk vetch					
Lamberton	102	59	115	479	755
Waseca	169	60	106	442	776
St. Paul	175	72	105	401	753
Becker	225	-	95	357	677
Average	**16 8**	**63**	**105**	**420**	**740**
Maximilian sunflower					
Lamberton	44	43	129	522	738
Waseca	31	51	125	502	709
St. Paul	69	-	128	376	-
Becker	75	92	137	386	689
Average	**55**	**62**	**130**	**446**	**712**

Table 18. Summary of structural carbohydrates present in various tallgrass prairie species. Results are presented as an average across locations and replications. CWR= Canada wild rye, CMV = Canada milkvetch, and Max. Sunflower = Maximilian sunflower.

Species	Glucans ($g\ kg^{-1}$ DM)	Galactans ($g\ kg^{-1}$ DM)	Xylans ($g\ kg^{-1}$ DM)	Arabians ($g\ kg^{-1}$ DM)	Mannans ($g\ kg^{-1}$ DM)	Lignin ($g\ kg^{-1}$ DM)	Ash ($g\ kg^{-1}$ DM)
Switchgrass	301	25	189	37	5	156	76
Big bluestem	311	22	163	35	13	172	80
Indiangrass	308	19	167	35	6	168	92
CWR	318	18	169	31	7	165	82
CMV	219	46	100	39	16	105	63
Max. Sunflower	278	27	102	21	18	130	62

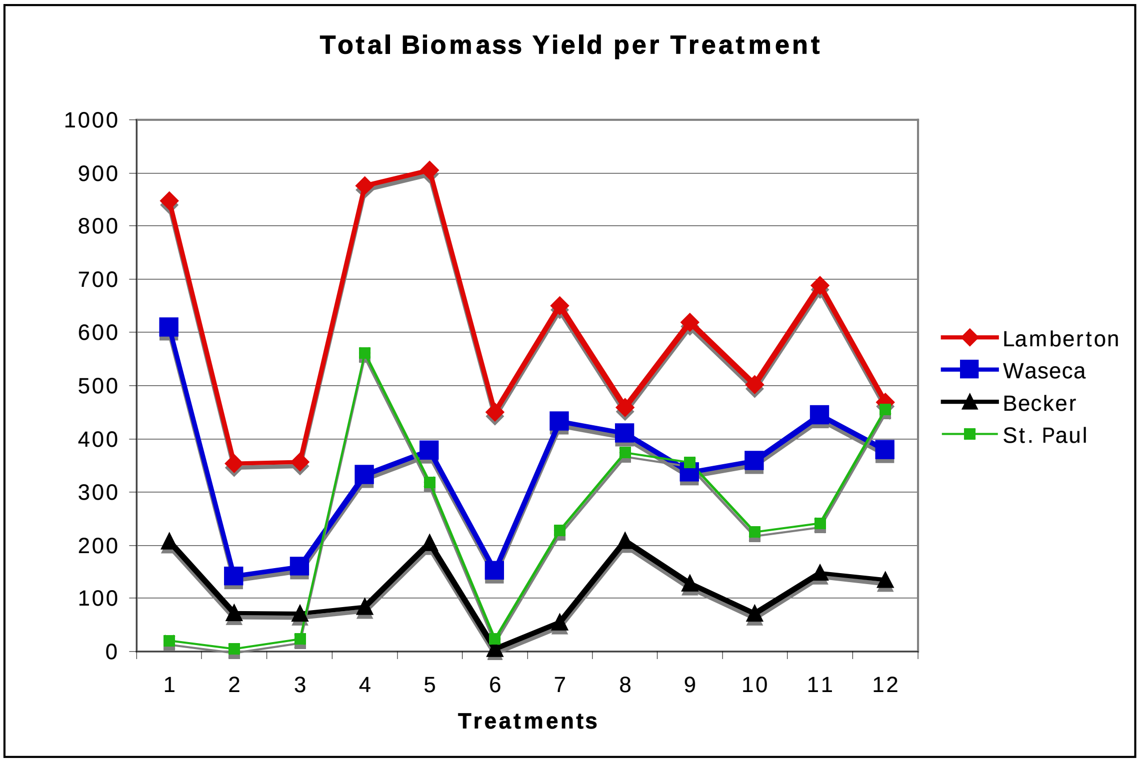
Table 19. Summary of Klason lignin, C_5 and C_6 carbohydrates in six tallgrass prairie species. Results are presented as an average across locations and replications. C_5 carbohydrates include xylose and arabinose and C_6 include glucose, galactose, and mannose.

