2007 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Cedar Creek Groundwater Project Using Prairie Biofuel Buffers
PROJECT MANAGER: Dr. Clarence Lehman
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2007, [Chap. 30], Sec.[2], Subd. 5(n).

APPROPRIATION AMOUNT: $659,000

Overall Project Outcome and Results

Two great environmental challenges ahead—for Minnesota and the world—concern water and energy. This project has gathered new information on how the production of bioenergy can simultaneously improve water quality in the state. It is one of an integrated suite of existing and proposed projects to understand the potential for bioenergy to help improve wildlife habitat, water quality, natural landscape management, electrical generation efficiency, climate, and the general ecological integrity of the landscape.

The project has established an “underground observatory" to monitor water and what it carries from the surface to our groundwater and aquifers below. The project examined water filtered by the soil and roots beneath three different potential bioenergy sources: prairie, hay, and corn.

As expected, the deep roots of restored native prairies were best at filtering nitrogen contaminants from water. In addition, a number of less expected discoveries of the project will help in future planning and development:

1. Water retention in the soils was poorest in corn and bare ground, intermediate in hay, and greatest in prairie.
2. Prairies did not significantly decrease the total quantity of water re-supplied to groundwater but improved its quality.
3. Nitrogen removed by prairie plants significantly increased the quantity of biofuel they produced while not reducing biodiversity.
4. Effects on levels of pharmaceutical contaminants is still under analysis.
5. Significant carbon sequestration occurred in prairie soils but not those of hay, corn, or bare ground.
6. The downward flow of dissolved substances through even sandy soils is much slower than expected.

The underground observatory is a valuable ongoing resource, with much remaining to learn. The project organizers will seek continued funding from various sources to enable further understanding of how we can sustainably inhabit our planet.

Project Results Use and Dissemination

We have a project website available through the Cedar Creek Natural History Area website (www.cedarcreek.umn.edu). Many public and private tours are conducted at Cedar Creek annually and the plots in the present study were featured among them during relevant tours. Visitors receive verbal and written descriptions of the research and its implications, including handouts and review of installed signage. Presentations (oral or poster) to special interest groups, research groups, and other interested parties were given by project collaborators throughout the duration of the project. Publication of the results in a peer-reviewed scientific journal will be completed after field data has all been collected, summarized, and analyzed.

Trust Fund 2007 Work Program Final Report

Date of Report: 8/19/2010
Trust Fund 2007 Work Program Final Report
Date of Work program Approval:
Project Completion Date: June 30, 2010

I. PROJECT TITLE: Cedar Creek Groundwater Project Using Prairie Biofuel Buffers

Project Manager: Dr. Clarence Lehman
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Location: The work will take place at Cedar Creek Ecosystem Science Reserve (CCESR), formerly known as Cedar Creek Natural History Area, which straddles the border of Anoka and Isanti Counties just north of the Twin Cities. The main lab building address at CCNHA is 2660 Fawn Lake Drive, Bethel, MN 55005. See map for further details.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$**	**659,000**
	Minus Amount Spent:	**$**	**659,000**
	Equal Balance:	**$**	**0**

Legal Citation: ML 2007, [Chap. 30], Sec.[2], Subd. 5(n).

Appropriation Language:
Cedar Creek Groundwater Project using Prairie Biofuel Buffers

$659,000 is from the trust fund to the University of Minnesota, Cedar Creek Natural History Area, to provide quantitative data on the ability of diverse prairie buffers to capture runoff pollutants, to produce biofuel with minimal water requirements, and to provide high carbon sequestration. This appropriation is available until June 30, 2010, 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

Two great environmental challenges ahead—for Minnesota and the world—concern water and energy. This project has gathered new information on how the production of bioenergy can simultaneously improve water quality in the state. It is one of an integrated suite of existing and proposed projects to understand the potential for bioenergy to help improve wildlife habitat, water quality, natural landscape management, electrical generation efficiency, climate, and the general ecological integrity of the landscape.

The project has established an “underground observatory" to monitor water and what it carries from the surface to our groundwater and aquifers below. The project examined water filtered by the soil and roots beneath three different potential bioenergy sources: prairie, hay, and corn.

As expected, the deep roots of restored native prairies were best at filtering nitrogen contaminants from water. In addition, a number of less expected discoveries of the project will help in future planning and development: (1) Water retention in the soils was poorest in corn and bare ground, intermediate in hay, and greatest in prairie. (2) Prairies did not significantly decrease the total quantity of water re-supplied to groundwater but improved its quality. (3) Nitrogen removed by prairie plants significantly increased the quantity of biofuel they produced while not reducing biodiversity. (4) Effects on levels of pharmaceutical contaminants is still under analysis. (5) Significant carbon sequestration occurred in prairie soils but not those of hay, corn, or bare ground. (6) The downward flow of dissolved substances through even sandy soils is much slower than expected.

The underground observatory is a valuable ongoing resource, with much remaining to learn. The project organizers will seek continuing funding from various sources to exploit the established infrastructure for further understanding of how we can sustainably inhabit our planet.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: Establishment of Vegetation and Experimental Design

Description: Included in this result are the set up and initial characterization of the field site so that we can compare diverse restored native prairie with non-native grassland and agricultural row crops for (1) leaching of chemical pollutants to groundwater, (2) production of renewable biofuel energy, and (3) other relevant criteria such as carbon sequestration. This establishment phase includes several deliverables:

1. *Plot establishment and site characterization.* The goal of this deliverable is to finalize details of the experiment, establish the plots, and assess the initial conditions present in the plots (i.e. plant community composition, root biomass, soil properties, and ground-water parameters). The budget for this includes funds for field supplies, treatment application, chemical analyses of the soils and groundwater, and personnel time including the

project management team (for planning and managing), undergraduate interns (for planting and maintaining plots), and a USGS technician (for sampling soil and groundwater).

2. *Plot Instrumentation.* The goal of this deliverable is to purchase and install the hydrologic equipment necessary for monitoring soil and ground-water quality. The budget for this includes funds for hydrologic monitoring equipment and personnel time including the project management team (for planning and managing), undergraduate interns (for installation of equipment), and a USGS technician (for quality control of equipment installation).
3. *Educational media.* The goal of this deliverable is to provide media to help explain the project, the societal need, the underlying science, and sources of funding to visitors from the general public as well as from professional groups. Media will include interpretative signage at the site, brochures, and a project web site. The budget for this includes funds for the project management team (for writing and management) and undergraduate interns (for installation and technical assistance), plus funds for supplies.

Amendment Approved [3/18/2010]: 3/10/2010 Result 1 Amendment details: The total budget for each of Deliverable 1 and Deliverable 2 remains unchanged, however funds are being moved between line items within each budget. Within Deliverable 1, we request that the excess funds from UMN lab analytical and supply/equipment line items be moved into UMN personnel to cover labor costs necessary to establish and characterize the plots. Some analytical work originally planned in this deliverable was paid for with other non-LCCMR Cedar Creek funds, thus freeing up funds for the increased labor expense. Within Deliverable 2, we request that the excess funds budgeted for UMN supplies and equipment be used to cover UMN labor costs necessary for instrument installation and troubleshooting. We further request that excess UMN supply and equipment funds be used to cover UMN travel expense which includes mileage reimbursement for travel to and from and around the field site. The total cost of Deliverable 3 was lower than anticipated because of labor cost reductions. Labor for installing signage was paid for by non-LCCMR Cedar Creek funds. We request that the remaining dollars ($1197) be shifted to cover labor costs in Result 2, deliverable 5, Final Reports.

