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Date of Report: June 30, 2000

SEP - 6 2000

LCMR Work Program Final Report

Project End Date: June 30, 2000

I. PROJECT TITLE: ALFALFA BIOMASS PRODUCTION

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Total Biennial Project Budget:

$LCMR	$ 200,000
- $LCMR Amount Spent	$ 200,000
= $LCMR Balance	$ 0

A. Legal Citation: **ML 1997, Chap. 216, Sec. 15, Subd. 12 (c).**

Appropriation Language: 12(c) ALFALFA BIOMASS PRODUCTION 200,000
This appropriation is from the future resources fund to the University of Minnesota for the evaluation of the environmental impacts and benefits of production of alfalfa for electrical power generation. This appropriation is available until June 30, 2000, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. PROJECT SUMMARY AND RESULTS:

In the alfalfa biomass system, alfalfa leaf and stem components are separated. The stems are gasified and used for generation of electricity. The leaves are sold as an animal feed co-product. Replacing a corn-soybean rotation grown with an aggressive soil and water conservation approach with alfalfa has several potentially positive advantages on surface water quality. Loss of sediment and other particulate potential pollutants such as P and oxygen demanding materials are reduced substantially. During snowmelt runoff losses of soluble forms of potential pollutants are similar between the two cropping systems. Chemical analyses and green house studies show that alfalfa ash is a potential source of K in K-deficient soils and liming agent for acid soils.

III. PROGRESS SUMMARY:

Paired Watershed Study: Two pairs of field size watersheds are established at the West Central Research & Outreach Center in Morris with funding from MN Department of Agriculture and USDA-USDOE / Minnesota Agri-Power Project in 1996. Two fields each are planted with perennial alfalfa and corn-soybean in rotation. The corn-soybean crop is cultivated with a minimum-tillage-high-residue (MTHR) management system. At the downslope end of each field, we installed and maintained instrumentation to measure precipitation, runoff, and automatically sample water for quality assessment. Water samples from snowmelt and rainfall runoff are analyzed for sediment load, biochemical oxygen demand, chemical oxygen demand, phosphorus, and nitrogen.

Beginning with the snowmelt of 1997, we have compiled each snowmelt and rainfall-runoff event into seasonal totals and evaluated season by rotation interactions. The analysis of data from 1997, 1998, and 1999 show that during snowmelt and intense thunderstorms, alfalfa fields generated about 1.6 times more runoff but produced half the load of sediments than the corn-soybean fields managed with aggressive soil conservation practices. Both season and rotation affected BOD with more coming from alfalfa and more during snowmelt events while there was no effect on COD. Snowmelt runoff contained more total, dissolved, and bioavailable phosphorus and less particulate phosphorus than rainfall-runoff. During snowmelt runoff, alfalfa released significantly more ammonium N while the corn-soybean fields lost more nitrate N. The effect of rotation on total mineral N loss was statistically not significant.

Simulation Study: We selected the EPIC (Erosion Productivity Impact Calculator) model to simulate long term and short term productivity and water quality effects of corn-soybean vs. alfalfa based cropping systems. EPIC program codes and documentation were acquired and installed on a PC. For the simulation we used a six-year alfalfa-corn (CAAAAC) rotation vs. a two-year corn-soybean rotation with generic management schedules similar to that followed in the watershed study. We used the Barnes-Loam as the base soil and the CLIGEN weather generator for the Morris weather database to simulate climate and management effects on the two cropping systems for 48 years. The simulation results also showed that alfalfa fields produce about 1.6 times more runoff and half the amount of soil erosion than corn-soybean field.

Ash Evaluation Study: Samples of alfalfa fly ash and bottom ash received from a biomass power plant in Norway were analyzed at the Soil, Water and Climate Department, University of Minnesota and other state certified laboratories to determine various organic and inorganic chemical constituents. Chemical analysis indicated that organic carbon was the major constituent of the fly ash; heavy metals were below the detection limits in both fly and bottom ash samples. The chemical analyses and green house studies show that alfalfa ash could be a potential source of K in K-deficient soils and serve as liming agent for acid soils.