Species	**Klason lignin**	**C_6 Carbohydrates**	**C_5 Carbohydrates**
	($g\ kg^{-1}$ DM)	**($g\ kg^{-1}$ DM)**	**($g\ kg^{-1}$ DM)**
Switchgrass	156	331	226
Big bluestem	172	346	198
Indiangrass	168	333	202
Canada wild rye	165	343	200
Canada milkvetch	105	281	139
Maximilian sunflower	130	323	123

Table 20. Potential ethanol yield calculated from the sum of hexose and pentose sugars. The theortiical ethanol yeidl calculator is located at: www.eere.energy.gov/biomass/ethanol_yield_calculator.html.

Species / Location	Ethonol Yield (gal dry ton^{-1} DM)	Ethanol Yield (L ha^{-1})	60% efficiency Ethanol Yield (L ha^{-1})	90% efficiency Ethanol Yield (L ha^{-1})
Switchgrass				
Lamberton	104	3682	2209	3314
Waseca	102	2581	1549	2323
St. Paul	82	71	43	64
Becker	100	868	521	781
Average	97	1801	1080	1621
Big Bluestem				
Lamberton	99	1468	881	1321
Waseca	92	543	326	488
St. Paul	-	-	-	-
Becker	93	281	169	253
Average	95	764	458	688
Indiangrass				
Lamberton	98	1463	878	1317
Waseca	104	694	417	625
St. Paul	86	85	51	77
Becker	85	252	151	227
Average	93	624	374	561
Canada wild rye				
Lamberton	105	3851	2310	3466
Waseca	94	1304	782	1173
St. Paul	-	-	-	-
Becker	85	295	177	265
Average	95	1816	1090	1635
Canadian milk vetch				
Lamberton	83	1563	938	1407
Waseca	77	482	289	434
St. Paul	70	69	41	62
Becker	62	14	8	12
Average	73	532	319	479
Maximilan sunflower				
Lamberton	91	2348	1409	2113
Waseca	88	750	450	675
St. Paul	65	52	31	47
Becker	67	148	89	134
Average	78	825	495	742

Figure 12. Total biomass yield per treatment at all locations.



b. Perennial germplasm evaluation

Studies will be conducted at the University of Minnesota SROC and UMore Park to evaluate two promising crops that can produce biomass, economic as well as environmental benefits. At least five germplasms of false indigo and perennial flax will be measured for establishment, biomass, and fiber yield. Plot size will be 18-22 feet long by 20 feet wide. False indigo will be planted in 4 foot spacings (4 rows wide). Perennial flax will be broadcast seeded.

Plant establishment will be assessed in each plot at the end of each growing season by counting plants within the plot area. We will measure biomass by cutting plants within a meter square area to a 3 cm height. The biomass will be ground and the N, P, Ca, K, and Mg concentrations determined at the University of Minnesota Plant and Soil Testing laboratory in St. Paul. Perennial flax grain, and fiber yield will be measured.

The value of the biomass crops for energy production will be measured for direct combustion applications. For potential use in direct combustion, and ultimate proximate heating analysis will be conducted to determine BTU, ash, ash composition, fixed C, volatiles, major elements, and moisture content. Fiber content of all germplasm will also be determined.

Activity 4 – U of MN Applied Economics and CINRAM will conduct economic assessment of 3rd crops for bio-energy and bio-products compared to traditional production systems.

a. A systems analysis will evaluate the profitability of producing, harvesting, transporting, and processing of biomass.