Amendment Approved [3/18/2010]: USGS subcontract work: The USGS personnel time required to characterize the groundwater of the site (Deliverable 1) and instrument the plots (Deliverable 2) was greater than anticipated. Additionally, the USGS worked on the project web page (Deliverable 3). USGS site visits consumed more fuel than originally planned for Deliverable 1 and 2. USGS supply and equipment costs were greater than anticipated for completing Deliverables 1 and 2. Travel expenses from attending a USGS training meeting on unsaturated zone processes and instrumentation were underestimated originally. Given that the USGS matching funds paid for most of the analytical analyses for Deliverable 1, we request that funds be transferred from the lab analytical line item to cover the expenses listed above. Additional supplies required above and beyond the original budget that are part of the plot instrumentation include: tensiometer construction materials (PVC pipe, glue, rubber stoppers, wire, pressure sensors), grounding rods, data collection shelters and mounting equipment, solar panels, and voltage controllers. Other supplies required for the experimental establishment include tracers (KBr and Rhodamine WT), PPE for application, and related items. Items purchased for plot instrumentation (hydrologic monitoring) by the USGS will remain at Cedar Creek after the LCCMR funded portion of the project is completed. Since the USGS matching funds covered most of the lab analytical for Result 1, we request that LCCMR funds originally budgeted for lab analytical under Result 1 be used to cover the additional personnel, supply, and vehicle costs listed above.

Amendment Approved [3/18/2010]:

Summary Budget Information for Result 1: **Trust Fund Budget: $113,803**
Amount Spent: $113,803
Balance: $ 0

Deliverable	Completion Date	Budget	Status
1. Plot establishment and site characterization	11/2007	$59,280	Complete
2. Plot Instrumentation	11/2007	$46,820	Complete
3. Educational media	11/2007	$ 7,703	Complete

Completion Date: 7/31/2010

Final Report Summary:

Deliverables 1 and 2: The site specific data collected for this project will be accessible to future CCESR researchers through the Cedar Creek web page at www.cedarcreek.umn.edu. The plot instrumentation will remain in place and will be used for future investigations as funds are available.

For the period of January 1, 2008 through June 30, 2010, over 900 people toured this experiment and others at CCESR. This project is the sole investigation into groundwater quality currently in process at CCESR and complements the broader topics of biodiversity and biofuel production, which are investigated extensively at CCESR. Many K-12 students, college students, and high school teachers visited the site. Notable international visitors also toured this research project, including the Prime Minister of Norway, Jens Stoltenberg and former Vice President Walter Mondale. This project was also highlighted during a national site review by a panel of scientists in the Long Term Ecological Research (LTER) program. This particular project was viewed favorably since it added a new dimension to the existing CCESR research into the ecosystem services provided by biodiversity.

In addition to the site tours given, the project has been highlighted in numerous national and international presentations by principal investigators, Clarence Lehman, David Tilman, and others, and several formal presentations were dedicated specifically to this project:

- St. Thomas University Hydrogeology Course guest speaker, April 2009?. Jared Trost gave a presentation titled, “Prairies: biofuels for clean water.”
- Cedar Creek Ecosystem Science Reserve Research Symposium. June 22, 2009. Jared Trost gave a presentation titled, “Prairies: biofuels for clean water.”
- Minnesota Water Resources Conference, October 26-27, 2009. Jared Trost gave a presentation titled, “Can perennial biofuel crops be used to remove pharmaceuticals (and nutrients) from the environment?”
- University of Minnesota, May 4, 2010. Jared Trost presented his thesis titled, “Effects of perennial and annual vegetation on a soil water balance and groundwater recharge.”

Additionally, four undergraduate research projects were advised by the management team of this project. These projects both provided insight into the broader questions being asked and educated the students in the process of scientific investigation.

- “Leaching of N and pharmaceuticals through lab microcosms.” Done by Joy Deglinnocenti, Fall 2007
- “A biofuel economy: improving yields and saving on costs in the production of biofuels” Done by Jason Williams. Summer 2008.
- “Determination of antibiotics in aqueous and plant samples via ELISA method.” Done by A. Bertsch, K. Thapa, and M. Persenaire. Summer 2008
- “Measuring the distribution of bromide in vertical soil profiles.” Done by M. Sullivan, A. Brandstetter, and B. Brown. Summer 2010.

The project website will remain accessible indefinitely through the USGS at: http://mn.water.usgs.gov/projects/cedarcreek/index.html.

Result 2: Measurement, analysis, and reporting

Description: Included in this result are field data collections, chemical analyses, data management and interpretation, and final reporting. Samples of water, soil, and plant tissue will be collected and analyzed throughout the project. Water balance analyses will be conducted for each plot. Final reports will cover (1) a summary of direct measurements; (2) interpretation and analysis of data collected; (3) estimates of effects the present study is not large enough nor long enough to directly measure, such as wildlife enhancements and carbon sequestration; (4) recommendations about future related studies, such as extensions to a multiplicity of soil types, slopes, and landscapes. This measurement and reporting phase includes several deliverables:

1. *Bioenergy production assessment.* The goal of this deliverable is to determine the bioenergy available in diverse prairie used as a water filter and in non-native grass communities used for the same purpose. The budget includes funds for the project management team (for planning and

managing), undergraduate interns (for mowing, drying, sorting, weighing, and evaluating plant material), and laboratory costs (for analysis of plant tissue).

2. *Soil hydrology assessment.* The goal of this deliverable is to document the water movement through the unsaturated zone and its potential for reaching groundwater. The budget includes funds for the project management team (for planning and managing) and USGS hydrological technicians (for sampling), plus laboratory costs (for analysis of tracers) and field supplies for sample collection purposes. Some USGS matching funds apply to this deliverable.

3. *Contaminant transport assessment.* The goal of this deliverable is to determine the level of filtration accomplished by the plant communities under study. The budget includes funds for the project management team (for planning and management), USGS technicians (for sampling and analysis), chemical assay equipment, and laboratory costs for analysis of the samples. The bulk of the USGS matching funds are allocated to this deliverable.

4. *Carbon sequestration estimates*. The goal of this deliverable is to estimate the level of carbon captured in the roots and soils of the plant communities under study, both to understand effects on atmospheric greenhouse gases and to parameterize potential for restoration of degraded soils. The budget includes funds for the project management team (for planning and management), undergraduate interns (for sampling and data recording), and laboratory costs (for analysis of soil samples).

5. *Final reports.* The goal of this deliverable is to collect and archive the project and its results, to suggest extensions of the project to other parts of the region and the world, and to offer ideas for future refinements based on lessons learned during the project. The final reports will be prepared in hard copy form and will also be distributed through the project website. The budget includes funds for the project management team (for writing), USGS technician (for writing), and printing costs.

Amendment Approved [3/18/2010]: **Deliverables 1 and 4.** The total budget for Deliverables 1 and 4 remain unchanged, however we request that excess funds in the UMN supply/equipment, UMN lab analytical, and UMN travel line items be transferred into UMN labor to cover the true labor required to complete these deliverables. The UMN lab analytical budget decreased because some analytical work originally planned in this budget is being paid for with other non-LCCMR Cedar Creek funds and the analyses are cheaper per sample than originally estimated.

Amendment Approved [3/18/2010]: **Deliverable 3**. The total budget for Deliverable 3 remains unchanged, however an amendment to the allocation of funds within the USGS subcontract portion of this deliverable is requested. We request that funds be shifted from the lab analytical line item into USGS personnel, UMN personnel, and USGS equipment/supplies for two reasons: (1) to provide funding for analyzing the samples locally using trained UMN students rather than a contract lab in Kansas and (2) to provide adequate funding for labor and non-capital equipment expenses necessary for generating quality reportable data.