IV. OUTLINE OF PROJECT RESULTS:

Result 1 - Measurement of impact on surface water quality $ 0

The objective is to establish field instrumentation to measure and monitor natural runoff (snowmelt and summer rainfall) and a suite of pollutants coming from paired watersheds of alfalfa and corn-soybean in western MN. Tangible products expected from this activity include: data for evaluation of water quantity and quality contrasts between alfalfa and corn-soybean and data needed for calibration and/or validation of the computer simulation work described in Objective 2.

Time line

Activity	Completion Date
Establishment of paired watersheds	December 1997
Measurement of runoff and collection of water samples	June 30, 2000
Organizing data and interpretation	June 30, 2000

Status:

Establishment of paired watersheds:

We have established four field size watersheds on east ½ of West Central Research & Outreach Center field E-5 at Morris. Appendix – Fig. 1 shows the general layout of the study area. The corner fields (Plots 5 and 8) were direct seeded with alfalfa in 1996 and maintained for optimum stand. Three cuttings are taken every year at 1/10th to 1/5th bloom stages to insure good forage quality. The central two fields were planted with corn in 1996 followed by soybean in 1997, and corn in 1998.

A pair of specially constructed fiberglass flumes was installed to measure runoff water at the down slope end of each plot. Earthen berms at the lower and side boundaries of each field guide runoff water toward the flumes. We use a 15cm Parshall and 10cm Palmer-Bowlus flume arranged in series to accommodate both large and small runoff amounts expected to occur during snowmelt and rainfall events. The flumes were installed during the winter and early spring of 1996-97.

Measurement of runoff and collection of water samples

Along the side of the two flumes at each field, a specially constructed instrument shelter houses a data logger and a water sampler. A pressure sensor connected to a N-gas-bubbling device and gage tube at each flume measures the height of water in the flumes. A recording raingage and thermocouples are also connected to the data-logger to measure rainfall and temperature. A computer program written for the data-logger sends a signal to instruments every minute and measures the height of water in each flume. Whenever a minimum depth of flow is recorded, the program also triggers a water quality sampler to periodically grab runoff samples for water quality. The rainfall, runoff, and temperature data are recorded in a storage module. A RS232 serial cable link and communication software are used to periodically transfer data to a PC.

Organization of data and interpretation

Beginning with the spring of 1997, we have compiled runoff and pollutant load data for each snowmelt and rainfall-runoff event. Since each hydrologic event is unique in itself, rainfall-runoff hydrographs from each event were carefully scrutinized for data validation. The measured heights of water in each flume was checked for validity with 'h' ranging from 0.5 to 7.5 cm for the smaller Palmer Bowlus flume and 3.0 to 40.0 cm on the larger Parshall flume. The data validation exercise was critical for snowmelt flow data specifically for events when the night temperature fell below the freezing point. When water freezes during the night, the N-gas passing through the gage tubes experiences great pressure or do not flow at all. During such conditions, the transducers record erroneous measurements.

From the measured height (h, cm) in the 10-cm Palmer Bowlus flume, flow rates (V, $L.s^{-1}$) were calculated based on the following equation developed from calibration flow data supplied by the manufacturer of the flume.

$$V = 0.0495h + 0.04678\ h^2 + 0.00097\ h^3 \qquad [1]$$

For the 15-cm Parshall flume, the following calibration equation was used to calculate the flow rate.

$$V = 0.26372 * h^{1.58} \qquad [2]$$

The data-logger was programmed to read the instruments every 30 seconds. Whenever the smaller Palmer Bowlus flume recorded a flow height >5 mm, the program triggered the water sampler to collect about 150-ml runoff sample every 5 minutes. For rainfall-runoff events, a composite sample of one bottle was filled in 30 minutes. For snowmelt event, every third signal from the datalogger was used to sample about 110 ml of samples in one bottle representing two hours of composite sample. Each day, the collected runoff samples from Morris were transported in a cooler to the University of Minnesota, Soil Water & Climate laboratory at St. Paul and stored at 4 °C for determination of chemical constituents. Along with retrieval of water samples, stored flow data were transferred to a personal computer by connecting an RS-232 cable with the storage module and using communication software provided by Campbell Scientific, Inc.