We have gathered production cost and benefit information on hazelnuts, switchgrass, hybrid poplar and willows that will also allow us to estimate costs and benefits for other grass based systems. We are also able to use estimates of costs and benefits from native prairie plantings although most prairie restoration that goes on currently is not put in for production and is probably more expensive than what would be expected for a commercial operation. This work will be continued and refined through our current Xcel Renewable Energy Fund Grant that runs through 2013.

b. Estimate the costs and benefits of planting 3rd crops and prepare a decision making model to inform producers.

We currently have a spreadsheet model that has been developed based upon a hazelnut planting that can and will be adapted to other 3rd crops. As in "a" above, this work is being continued through our Xcel Renewable Energy Grant. Copies can be made available to interested parties.

Personnel: $ 220,000 Other: $ 39,000 Travel and Monitoring Supplies

Summary Budget Information for Result 2:	**LCMR Budget**	**$ 259,000**
	Balance	**$ 0**

Completion Date: June 30, 2008

<u>Result 3</u> – "Education, Outreach, Marketing and Communication" Budget: $ 110,055

This result is now under a separate workplan for Rural Advantage

V. TOTAL LCMR PROJECT BUDGET: [7/1/05 TO 6/30/08] – UMN PORTION

All Results: Personnel:	**$220,000**	1.0 FTE Waseca SROC; 1.5 FTE/ Forestry; 1.0 FTE Agronomy
All Results: Other:	**<u>$ 39,000</u>**	travel; supplies; outreach; printing; promotion of 3rd crops

TOTAL LCMR PROJECT BUDGET (UMN Portion): $259,000

VI. Other Funds and Partners:

A. Project Partners: Rural Advantage–Meschke, $241,000; UMN Agronomy–Wyse, Scheaffer, Jordan $61,000; CINRAM/Applied Economics-Current $42,000; Forest Resources-Brooks, $96,000; Waseca SROC-Johnson $60,000; Koda Power-Ellison, $0; State Energy Office, Dept. of Commerce-Taylor, $0

B. Other Funds Being Spent during the Project Period: [Selected Projects]
DOD and IREE- UMN Biorefining Center $400,000 Value Added Technologies to Utilize Crops
General Mills & UM- Biorefining Center $300,000 for spectrometer for biomaterial study
UM BioTech Institute- $43,000 Value Added Processing of Minnesota Cereal Crops
Koda Power- $25,080,000 investment in Engineering, Boiler and Turbine for Shakopee Plant
UMN-EPA Section 319 - $ 295,516 - Assessing Potential of Watershed and Stream Channel Modifications on Suspended Sediment, Turbidity and Nutrients n the Blue Earth River Basin.

C. Required Match: None

D. Past Spending: [Selected Projects]
BERBI - 2003 LCMR "Native Plants and 3rd Crops For Water Quality" $622,000
U of MN - CSREES "Improving Water Quality and Enhancing Hydrologic Stability of the Minnesota River through Agroforestry and Other Perennial Cropping Systems" $556,500
BERBI -Bush Foundation $140,000 BERBI - McKnight Foundation $ 30,000
BERBI- EPA Section 319 – Accelerated Implementation $300,000
IREE – UMN- Production of Bio-energy & Bio-Products from Alfalfa & Willow $25,000
IREE- UMN- Sustainable Fuel Sourcing Systems for Biomass Energy Production $24,500
UMN - Greater Blue Earth Turbidity TMDL $179,000

DOD- Biorefining Center $560,000 Value added technologies for utilizing crop byproducts/residues

E.TIME: July 1, 2005 through June 30, 2008 to allow two full growing seasons

VII. DISSEMINATION:

Dissemination activities for this project were the responsibility of Rural Advantage and are reported by Rural Advantage in a separate report. Nonetheless results from our research were reported through presentations at scientific meetings and a number of Master's and Doctoral Theses have been prepared as a result of this project and leveraged research.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than December 31 and June 30 each year of the project.

A final work program progress report and associated products will be submitted by June 30, 2008.