LAB: By analyzing samples locally, it will decrease the cost/sample and increase the total number of samples analyzed for contaminants. This will (1) provide greater assurance that we capture the plume front as it moves through the unsaturated zone (2) better utilize the replicated experimental design of this project by increasing the strength of statistical comparisons through time; and (3) allow us to develop and test methods necessary to detect compounds in plant material. The total equipment and supply budget for the lab work is estimated to be $62,000, of that an estimated $57,800 will be spent on consumable supplies. The ELISA kits used for contaminant analysis are the largest individual expense in the supply budget at a total of $51,000. No single item will cost more than $1,000. The lab labor budget is estimated to be $89,000. Equipment and supplies purchased to accomplish this deliverable include: clean and quality assured sample bottles, Teflon tubing, C-flex tubing, pipettors (200 ul, 1000 ul, 10ml), glass fiber filters, syringe filters, solvents (citric acid, methanol, organic free water, inorganic free water), analytical standards, ELISA kits, UHP nitrogen gas, labels, sample storage freezers, a vortex shaker, rotators, and related items. In summary, we request the lab analytical line item be reduced by $151,000 to cover the supplies and labor as described above for analyzing samples locally.

SAMPLING: The collection of field samples, quality control, equipment maintenance, and data management and archiving necessary to produce a defendable final report to USGS standards requires more labor than originally budgeted. The non-capital equipment and supplies associated with USGS methods of field sample collection, processing, and storage cost more than anticipated. Additional items (above the original budget) necessary to complete Deliverable 3 include: batteries, teflon tubing, silicone tubing, field calibration standards, sample storage bottles, filters, vacuum pumps, repairs of broken equipment, clean soil sampling equipment, and related items. Additionally, the USGS subcontract will be reduced by $10,000 from the lab analytical line item to pay for UMN personnel who completed water quality sampling originally planned to be done by the USGS. In summary, we request that the lab analytical line item be reduced by $120,310 to cover the supplies and labor for field data collection and management ($7,346 to USGS supplies, $10,000 to UMN for labor, and $102,964 to USGS labor).

Amendment Approved [3/18/2010]: **Deliverable 5.** Given the broad scope of research objectives set forth in this project and the variety of methods employed that require documentation, the final reporting will take longer than originally expected. Therefore we request that the extra UMN funds from Result 1, Deliverable 3 ($1,197) be added to this deliverable to cover UMN labor expenses.

Amendment Approved [3/18/2010]:

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$545,197**
	Amount Spent:	**$545,197**
	Balance:	**$ 0**

Deliverable	**Completion Date**	**Budget**	**Status**
1. Biofuel production assessment	12/2009	$ 19,850	in process
2. Soil hydrology assessment	12/2009	$ 63,652	in process
3. Contaminant transport assessment	12/2009	$417,244	in process
4. Carbon sequestration	12/2009	$ 16,550	in process
5. Final reports	07/2010	$ 27,901	in process

Completion Date: 7/31/2010

Final Report Summary:

Deliverable 1: As introduced in our 2006 Science paper (Tilman etal 2006), native prairie flora can be a superior low-input source of bioenergy. This project extended our understanding by testing the auxiliary benefit of water purification by prairie biofuel plantations. Details will be forthcoming in peer-reviewed scientific publications. In summary, prairie biofuel plantations significantly improved water quality compared with the alternative treatments without reducing its quantity. Even in the short three-year term of the project, carbon sequestration in the soils was evident in the prairie plots but not in the other treatments. Preliminary results indicate that pharmaceuticals can be removed from waters by the roots in the prairie plots, but these results are still being analyzed. In a completely unexpected finding, when nitrogen and water were added to prairie biofuel plots, simulating intentional irrigation and fertilization from agricultural runoff, it did not decrease their biodiversity when they were harvested each year (Figure 1b), though it did increase their yields (Figure 1a). The increase in yield is directly related to water purification, since it derives from nitrogen removed from rooting zone (Figure 1c).

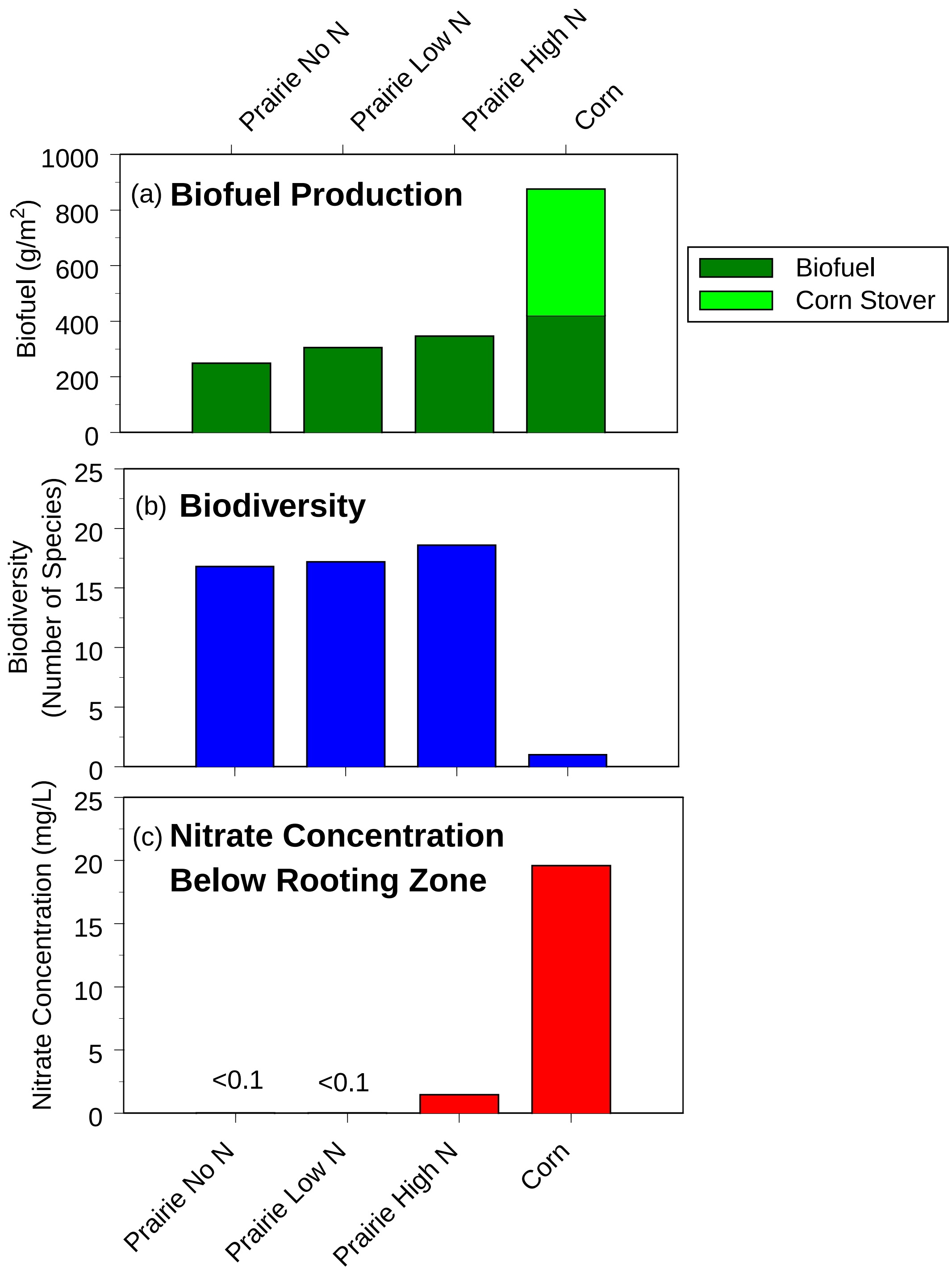


Figure 1. Mean (a) biofuel production, (b) biodiversity, and (c) nitrate concentration below rooting zone of prairies receiving different rates of nitrogen fertilization and corn fertilized at an average rate of 146 lb N/acre/yr. For the prairie treatments, No N = no fertilizer added, Low N = 62.5 lb N/acre/year , High N = 125 lb N/acre/yr. Only corn kernels were considered corn biofuel (dark green), whereas all prairie aboveground biomass was considered biofuel. The corn stover is included in (a) to show the total above ground biomass production.