Precipitation, runoff, and sediment load

Beginning with the snowmelt runoff of spring 1997, the instrumentation is being continuously maintained to monitor precipitation and runoff, and sample water for quality. The collected runoff water samples are analyzed for sediment load, biochemical and chemical oxygen demand (BOD,COD), dissolved molybdate reactive phosphorus (DMRP), bioavailable phosphorus (BP), total phosphorus (TP), and ammonium and nitrate nitrogen.

Appendix Table 1 summarizes the total amounts of precipitation (rain and snow) recorded during 1996-1998 and historical (1886-1996) precipitation at Morris, Minnesota. The snowmelt event of 1997 dominated the total flow that occurred in 1997. Compared to historical records and 1997-98, about 100-mm more snow occurred at Morris during 1996-97 winter months, and most of the 200 mm of the total snow stayed on the ground till the historical snowmelt event of 1997. The snowmelt started during the third week of March and continued until the beginning of April. In 1998, only about 37 mm out of 104 mm of precipitated snow stayed on the ground prior to snowmelt. The snowmelt started in the third week of February, and it was over in about a week.

The rainfall events during April to October in 1997 were few and far-between. Only three rainfall events generated runoff from all four plots in very small amounts. In 1998, the total rainfall during the same period was about 100 mm more than the total for 1997 and the historical average total rainfall. Seven rainfall events generated significant runoff from all four fields. Appendix Table 2 shows the total runoff, sediment load, and sediment load per unit runoff from alfalfa and corn-soybean fields.

During both snowmelt and rainfall-runoff events of 1997 and 1998, alfalfa fields produced more runoff than corn-soybean fields. On the other hand, the corn-soybean fields generated more total sediments than alfalfa. The ratio of the two-year total runoff from alfalfa to that of corn-soybean is 1.56 while that of sediment load is 0.48. The weighted average sediment concentration (sediment load / runoff) data further emphasize the point that "About one-and-half times more volume of runoff is generated from alfalfa fields, however the water is twice as cleaner than runoff coming from best-managed corn-soybean fields".

Biochemical (BOD) and Chemical Oxygen Demand (COD)

The amount of BOD represents the potential demand for oxygen when aerobic microorganisms start decomposing organic substrates present in runoff water. The COD on the other hand assesses the total organic and inorganic sources of carbon available for biochemical and chemical decomposition. The summary data and the analyses of variance (Appendix Table 3) did not show any season and rotation effects on COD. On the other hand, both season and season by rotation significantly affected BOD. In general, snowmelt runoff contained more BOD, and alfalfa biomass produced more BOD materials than corn-soybean.

Phosphorus and Nitrogen

Load of phosphorus in runoff water is a major concern to the environment due to potential eutrophication of streams and lakes. Appendix Table 4 shows that, in general, the effect of crop rotation on various forms of phosphorus is insignificant while the runoff season (snowmelt vs. rain) has an effect. The snowmelt runoff water contained most of the total P in dissolved (DMRP) form while the runoff generated during significant rainfall events (especially 1998) produced more PP. Similar to DMRP, snowmelt runoff contained more bioavailable phosphorus (BP). The similarities in the amounts of BP and DMRP also indicate that dissolved P in snowmelt runoff is the major contributor to potential bioavailability.

Appendix Table 5 summarizes the total loads of ammonium and nitrate nitrogen in snowmelt and rainfall runoff from alfalfa and cornfields. Loads of these two forms of N in runoff water show consistent effects of both season and rotation. Alfalfa fields yielded significantly more ammonium and the corn-soybean fields yielded more nitrates in runoff water. Overall, snowmelt runoff water contributed to more loss of total nitrogen while the effect of crop rotation was not significant.