IX. RESEARCH PROJECTS:

X. APPENDICES

Appendix A - Water Quality Summaries for Runoff Plots, SROC, Waseca, 2004 (establishment year) and 2007 (when perennials were well established)

Appendix B - Summary of Tile Flow Data from SROC, Waseca

Appendix C - Soil Frost and Snow Data for 2006-2008 at SROC, Waseca

Appendix A
Water Quality Summaries for Runoff Plots, SROC, Waseca, 2004 (establishment year) and 2007 (when perennials were well established)

Table 1A: Summary of total suspended solids for snowmelt and rainfall events in 2004, Waseca, MN.

	Average TSS loadings in kg/ha per treatment				
Event Date	Willow	Soybean	Illinois bundleflower	Hazelnut	Perennial flax
2-Mar-04	21	N/A	57	55	16
9-Jun-04	1750	297	441	N/A	58
11-Jul-04	3017	1194	348	96	248
22-Aug-04	160	97	10	9	0
15-Sep-04	1968	204	257	11	128
7-Oct-04	498	192	0	0	11
Total	7414	1983	1112	171	461

Table 2A: Summary of total phosphorus production for snowmelt and rainfall events in 2004, Waseca, MN.

	Average TP loadings in kg/ha per treatment per event				
Event Date	Willows	Soybeans	IBF	Hazels	Perennial Flax
2-Mar-04	0.13	N/A	0.27	0.18	0.16
9-Jun-04	4.04	0.99	1.02	0.00	0.14
11-Jul-04	2.26	1.47	0.11	0.11	0.27
22-Aug-04	0.37	0.20	0.02	0.02	0.00
15-Sep-04	3.59	0.48	0.56	0.08	0.33
7-Oct-04	1.79	0.43	0.00	0.00	0.03
Total					

Table 3A: Summary of nitrate production for snowmelt and rainfall events in 2004, Waseca, MN.

	Average NO-3 loadings in kg/ha per treatment per event				
Event Date	Willows	Soybeans	Illinois bundleflower	Hazels	Perennial Flax
2-Mar-04	0.644	N/A	0.114	0.354	0.238
9-Jun-04	0.029	0.036	0.051	0.000	0.005
11-Jul-04	0.131	0.089	0.035	0.037	0.052
22-Aug-04	0.055	0.043	0.002	0.003	0.000
15-Sep-04	0.276	0.222	0.314	0.031	0.358
7-Oct-04	0.172	0.071	0.000	0.000	0.006

Table 4A: Summary of Total suspended Solids (TSS) in Kg/Ha for 2007 and part of 2008, Waseca runoff plots.

			Rainfall		TSS (Kg/Ha)						
			mm (in)		Corn/Soy	Corn/Corn	Corn/Corn+Rye	Alfalfa	Native Grass/Legume	False Indigo+sod	Willow
March	2007		114 (4.5)		1.5	2.4	0.1	0.3	0.1	0.0	16.6
April	2007		48 (1.9)		0.0	0.0	0.1	0.0	0.0	0.0	0.0
May	2007		86 (3.4)		2.9	12.1	1.0	0.2	0.2	0.3	86.8
June	2007		107 (4.2)		737.6	398.7	9.3	4.5	0.9	0.8	534.0
July	2007		59 (2.3)		5.0	3.7	0.4	0.8	0.1	0.2	79.4
Aug	2007		273 (10.8)		18.7	81.4	3.2	1.0	0.4	0.8	639.9
Sept	2007		119 (4.7)		24.0	243.5	2.1	0.2	0.1	0.2	359.2
Oct	2007		144 (5.7)		125.6	1027.4	3.7	0.2	0.1	0.1	606.4
Total	2007		835 (32.9)		915.2	1769.2	19.8	7.2	1.9	2.5	2322.4
March	2008		47 (1.9)		0.0	0.0	0.0	0.0	0.0	0.0	0.0
April	2008		140 (5.5)		1.6	2.7	0.9	0.2	0.1	0.5	0.2
May	2008		164 (6.5)		2.6	17.6	0.8	0.2	0.6	0.4	10.0
June	2008		146 (5.7)		0.5	15.7	0.4	0.1	0.3	0.1	4.2
July	2008		174 (6.9)		0.4	34.0	1.3	0.0	0.2	0.2	10.4
YTD	2008		671 (26.4)		5.2	69.9	3.4	0.5	1.2	1.1	24.8

Table 5A: Summary of Nitrate-N in g/Ha for 2007 and part of 2008, Waseca runoff plots.