Deliverable 2: This deliverable is explained in detail in the attached document, Trost, J.; "Effects of perennial and annual vegetation on a soil water balance and groundwater recharge." M.S. Thesis, University of Minnesota, 2010.

Summary from this document: The movement of land applied fertilizers, pesticides, and other agricultural chemicals from land surface to groundwater is a major environmental concern, especially in regions of coarse textured soils with shallow unconfined aquifers. A replicated field experiment was conducted on the Anoka Sand Plain, Minnesota, to examine the effects of perennial and annual vegetative cover on the movement of water through the unsaturated zone to groundwater. A Darcian analysis of soil water flow, water table hydrograph analysis, and chemical analysis of a bromide tracer in pore water in the unsaturated and saturated zones were utilized to estimate recharge rates and amounts to a shallow unconfined aquifer beneath four land cover types: corn (*Zea mays*), well-established prairie, newly-established hay, and bare ground. Soil water storage and precipitation were measured directly. Evapotranspiration (ET) estimates were determined by difference in the other water balance terms. The following results were found:

1. ***Perennial prairie and hay place a higher demand on soil water earlier in the growing season as compared with annual corn.*** Prairie soils to 125 cm were maximally drier than corn soils by mid-July each season due to greater early season ET demands by prairie than corn, with the maximum difference in soil water storage being -6.3 cm.
2. ***Perennial prairie and hay cause slight reductions in drainage (groundwater recharge) through greater ET losses than annual corn.*** Hay, prairie, corn, and bare ground recharge (drainage) estimates from 6/3/2008 through 12/31/2009 were 31.6 +/- 4.5 cm, 37.9 +/- 3.3 cm, 40.2 +/- 3.4 cm, and 43.7 +/- 6.8 cm representing 28 %, 33%, 35%, and 39% of precipitation, respectively. ET losses during this time were 71.6 cm, 73.9 cm, 69.1 cm, and 59.8 cm for hay, prairie, corn, and bare ground, respectively.
3. ***Residence time and pore velocity in the unsaturated zone are affected both by crop type and by local soil properties.*** Piston flow model estimates of residence time in the upper 225 cm of the soil profile were 312, 410, 352, and 318 days for hay, prairie, corn, and bare ground respectively. Hay and bare ground had significantly different recharge (31.6 cm versus 43.7 cm); however the residence time and pore velocities were nearly identical due to a greater physical soil water storage capacity in the bare ground relative to hay.
4. ***Well established perennial prairies reduce solute leaching to groundwater.*** Bromide mass loss as determined for soil pore water 160 cm below land surface in one continuously monitored plot of each treatment resulted in 0.7%, 34%, 34%, and 100% of applied bromide leaching in prairie, hay, corn, and bare ground plots respectively. Peak bromide concentrations in prairie soil water were marginally significantly lower than all other treatments, primarily due to the lack of early high

concentration peaks. Bromide was detected in the groundwater of all five replicate plots for hay, bare ground, and corn treatments, but only detected in two of five prairie replicate plots.

Implications for water quality. Results indicate annually harvested perennial crops show potential for reducing the risk of groundwater contamination from land applied chemicals through two mechanisms. First, annually harvested perennial crops reduce groundwater recharge slightly as compared to annual corn. Since advective flow is the primary mechanism by which solutes are transported through the unsaturated zone to ground water (Green et al., 2008) any reduction in this property will slow the migration of contaminants to groundwater. Second, well established perennial prairies reduce leaching losses and peak concentrations of a conservative tracer below the rooting zone. While the exact mechanism explaining this observation was not determined, it is an important characteristic that holds enormous potential for well-established perennial prairies reducing inputs of land-applied contaminants to groundwater.

Deliverable 3: Selected antibiotics and estrogens, both common environmental contaminants, were applied to the treatments. All samples have been collected and analyzed in our local lab, however analyses have not been completed in the USGS Organic Research Geochemistry Lab. In our local lab, over 1,000 plant, soil, and water samples have been analyzed for 17 beta estradiol, sulfamethazine, and sulfamethoxazole. Interpretive results will be reported when the data return from the USGS lab and the chemistry database is fully quality assured. No further LCCMR funds will be spent in this process.

Deliverable 4: Significant carbon sequestration was measurable in the prairie plots but not in the other treatments even during the relatively short three-year term on the project. Total soil carbon percent (C) in the upper 30 cm of the profile was determined by dry combustion-GC analysis on a Costech ECS4010 using the following equation:

$$C = m_{carbon}/(m_{soil}+m_{carbon}) \quad (1)$$

where m_{carbon} = mass of carbon in grams
m_{soil} = mass of dry soil in grams.

The total percent soil carbon is an estimation of the total soil carbon pool including all forms of carbon, inorganic and organic with the exception of intact plant roots, as they are removed prior to soil sample analysis. It was assumed that any change observed in the total percent soil carbon reflected carbon additions or losses from the recalcitrant, long term storage pools rather than labile pools. The percent soil carbon (C) data is presented in Table 1 did not differ significantly (ANOVA F statistic = 0.52, p = 0.67) between plots assigned to each of the experimental treatments prior to crop establishment.

When the two sample points in each plot were considered a matched pair, only the prairie treatment showed a significant positive change in total soil carbon (Figure 2). A significant positive change is defined as zero not included in the 95% confidence interval of the mean. The mean change for corn was greater than zero,

though not statistically different from zero. This change in corn soils, in contrast to prairie, is partly due to the addition of pel-lime to the plots rather than vegetation-driven carbon storage. The prairie plots (n=10) had an average percent total carbon increase of 0.065 over the period from August 2007 through April 2010.
According to the equation:

$$C_{mass} = 0.367*(C_{mean}/100)*V_{soil}*B$$

Where C_{mass} = mass of carbon (short tons/acre)
C_{mean} = mean change in soil carbon percent = 0.065
V_{soil} = volume of soil (cm^3) = 300,000 cm^3 for the upper 30 cm of a 1 m^2 area.
B = soil bulk density (g/cm^3) = 1.5 g/cm^3 for the experimental field.

The average carbon accumulation in the upper 30 cm of the prairie soils was 1.07 short tons of carbon per acre, corresponding to an average soil carbon accumulation rate of 0.39 short tons/acre/year.

Table 1. Percent total soil carbon and change in percent total soil carbon from 2007 through 2010 in each of the crop treatments. Standard errors of the means are given in parentheses.

Crop Treatment	Number of replicates	2007 Mean Percent Total Soil Carbon	2010 Mean Percent Total Soil Carbon	Mean Carbon Change
Bare ground	10	0.56 (0.04)	0.53 (0.03)	-0.03 (0.03)
Corn	5	0.54 (0.03)	0.65 (0.04)	0.10 (0.05)
Hay	10	0.52 (0.04)	0.53 (0.04)	0.01 (0.03)
Prairie	10	0.58 (0.03)	0.64 (0.03)	0.07 (0.01)

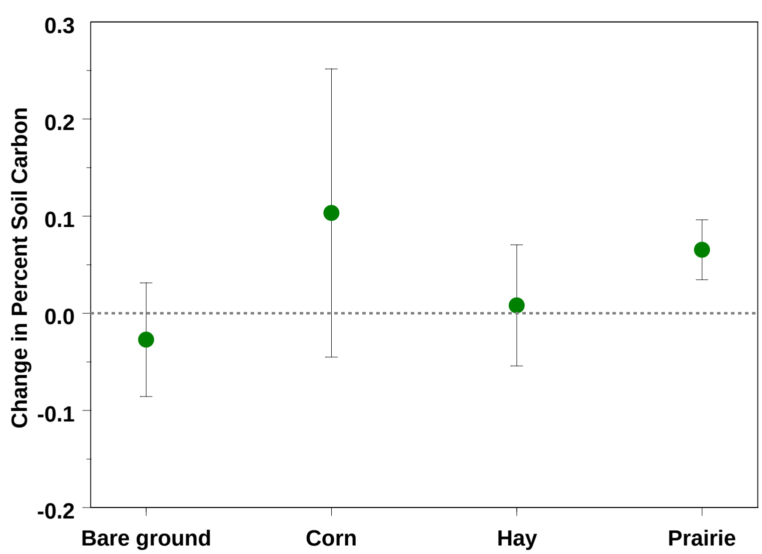


Figure 2. Mean change in soil carbon and 95% confidence interval, including all plots in the experiment (n=5 for corn plots, n=10 for bare ground, hay, and prairie plots).