Result 2 - Estimate Impact Using Computer Simulation $0

The initial objective was to use Soil and Water Assessment Tool (SWAT) or an appropriate computer model to estimate the influence of alfalfa on surface water quality in the Upper Minnesota River sub-basin. The modeling exercises would allow scaling up of watershed scale data in an areal and temporal sense to estimate the potential impact of the biomass project on water quality.

Products expected in this effort include an estimate of the environmental impact of the biomass project on water quality over a long period of time and large area of MN.

Time line

Activity	Completion Date
Compiling computer code and familiarization with program	December 1997
Review of literature for pertinent data	December 1997
Testing of computer model	December 1998
Estimate of biomass project on water quality	June 30, 1999

Status:

Soil Water Assessment Tool (SWAT) is a basin scale model that integrates hydrology, soil and management information with geographic information system (GIS) database. During preliminary model installation and testing, and interactions with research scientists involved in developing the SWAT model, it was revealed that the hardware, software, and skill-set needed for SWAT far exceeded the time frame and money available for this objective to be completed during this project appropriation period. Moreover, the spatial scope of the SWAT model would not accommodate validation with field data collected from small watershed scale experiments as described in Objective 1.

Instead, we used EPIC (Erosion Productivity Impact Calculator) which is a daily time-step, long-term simulation model that uses a climate generator (CLIGEN) and soil information to simulate the effect of management strategies on agricultural production and environment. The designed spatial scope of EPIC model corroborates with the size of experimental watersheds used in this study.

The product of this activity is the acquisition of the EPIC program code, model documentation, and test runs. Through interaction with scientists at USDA-ARS, Temple, Texas, the model was run for typical weather and soil parameters from Morris, MN. The following generic management options, similar to the field study, were used to simulate the long-term environmental effects of the two cropping systems for 48 years.

Management Strategy

Crop Rotation: Six-year alfalfa-corn (CAAAAC) vs. biannual corn-soybean (CS)

Alfalfa: Chisel corn in fall, field cultivate in spring, use pre-post herbicide(s), drill seeds, re-seed if needed, harvest 1 or 2 times in 1st year, and 3-times in other years.

Corn: Field cultivate in spring, row plant, use pre-post herbicide, fertilize with NH_3, harvest, chisel in fall.

Soybean: Field cultivate in spring, drill, use pre-post herbicides, harvest, apply NH_3 for corn.

Planting and Harvesting Dates: Based on growing degree-day accumulation for each year.

Management Options: Same sequence of MTHR management strategy adopted in the field study.

Simulation results:

Appendix Figures 2 and 3 summarize the predicted average monthly runoff and erosion amounts from alfalfa and corn-soybean fields. Similar to observations during the last two years, the model predictions also show that alfalfa fields, in general, generate more runoff than corn-soybean fields. The ratio of predicted runoff from alfalfa fields over corn-soybean is about 1.58 and the ratio for soil erosion is 0.52. These values are similar to those observed in the field during the last two years. The simulation results demonstrate that, with valid inputs of soil and management information, EPIC can be used to simulate production and environmental effects on other soils in western Minnesota.

Result 3 - Ash Characterization and Evaluation $0

The ash from gasification of alfalfa stems is physically and chemically characterized. Crop responses to soil amended with ash are determined through green house studies. The primary result of this objective is ascertaining the potential value of the ash from gasification of alfalfa stems as a soil amendment.

Time line

Activity	Completion Date
Procurement of ash samples	December 1998
Chemical & physical characterization of ash	June 30, 1999
Greenhouse study	June 30, 2000
Final recommendations and report	June 30, 2000

Status:

Procurement of ash samples: To verify the suitability of alfalfa stem as feedstock for energy production, 380 Mg of alfalfa stem produced by cooperator farmers in western Minnesota were shipped to Finland for a pilot gasification test in 1997. The operational parameters for the test gasification were similar to that of the proposed plant in Minnesota, therefore, the ash generated during the pilot test is a reasonable representation of the ash that will be generated from the power plant in Minnesota. Three fly ash and one bottom ash sample were collected during the test gasification. The ash samples were shipped to the USA for research reported here.