Month	Year		NO 3	(g/Ha)						
			Corn/Soy	Corn/Corn	Corn/Corn+Rye		Alfalfa	Native Grass/Legume	False Indigo+sod	Willow
March	2007		3.9	4.4	0.8		0.6	1.7	0.7	17.3
April	2007		0.0	0.0	0.9		0.0	0.1	0.0	0.0
May	2007		2.5	80.4	3.7		3.5	3.8	2.1	17.8
June	2007		214.6	315.0	63.4		43.6	12.4	6.1	238.7
July	2007		1.6	2.8	3.6		1.2	1.2	0.7	10.3
Aug	2007		11.7	47.8	31.1		10.2	6.2	6.0	75.4
Sept	2007		10.9	39.0	7.8		3.8	5.7	4.3	31.7
Oct	2007		30.6	137.3	5.2		6.6	2.7	1.0	52.9
Total	2007		275.8	626.8	116.6		69.6	33.7	20.9	444.2
			0.0	0.0	0.0		0.0	0.0	0.0	0.0
March	2008		0.0	0.0	0.0		0.0	0.0	0.0	0.0
April	2008		0.3	0.6	0.3		0.3	0.2	0.2	0.2
May	2008		2.6	3.1	1.0		1.7	3.0	0.4	2.4
June	2008		2.1	2.5	0.1		1.3	2.4	0.6	1.5
July	2008		2.2	1.4	0.1		0.7	1.7	0.5	15.4
total	2008		7.3	7.6	1.6		4.1	7.4	1.7	19.4

Table 6A: Summary of total P in g/Ha for 2007 and part of 2008, Waseca runoff plots.

Month	Year		TP	(g/Ha)						
			Corn/Soy	Corn/Corn	Corn/Corn+Rye		Alfalfa	Native Grass/Legume	False Indigo+sod	Willow
March	2007		1.4	1.8	0.2		0.2	0.4	0.2	9.3
April	2007		0.0	0.0	0.0		0.0	0.0	0.0	0.0
May	2007		0.3	1.3	1.2		0.4	0.5	0.2	7.3
June	2007		11.1	17.9	12.1		3.7	0.6	0.2	59.3
July	2007		0.6	0.5	0.5		0.2	0.2	0.2	5.6
Aug	2007		6.2	15.0	5.9		3.0	3.5	1.6	39.1
Sept	2007		2.3	19.6	2.1		0.6	0.9	1.0	14.8
Oct	2007		6.6	74.3	2.7		1.2	0.3	0.1	12.5
Total	2007		28.4	130.5	24.7		9.3	6.5	3.5	147.9
March	2008		0.0	0.0	0.0		0.0	0.0	0.0	0.0
April	2008		0.2	0.4	4.6		2.5	0.2	0.5	11.5
May	2008		0.5	0.8	0.5		2.0	6.3	1.5	3.1
June	2007		0.9	1.5	0.0		0.3	1.0	0.3	1.0
July	2008		0.9	0.8	0.0		0.2	0.7	0.3	10.6
total	2008		2.5	3.6	5.1		5.1	8.2	2.6	26.2

Appendix B
Summary of Tile Flow Data from SROC, Waseca

Table 1B. Mean tile drainage in (a) 2004, (b) 2005 and (c) 2006 as influenced by crop (Clipper 2007).