Higher soil carbon accrual is known to result from higher root biomass (Fornara and Tilman, 2008). No statistically significant difference in root biomass existed between treatments in 2007 (note that no data was available for the corn plots) prior to the establishment of the crop treatments. After the establishment of treatments, the prairies had significantly more root biomass than all other treatments in both 2008 and 2009, a likely explanation for the soil carbon sequestration observed over the project period. In both 2008 and 2009, prairie root biomass was significantly greater than all other treatments. In 2008, mean prairie root biomass to a depth of 30 cm was 76%, 82%, and 430% greater than hay, bare ground, and corn root biomass, respectively. In 2009, mean prairie root biomass to a depth of 30 cm was 37%, 186%, and 215% greater than hay, bare ground, and corn root biomass, respectively. Corn showed no potential for soil carbon storage as its root biomass was not statistically different from bare ground in any year. Stover was completely harvested and removed each year, leaving only corn roots to input carbon below ground.

The root biomass that existed in the bare ground plots remained from pre-existing vegetation and from annual weeds that grew up prior to herbicide application. The corn root biomass was so low relative to bare ground in 2008 due to the tilling of only the corn plots. Tilling broke up the root mass from pre-treatment vegetation, resulting in lower recovery during the 2008 root sampling efforts.

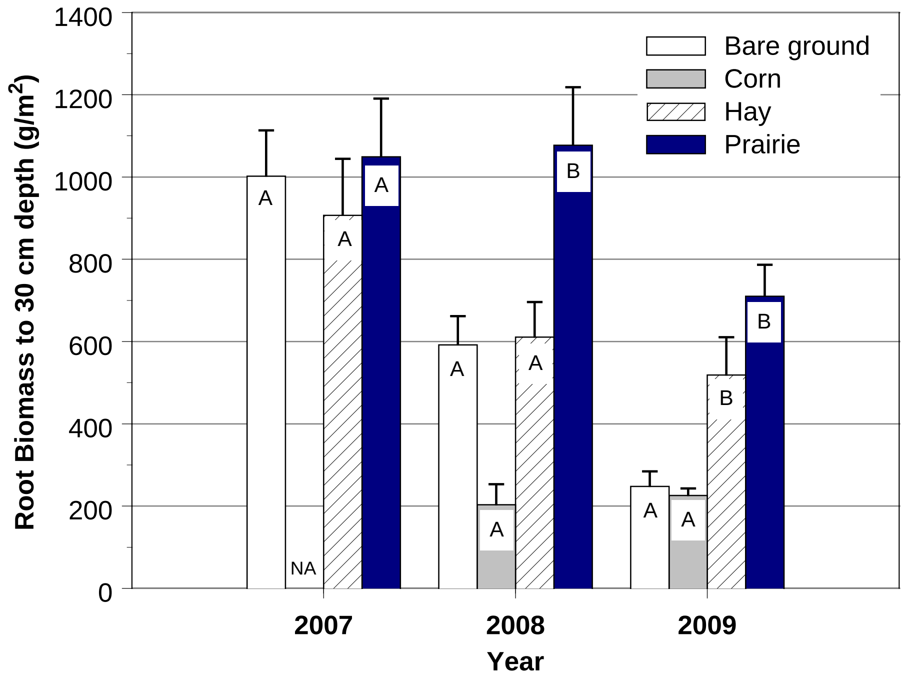


Figure 3. Yearly mean root biomass in g/m^2 and standard error for each crop type to a depth of 30 cm. Treatments marked by different letters within a year were significantly different from one another as indicated by a Tukey pair-wise comparison. No significant difference in root biomass existed between treatment and control plots within each vegetation treatment, therefore, the means in this graph include all experimental replicate plots, n=5 for corn and n=10 for bare ground, hay, and prairie.

V. TOTAL TRUST FUND PROJECT BUDGET: SEE ATTACHMENT A.

Staff or Contract Services: Amendment Approved [3/18/2010]:

UMN Wages and Benefits: Includes salary+ benefits, benefits rate ranges from 9.4% to 32.7% depending on appointment

- $54,608- Academic salary and benefits for Clarence Lehman (6 months) for project management, data analysis, reporting, and related tasks.
- $93,142- Salary and benefits for research assistants and research managers for sampling, data collection, project coordination, and related tasks.

USGS Subcontract Wages and Benefits: Includes salary+ benefits, benefits rate ranges from 7% to 42%, depending on appointment

- $30,279 - Hydrologist salary and benefits for project planning, design, data analysis, reporting, and related tasks.

- $296,096 – Hydrologic technician and student salary and benefits for sample collection, sample processing and analysis, data management and analysis, field activity coordination, and related tasks.

Equipment: Amendment Approved [3/18/2010]:

UMN Non-Capital Equipment and Supplies: $7,341
- seeds, biomass harvest equipment, nutrient application equipment, sample collection equipment, shipping costs, repair costs, and other necessary supplies

USGS Subcontract Equipment and Supplies: $110,444
- **$12,964 Capital Equipment**** dataloggers, soil-moisture probes, multiplexers, pressure transducers, thermocouples, a tipping bucket rain gauge, solar panels, voltage controllers, cable, grounding rods, shelters, tensiometers, and mounting hardware. (***although each individual part (sensors, wires, etc.) of this system was purchased separately at a cost well below the $3,500 cutoff, the combined system as a whole cost more than $3,500 and will remain at Cedar Creek after the LCCMR project completion)*
- **$97,480 Non-capital Equipment and Supplies**: tracers (KBr and Rhodamine WT), various hardware and tools, PPE for application, suction lysimeters and well construction materials, batteries, teflon tubing, silicone tubing, field calibration standards, clean and quality assured sample collection and storage bottles, capsule filters, vacuum pumps, repairs of broken equipment, pipettors (200 ul, 1000 ul, 10ml), glass fiber filters, syringe filters, solvents (citric acid, methanol, organic free water, inorganic free water), analytical standards, ELISA kits, UHP nitrogen gas, labels, sample storage freezers, and other necessary items.

Development: $0
Restoration: $0
Acquisition, including easements: $0

TOTAL TRUST FUND PROJECT BUDGET: $659,000

Explanation of Capital Expenditures Greater Than $3,500:

USGS Equipment / Tools: The equipment purchased here is for monitoring the hydrology and contaminant movement in the project. Specific purchases will include dataloggers, soil-moisture probes, multiplexers, pressure transducers, thermocouples, and a rain gauge.

USGS Suction lysimeters and well construction materials ($21,000): These are for collecting soil- and ground-water samples for chemical analysis.

UMN Lab and Field Supplies ($8,000): The equipment purchased here is for the installation of our project, maintenance of our project, and sample collection. Specific purchases will include: seeds, fertilizers, equipment for nutrient application, emerging contaminants (ie. growth hormones and antibiotics), vials and bags for sample storage, equipment for preparation of tissue and soil samples for analysis.

All capital equipment will be useful in ongoing aspects of the experiment and its extensions.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

1. United States Geological Survey (USGS): $502,000

    James Stark

    Geoffrey Delin

    Kathy Lee

    Richard Kiesling

2. University of Minnesota: $147,000

    Clarence Lehman

    David Tilman

    John Nieber

    Jared Trost

    Troy Mielke

B. Other Funds Proposed to be Spent during the Project Period:

The USGS will provide an additional $410,000 of federal matching funds towards this project during the funding period

C. Past Spending: This specific project is new, but it will use an existing experimental area at Cedar Creek established with over $1 million of National Science Foundation support during the past 12 years.