Chemical and physical characterization of ash

Elemental composition. Chemical characterization was initiated by performing a total elemental analysis of the ash using standard EPA methodology. The ash sample was digested in a microwave with concentrated HNO_3-H_2O_2 and then Inductively Coupled Plasma (ICP) spectroscopy, IR detection, and calorimetric methods were used to analyze the digest for various elements and compounds. In addition to microwave digestion, a saturated water extract of the ash was prepared and analyzed for various inorganic elements by ICP and ion chromatography. Alfalfa ash was also characterized with respect to chemical parameters that are important in its utilization as an agriculturally beneficial soil amendment. Parameters included are: ash pH, electrical conductivity (EC), available P_2O_5, K_2O, Calcium Carbonate Equivalent (CCE), total B, and total N, nitrate-N, and NH_4-N.

Elemental analysis indicated that C was the most predominant constituent of the fly ash (42%). Carbon content of the bottom ash was considerably lower (6.3%). Following C and in the order of decreasing abundance K, Ca, Cl, Mg, and P were other predominant constituents of the fly ash. Calcium, Mg, K, and P were the predominant constituents of the bottom ash. The following empirical formulae approximately represent the major constituents of fly and bottom ash.

$C_{35}\,K_3\,Ca_{2.1}\,Cl_{0.8}\,Mg_{0.8}\,P_{0.5}\,N_{0.7}\,S_{0.1}\,Na_{0.1}\,Fe_{0.04}\,Al_{3.7}\,Si_{0.3}$ (Fly ash)

$C_{52}\,K_{15}\,Ca_{48}\,Mg_{43}\,P_{9.6}\,N_{0.9}\,S_{5.6}\,Na_{0.8}\,Fe_1\,Al_{2.1}\,Si_{1.8}$ (Bottom ash)

The high concentration of C in the fly ash is a reflection of incomplete conversion of C compounds present in the alfalfa stem while the higher Ca and Mg concentration of the bottom ash is a reflection of dolomite used in the reactor bed.

Soluble elements. The elemental composition of a saturated extract prepared from alfalfa fly and bottom ash show that K, Cl, S, Na, and Si were the predominant ions in the saturated extract of alfalfa fly ash and K, Cl, Si, S, and Na were predominant in the bottom ash. Comparison of elemental concentration in the saturated extract and total elemental composition of alfalfa fly ash indicated that 85% of total Cl, 65% of total K, 39% of total Mo, 35% of total Na, 26% of total S, 15% of total Li, 7% of total Si, 6% of total V, and 2% of total Cr were in soluble forms. High K concentration of saturated extract suggests that ash is a potentially good source of plant available K. However only 0.3% of the total P was water soluble, indicating lesser potential of ash as a P fertilizer. Concentration of As, Ag, Be, Cd, Co, Cr, Cu, Pb, Ti, Mn, and Zn were generally below the detection limit or less than 0.3 mg/L. This suggests that in the short term, leaching of these metals from alfalfa ash amended soils is unlikely.

Agriculturally important parameters. The mean pH of alfalfa stem fly ash was 11.5 and that of the bottom ash was slightly more alkaline, 13.1. Calcium carbonate equivalent (CCE) of bottom ash was almost twice as high as fly ash. Relatively high pH and CCE value of the alfalfa stem ash suggests that it can potentially be used as a liming agent to increase the pH of acid soils. Electrical conductivity of the fly ash saturated extract was much higher than bottom ash and reflected the higher levels of soluble K and Cl in the fly ash. The data suggest that consideration should be given to the potential salinity problems that may be associated with excessively high rates of ash application.

Total N content of the fly ash was low (1.3%) and that of bottom ash was even lower (0.17%). Most of the N in fly and bottom ash was in organic forms as indicated by low concentration of NH_4-N and NO_3-N. The predominance of organic forms of N in the alfalfa ash is most likely due to the fact that the entire N in the alfalfa is in organic forms. Fly ash was high in available K_2O (11.8-13.8%) extracted with ammonium citrate. This is equivalent to almost 88% of the total K content of the fly ash. Available P_2O_5 extracted by ammonium citrate in fly ash was 2.18% and that in the bottom ash was 0.56%. This indicates that 63% and 0.09% of the total P in the fly and bottom ash was in plant-available forms.