Cropping System †	Month						Total
	April	May	June	July	Aug.	Sept.	
	---------- mm ----------						
S	0	9	25	10	0	4	47
A	0	9	20	6	0	7	42
F	0	11	26	21	7	14	79
IBF - BB	0	3	6	7	1	4	21
P	0	8	17	10	2	11	48
T	0	11	29	17	3	15	74
W	0	12	25	14	8	17	75

(a)

Cropping System †	Month						Total
	April	May	June	July	Aug.	Sept.	
	---------- mm ----------						
C	14	23	7	2	0	3	49
A	6	10	0	0	0	3	19
F	11	13	1	0	0	8	33
IBF - BB	4	9	0	0	0	3	17
P	16	19	0	0	0	0	35
T	10	13	0	0	0	7	30
W	7	11	0	0	0	0	18

(b)

Cropping System †	Month						Total
	April	May	June	July	Aug.	Sept.	
	---------- mm ----------						
S	28	18	25	0	0	0	71
A	10	1	0	0	0	0	11
F	15	3	2	0	2	0	22
IBF - BB	9	3	0	0	0	0	12
P	25	6	0	0	0	0	32
T	14	2	2	0	5	1	23
W	19	2	0	0	0	0	21

(c)

† S = Soybean, C = Corn, A = Alfalfa, F = Flax, IBF-BB = Illinois Bundleflower – Big Bluestem, P = Poplar, T = Turf, W = Willow

Table 2B. Mean tile drainage for cropping systems in (a) 2004, (b) 2005 and (c) 2006 for the period April-June indicating significant difference among crops (Clipper 2007).

Cropping System †	S (33)	A (29)	F (38)	IBF-BB (9)	P (25)	T (40)	W (36)
W (36) ‡							
T (40)							
P (25)							
IBF-BB (9)							
F (38)							
A (29)							
S (33)							

(a)

Cropping System †	C (45)	A (16)	F (25)	IBF-BB (14)	P (35)	T (23)	W (18)
W (18) ‡							
T (23)							
P (35)							
IBF-BB (14)							
F (25)							
A (16)							
C (45)							

(b)

Cropping System†	S (71)	A (11)	F (21)	IBF-BB (12)	P (32)	T (18)	W (21)
W (21) ‡							
T (18)							
P (32)							
IBF-BB (12)							
F (21)							
A (11)							
S (71)							

(c)

† S = Soybean, C = Corn, A = Alfalfa, F = Flax, IBF-BB = Illinois Bundleflower – Big Bluestem, P = Poplar, T = Turf, W = Willow
‡ Values within parentheses represent mean drainage (mm) for the period April-June.
Treatments compared are defined by the intersection of the corresponding row and column.
Darkened blocks depict treatments which are different at the 0.1 probability level of significance.

Table 3B. Mean tile drainage for cropping systems in (a) 2004 and (b) 2005 for the period July-September (Clipper 2007).

Cropping System †	S (14)	A (13)	F (42)	IBF-BB (12)	P (23)	T (35)	W (39)
W (39) ‡		■		■	■		
T (35)							
P (23)			■				
IBF-BB (12)			■				
F (42)		■					
A (13)							
S (14)							

(a)

Cropping System †	C (5)	A (3)	F (8)	IBF-BB (3)	P (0)	T (7)	W (0)
W (0) ‡			■				
T (7)					■		
P (0)			■				
IBF-BB (3)							
F (8)							
A (3)							
C (5)							

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(b)

† S = Soybean, C = Corn, A = Alfalfa, F = Flax, IBF-BB = Illinois Bundleflower – Big Bluestem, P = Poplar, T = Turf, W = Willow
‡ Values within parentheses represent mean drainage (mm) for the period July-September.
Treatments compared are defined by the intersection of the corresponding row and column.
Darkened blocks depict treatments which are different at the 0.1 probability level of significance.