D. Time: We have requested a one-year extension, with the final report due in 2010. This will allow us to collect data through two complete field seasons; given the variability in natural systems, two complete years of data will increase confidence and reliability of the findings. The 2007 field season will be used for establishment of plots. 2008 and 2009 will be used for field data collection. The final report will be complete in July of 2010.

VII. DISSEMINATION: We will have a project website available through the Cedar Creek Natural History Area website (www.cedarcreek.umn.edu). Many public and private tours are conducted at Cedar Creek annually and the plots in the present study will be featured among them as during relevant tours. Visitors will receive verbal and written descriptions of the research and its implications, including handouts and review of installed signage. Presentations (oral or poster) to special interest groups, research groups, and other interested parties will be given by any number of the project collaborators throughout the duration of the project. Publication of the results in a peer-reviewed scientific journal will be completed after field data has all been collected, summarized, and analyzed.

VIII. REPORTING REQUIREMENTS:

Periodic work program progress reports will be submitted not later than November 1, 2007, May 1, 2008, November 30, 2008, May 31, 2009, November 30, 2009, May 31, 2010, August 1, 2010. A final work program report and associated products will be submitted between June 30 and August 1, 2010 as requested by the LCCMR**.**

IX. RESEARCH PROJECTS:

Attachment A: Budget Detail for 2007 Projects - Summary and a Budget page for each partner (if applicable)

Project Title: *Cedar Creek Groundwater Project using Prairie Biofuel Buffers (proposal #5n)*

Project Manager Name: *Clarence Lehman*

Trust Fund Appropriation: *$659,000 (with an additional $410,000 in Federal matching funds)*

2007 Trust Fund Budget	Result 1 Budget 08/17/2010	Amount Spent (08/17/2010)	Revised Balance 08/17/2010	Result 2 Budget 08/17/2010	Amount Spent (08/17/2010)	Revised Balance 08/17/2010	TOTAL BUDGET 08/17/2010	TOTAL BALANCE 08/17/2010
Cedar Creek Groundwater Project using Prairie Biofuel Buffers	Establishment of vegetation and initial characterization			Measurement, analysis, and reporting				
BUDGET ITEM								
UMN PERSONNEL: (includes salary+ benefits, benefits rate ranges from 9% to 33%). Academic salary for Clarence Lehman (6 months), Additional salary for Junior Scientists and summer interns.	44,484	44,484	0	103,266	103,199	67	147,750	67
UMN SUPPLIES AND MATERIALS: seeds, biomass harvest equipment, nutrient application equipment, sample collection equipment, shipping costs, repair costs, and other necessary supplies	4,714	4,714	0	2,626	2,626	0	7,341	0
UMN LABORATORY ANALYTICAL SERVICES: (includes soil C and N, plant C and N)	600	600	0	1,245	1,312	-67	1,845	-67
UMN TRAVEL	5	5	0	60	60	0	65	0
UMN TOTAL	**49,803**	**49,803**	**0**	**107,197**	**107,197**	**0**	157,000	**0**
								0
USGS SUBCONTRACT PERSONNEL: includes salary + benefits for hydrologist, lab technician, student hydrologists, and IT support	30,085	30,085	0	296,290	310,706	-14,416	326,375	-14,416
USGS SUBCONTRACT EQUIPMENT ($12,964): dataloggers, soil-moisture probes, multiplexers, pressure transducers, thermocouples, a tipping bucket rain gauge, solar panels, voltage controllers, cable, grounding rods, shelters, and mounting hardware. **USGS SUBCONTRACT SUPPLIES ($97,480):** suction lysimeters and well construction materials, batteries, teflon tubing, silicone tubing, field calibration standards, clean and quality assured sample collection and storage bottles, capsule filters, vacuum pumps, repairs of broken equipment, pipettors (200 ul, 1000 ul, 10ml), glass fiber filters, syringe filters, solvents (citric acid, methanol, organic free water, inorganic free water), analytical standards, ELISA kits, UHP nitrogen gas, labels, freezers, and other necessary items.	31,098	31,098	0	79,346	63,195	16,151	110,444	16,151
USGS SUBCONTRACT VEHICLE	231	231	0	500	337	163	731	163
USGS SUBCONTRACT PRINTING	0	0	0	500	0	500	500	500
USGS SUBCONTRACT TRAVEL	1,342	1,342	0	1,364	1,735	-371	2,706	-371
USGS SUBCONTRACT LAB ANALYTICAL	1,244	1,244	0	60,000	62,026	-2,026	61,244	-2,026
USGS TOTAL:	**64,000**	**64,000**	**0**	**438,000**	**438,000**	**0**	**502,000**	**0**
							0	0
OVERALL TOTAL:	**113,803**	**113,803**	**0**	**545,197**	**545,197**	**0**	**659,000**	**0**

Comparison of the Soil-Water Balance and Groundwater Recharge Among Annually-Harvested Perennial and Annual Biofuel Crops

Jared Trost[1], **John Nieber**[2], and **Clarence Lehman**[2], [1]United States Geological Survey, [2]University of Minnesota

Summary

Annually-harvested well-established diverse perennial prairies grown on coarse sandy soils reduced the movement of water and solutes to groundwater as compared with annually-planted corn (*Zea mays*). Perennial prairies grown on marginal soils offer a strategy to both produce biofuel and buffer shallow groundwater from land-applied fertilizers.

Introduction

Annually-harvested diverse perennial prairies grown on coarse-textured soils can provide a source of biofuel comparable to corn grain ethanol. The net energy production (energy output minus energy input) from unfertilized, annually-harvested diverse perennial prairies (18.1 GJ/ha) grown on sandy soils is similar to the net energy produced from corn grain ethanol grown on productive soils(18.9 GJ/ha) (Tilman and others, 2006). The replacement of perennial vegetative cover with annual row crops on productive soils in the Midwest, USA has resulted in increased groundwater recharge, which, in turn increases potential for transport of surface-applied fertilizers to groundwater (Brye and others, 2000; Schilling and Libra, 2003). Re-establishing perennial cover may offer a mechanism to both produce biofuel and buffer groundwater from surface-applied fertilizers. Prior to this project, little research had been done to compare the soil water balance and solute transport occurring beneath annually-harvested perennial and annual crops grown on coarse-textured soils, a prime landscape for perennial biofuel production.

Objectives

To compare among well-established perennial diverse prairie, newly-established perennial hay, annual corn, and bare soil the following hydrologic processes:

1. **The soil water balance including soil water storage (S), evapotranspiration (ET), and groundwater recharge (R).**
2. **The fate and transport of a surface-applied conservative tracer, bromide, through the unsaturated zone to groundwater.**

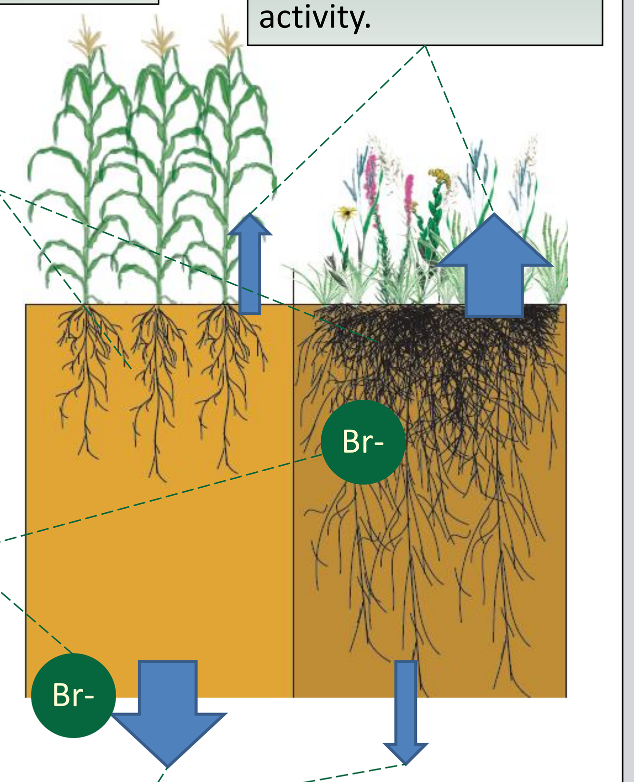
Conceptual Model

Big Idea: Well established perennial crops will utilize more water out of the soil profile than annual crops, thus reducing the flow of water and solutes to groundwater.