Our characterization of the ash with respect to agriculturally important parameters indicated that the ash is a potentially good liming agent. The fertilizer value of the fly ash is equivalent to 1-2-13 (N-P_2O_5 - K_2O, each expressed as percent total composition by weight). The ash can potentially be utilized as a beneficial soil amendment. However, this chemical characterization and availability assessment is based on using standard methods that employ chemical extractions and analysis techniques. A more comprehensive assessment of the potential for agricultural utilization of the ash should be based on controlled environment and field studies.

Fertilizer value and liming potential of the alfalfa fly ash were evaluated in a greenhouse study with two representative agricultural soil of Minnesota using corn as a test crop. Ash application significantly increased the K concentration and K uptake by corn in both soils. It also significantly increased plant available K and P in both soils and pH of the acid soil. However, it did not increase P concentration or P uptake by plants. At the rates up about 7,200 kg/ha, the concentrations of many metals were very low or below the detection limits. Thus, when used at agronomically reasonable rates, alfalfa fly ash did not pose any risk of excessive accumulation of toxic elements in soil or plants. This experiment showed that alfalfa stem fly ash appears to be a potential source of K for corn grown in K deficient soils and a potential liming agent for acid soils.

<u>Organic compounds of environmental concern.</u> The high C content of the ash raised concerns about the organic compounds that may be of potential environment and human health risks. Although not a part of the original proposal, ash was extensively characterized with respect to five groups of organic constituents of traditional environmental concern. Polyaromatic hydrocarbons (PAHs) and semi-volatile organics, total polychlorinated biphenyls (PCBs), dioxins, and furans were measured using standard EPA methods.

The analysis of alfalfa stem fly ash for semi-volatile organic compounds indicated that only two of the 76 compounds tested were present in ash in concentrations above the detection limits. The concentration of 2-methylnaphthalene was 4.4 mg/kg and that of bis (2-ethylhexyl) phthalate was 1.5 mg/kg. The concentration of individual dioxin and furan compounds and total dioxins and furans in both fly and bottom ash were below the detection limits.

Polyaromatic hydrocarbons (PAHs) are another group of organic compounds of potential environmental and human health concern. The concentration of PAHs in the bottom ash was below the detection limit of the GC-MS, and with the exception of naphthalene, the concentration of all other PAHs were below the detection limit or very small in the fly ash.

It should also be mentioned that when ash is land applied at reasonable agronomic rates of less than 22,400 kg/ha, then the actual concentrations in the soil would be at least 100 times less than their respective level in the ash. In addition to the dilution effects, many biogeochemical reactions in the soil have an attenuating effect on the concentration of PAHs. Some of these reactions include sorption by soil organic matter and the clay fraction, microbial biodegradation, photodegradation, and volatilization. The rate and extent of these reactions are determined by a complex array of conditions ranging from soil type and properties to type and initial concentration of the PAHs.

Greenhouse study:
Fertilizer value and liming potential of the alfalfa fly ash were evaluated in a greenhouse study with two representative agricultural soil of Minnesota using corn as a test crop. Ash application significantly increased the K concentration and K uptake by corn in both soils. It also significantly increased plant available K and P in both soils and pH of the acid soil. However, it did not increase P concentration or P uptake by plants. At the rates up to and including equivalent to 6,400 lb/acre, the concentrations of many metals were below the detection limits or were very low. Thus, when used at agronomically reasonable rates, alfalfa fly ash did not pose any risk of excessive accumulation of toxic elements in soil or plants. This experiment showed that alfalfa stem fly ash appears to be a potential source of K for corn grown in K deficient soils and a potential liming agent for acid soils.

The Minnesota Valley Alfalfa Producers and the Minnesota Pollution Control Agency are using results from these studies to develop a land application permit for the ash. A new shipment of ash from Finland is due to in Minnesota within the next few months. Studies to evaluate the ash in the field are currently being planned. Additional chemical and physical characterization of the ash are being conducted and the results will be reported in future.