Appendix C

Soil Frost and Snow Data for 2006-2008 at SROC, Waseca

Soil Frost & Snow Data 2006

Plot	# Sites	**Frost** Maximum Site Depth (cm)	Maximum Plot Average Depth (cm)	First Recorded Zero Frost Date	**Snow** Maximum Site Depth (cm)	Maximum Plot Average Depth (cm)	Maximum Plot Average Snow Water Equivalent (cm)
Mature Poplar	8	43	37.3	March 14	16	8.5	1.6
Landscape Corn	8	53.5	45.0	March 31	16	12.5	3.2
Landscape Willow	6	24	13.5	March 7	51	41.5	11
Landscape IBF	6	33	23.4	March 14	30	20	6.5
Landscape Poplar	5 (6)	46	40.3	March 31	27	17.5	5.5
Tile N Flax	4	33	31.7	March 25	20	20	5.5
Tile S Flax	4	30.5	28.0	March 14	24	22	5.5
Tile E Poplar	4	19.5	15.6	March 14	40	28	8.5
Tile W Poplar	4	30.5	27.2	March 25	18	15	6
Tile N IBF	4	35	20.4	March 14	46	30	8
Tile S IBF	4	29	24.8	March 14	52	31	8
Tile E Corn/Soy	4	40.5	35.4	March 31	22	19.5	5
Tile W Corn/Soy	4	37	35.9	March 31	22	17	3.5
Tile N Willow	4	27.5	20.4	March 14	32	20	6.5
Tile S Willow	4	34	18.6	February 25	46	27	9.5

Soil Frost & Snow Data 2007

Plot	# Sites	**Frost** Maximum Site Depth (cm)	Maximum Plot Average Depth (cm)	First Recorded Zero Frost Date	**Snow** Maximum Site Depth (cm)	Maximum Plot Average Depth (cm)	Maximum Plot Average Snow Water Equivalent (cm)
Mature Poplar	8	77.5	50.5	March 26	35	24.9	4.9
Landscape Corn	8	68.5	54.6	March 26	29	26.1	4.5
Landscape Willow	6	45	36.8	March 23	51	38.2	6.9
Landscape Poplar	5 (6)	82	68.8	March 26	48	37.3	9.1
Tile N Flax	4	55	44.0	March 23	48	42.3	8.0
Tile S Flax	4	47	42.3	March 23	48	42.3	7.3
Tile E Poplar	4	48	41.3	March 23	36	30	4.9
Tile W Poplar	4	46	40.0	March 23	33	30	5.9
Tile N IBF	4	47.5	44.0	March 23	70	67	11.1
Tile S IBF	4	48	46.3	March 26	76	53	12.0
Tile E Corn/Soy	4	69	64.8	March 28	31	27	5.8
Tile W Corn/Soy	4	66	62.0	March 26	26	23.3	5.0
Tile N Willow	4	50	42.5	March 23	51	34.3	7.2
Tile S Willow	4	52	36.9	March 23	52	40.8	8.9

Soil Frost & Snow Data 2008

Plot	# Sites	**Frost** Maximum Site Depth (cm)	Maximum Plot Average Depth (cm)	First Recorded Zero Frost Date	**Snow** Maximum Site Depth (cm)	Maximum Plot Average Depth (cm)	Maximum Plot Average Snow Water Equivalent (cm)
Mature Poplar	8	64	52.9	April 18	20	17	5.8
Landscape Corn	8	79	70.1	April 18	14	9.5	2
Landscape Willow*	6	82	66.2	April 18	18	12.8	5.2
Landscape Poplar	5 (6)	92	77.5	April 26	14	8.8	3.7
Tile N Flax	4	74	70.0	April 26	22	14.5	3.0
Tile S Flax	4	94.5	87.2	April 18	34	20.5	4.6
Tile E Poplar	4	64	51.5	April 15	32	23	7.8
Tile W Poplar	4	65	47.7	April 15	26	22.5	5.7
Tile N IBF	4	47	28.8	April 15	64	25.5	10.6
Tile S IBF	4	38	23.0	April 15	60	31	8.8
Tile E Corn/Soy	4	92	87.8	April 26	7	5.4	1.8
Tile W Corn/Soy	4	88	83.8	April 26	10	8.3	0.0
Tile N Willow*	4	103	95.0	April 18	10	7.9	4.7
Tile S Willow*	4	105	96.7	April 26	10	8.8	0