Greater annual ET in perennial crops compared to annual crops due to early and late season plant activity.

Lower soil water storage underlying perennial crops compared to annual crops during the growing season.

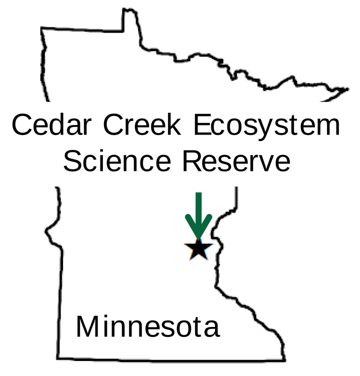
A conservative tracer, bromide, will be transported more slowly through the soil profile of perennial crops than annual crops due to reduced percolation through the rooting zone.



Reduced annual percolation below the rooting zone in perennial crops compared to annual crops. Percolation below the rooting zone is considered equivalent to groundwater recharge.

Experimental and Sampling Design

This study was established in the fall of 2007 and monitored from May 2008 through December 2009. The experiment consisted of thirty-five 11 x 11 m plots: 10 prairie, 10 hay, 10 bare soil, and 5 corn plots. All plots were prairie prior to the establishment of the vegetation treatments. Existing prairie vegetation remained intact for the prairie treatment but was eliminated for establishment of the hay, corn, and bare soil treatments.



Study Location

Soil-Water Balance: ET = P - R - ΔS

ET = evapotranspiration, estimated by difference in the water balance equation for ONE plot per treatment using continuous data from April through November.

P = precipitation, measured continuously with a tipping bucket rain gage.

R = groundwater recharge, calculated for ONE plot per treatment by converting the 2 m moisture content to a recharge rate using a plot-specific relationship.

ΔS = change in soil water storage, $S(t) = \sum \theta_i(t) * \Delta z_i$ where θ_i = volumetric water content % at depth i and Δz_i = vertical depth increment.

- *Continuous*: measured in ONE plot per treatment with Campbell CS616 TDR probes.
- *Discrete*: measured in ALL thirty-five plots with Trime TDR probe from May through October each year.

Tracer Study

Application

- Bromide applied at a rate of 10 g/m² in May 2008 on 5 plots per treatment.

Sample Collection

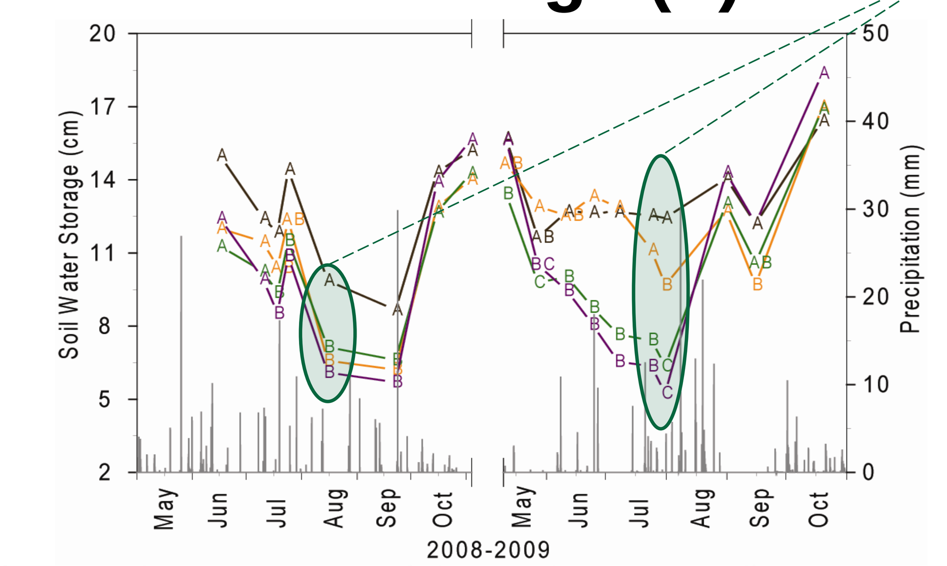
- Soil water sampled periodically with suction lysimeters (one per plot) at 1.6 m below land surface.
- Upper 5-10 cm of aquifer sampled periodically through water table monitoring wells (one per plot).
- Vertical soil profile sampled in 15 cm increments in ONE plot per treatment in November 2009.

Lab

- Extracted bromide from soil samples with deionized water at > 70% recovery.
- Analyzed samples with an ion chromatograph or an ion selective electrode.

Soil Water Balance

Soil Water Storage (S)



Perennial prairie and hay significantly reduced soil water storage compared to corn by late July in the upper 125 cm of the soil profile following a dry spring (2009) but not a wet spring (2008). Bare soil consistently had the most soil water storage.

The perennial "soil water storage effect" is transient and disappears by October.

Figure 1. Discrete measures of the growing season soil water storage (S) of the upper 125 cm of the soil profile and precipitation in millimeters. Different letters on a given sample date indicate significant differences among treatments (Tukey pairwise comparison, p< 0.05).

Evapotranspiration (ET)

Prairie had earlier peak daily rates of ET than corn.

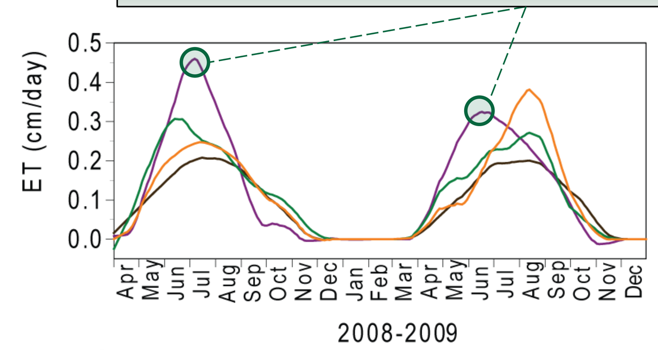


Figure 2. ET rates in cm/day. The smoothed lines are from applying Friedman's Super Smoothing function to three day average ET values.

Prairie and hay had slightly greater cumulative ET and reduced recharge compared to corn.

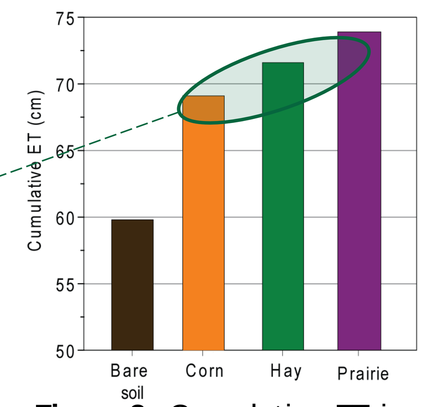


Figure 3. Cumulative ET in cm of water from May 2008 through December 2009.

Groundwater Recharge (R)

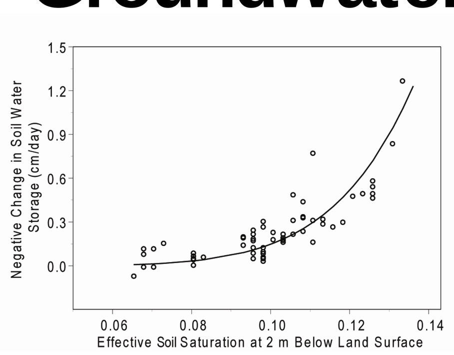


Figure 4. Example non-linear regression between the 2 m moisture content and the daily change in soil water storage.

In early spring and late fall on days with no precipitation, the daily water balance simplifies to -ΔS = R. Cumulative recharge in cm was calculated as follows: $\sum R(\theta_i)$ where $R(\theta_i) = a*(10*S_e)^b * \Delta t$

S_e = effective soil saturation at 2 m below land surface; Δt = time in days; a, b = empirical constants from derived from a regression as in Figure 4.

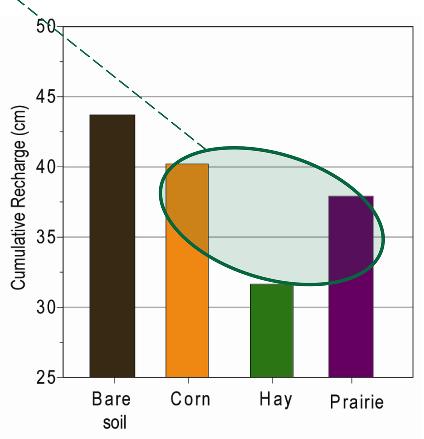
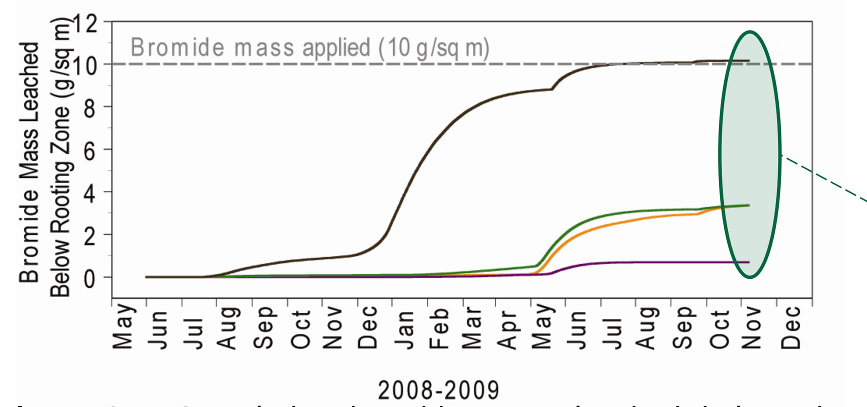


Figure 5. Cumulative recharge in cm of water from May 2008 through December 2009.

Tracer Transport to Groundwater

Bromide Leaching Below Rooting Zone



Prairie most effectively minimized leaching below the rooting zone. A mere 0.7% of applied bromide leached below the rooting zone in prairie, whereas corn and hay leached 34% and bare soil leached 100%.

Figure 6. Cumulative bromide mass leached below the rooting zone (1.6 m below land surface).

Bromide retained in soil profile

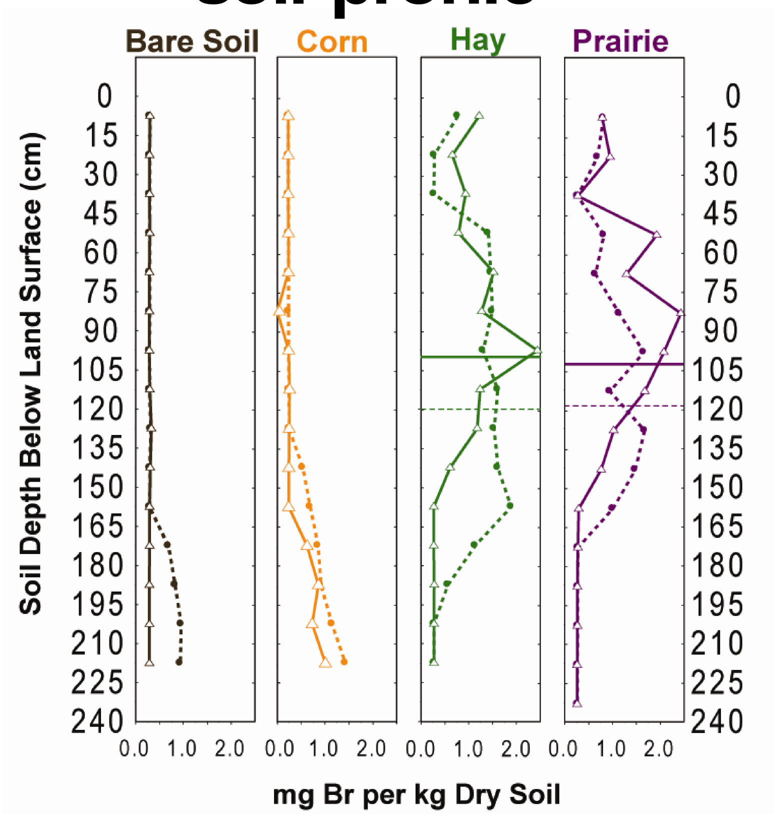


Figure 7. Bromide retained in the soil profile in November 2009 for 2 replicate profiles from 1 plot in each treatment. Horizontal lines indicate the center of mass. The center of mass calculation could not be completed for corn and bare soil as it had migrated below the sampling depth.

Bromide Mass Balance

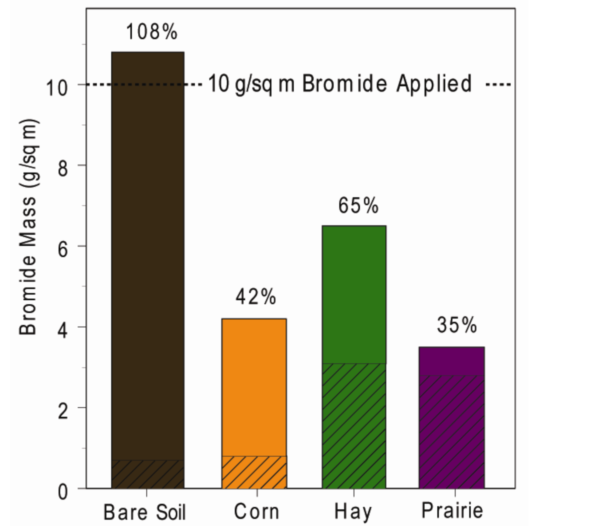


Figure 8. Bromide mass balance including leaching losses (non-hatched portion of bar) and soil retention (hatched portion of bar) to 1.6 m below land surface. Plant uptake was not measured to date. Percents indicate the percent of applied bromide recovered.

Prairie and hay retained more bromide in the soil profile. The center of mass of bromide in the soil underlying corn and bare soil had migrated well beyond the rooting zone (see Figures 7 and 8).

The mass recovered in vegetated plots was well below 100%, an indication of plant uptake.

Conclusions

Annually-harvested well-established diverse perennial prairies and newly-established perennial hay grown on coarse soils slightly reduced groundwater recharge and slightly increased evapotranspiration compared to annual corn.

Well-established diverse perennial prairies reduced leaching losses and increased retention of a conservative tracer in the soil profile compared to annual corn.

Application of these results:
While unfertilized perennial prairies demonstrate a similar efficiency to corn grain ethanol in terms of net energy output, the gross energy produced per area by prairie is only 25% of the gross energy production of corn grain ethanol (Tilman and others, 2006). Fertilization of prairie crops for biofuel production will increase the gross energy output per area. Prairies, if fertilized, will likely reduce impacts on groundwater quality compared to the fertilization of corn biofuel crops. Therefore, well-established diverse perennial prairies grown on marginal soils offer a strategy to both produce biofuel and buffer shallow groundwater from land applied fertilizers.

Acknowledgments

Funding for this project was provided by the USGS Cooperative Water Program and the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

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Schilling K. E., R. D. Libra. 2003. Increased baseflow in Iowa over the second half of the 20th century. Journal of the American Water Resources Association **39**:851-860.

Tilman D., J. Hill, and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science **314**:1598-1600