V. DISSEMINATION:

The instrumentation and results from this study were disseminated through poster presentations and bulletins at MN River Expo in St. Peter, Farmfest in Redwood, field days at Morris, articles in Morris Tribune, and technical presentations at American Society of Agronomy and Soil Science Society of America annual meetings.

VI. CONTEXT:

A. Significance: Runoff and soil erosion from row-cropped lands on rolling landscapes of south-western and western Minnesota contribute to sediments, P, and BOD (biochemical oxygen demand) of the Minnesota River. Being a deep-rooted leguminous crop that provides continuous ground cover, alfalfa improves soil quality through N-fixation, soil pore structure, increased infiltration, and reduced erosion. The use of a paired watershed technique to monitor the effects of alfalfa vs. corn-soybean cropping sequence accounts for topographic and year to year climatic variability. The advantage of the paired watershed approach is that watersheds need not be identical, area evaluated is of field sizes, and crop management schemes similar to farmer's fields are practiced on the research plots. In years with limited rainfall, simulated rainfall can also be used to estimate runoff and pollutant losses by establishing conventional runoff plots within the watershed.

In order to extend the evaluation to consider a longer time frame, more climatic variability, and a larger area, computer simulation will be used to estimate the influence of alfalfa on runoff losses of pollutants on watershed to a sub-basin scale.

Innovative combustion turbine technology designed for biomass has been developed by a number of companies. Unlike conventional combustion turbines that operate under oxidizing conditions, the combustion turbines operate under reducing conditions. Advantages of this technology include more efficient energy production and reduced air emissions. However, like conventional combustion technology, an ash residue remains after the material is burned. The characteristics of the ash are dependent on the material used and the conditions of combustion.

With limited landfill space, one of the major challenges in society today is to recycle or find beneficial uses of generated wastes. An ultimate intent of using alfalfa biomass as an energy source is to apply the ash generated from the gasification process on land to recycle nutrients for crop production. Thus, a nearly complete nutrient cycle can be achieved. While numerous studies have been conducted evaluating the use of various ash products as soil amendments, there is no information related to ash that has been generated under reducing conditions.

The effect of the ash on soil chemical properties and plant response needs to be known so that predictions can be made for appropriate rates to apply as well as frequency of application. The results of these experiments allow prediction which soils would be most suitable for land spreading of ash, and to predict with reasonable certainty what rates could be added without adverse impact on the environment.

B. **Time:** The project began in 1996-97 and will continue till year 2000.

C. **Budget Context:**

	July 1995- June 1997	July 1997- June 1999	July 1999- June 2000
	Prior expenditures	Proposed expenditures	Anticipated future expenditures
2. **LCMR**	$	$200,000	$
3. **Other State**	$200,000	$	$
4. **Non State Cash**	$100,000	$	$
Total	$	$	$

VII. COOPERATION:

Mr. Dave Birong, Assistant Scientist, Soil, Water, and Climate Department, UM; 25,000 LCMR dollars, 30% time on the project.

Mr. Ed Dorsey, Scientist, Soil, Water, and Climate Department, UM; 25,000 LCMR dollars, 30% time on the project.

Dr, Juanjuan Xia, Research Associate, Soil, Water, and Climate Department, UM; 20,000 LCMR dollars, 30% time on the project.

Dr. Satish C. Gupta, faculty, Soil, Water, and Climate Department, UM; 0 LCMR dollars, 5% time on the project.

Dr. John F. Moncrief, faculty, Soil, Water, and Climate Department, UM; 0 LCMR dollars, 5% time on the project.

Dr. Carl J. Rosen, faculty, Soil, Water, and Climate Dep., UM; 0 LCMR dollars, 10% time on the project.

Dr. Padam Sharma, Research Associate, Soil, Water, and Climate Dep., UM; 80,000 LCMR dollars, 30% time on the project.

Dr. Morteza Mozaffari, Research Associate, Soil, Water and Climate Depart., UM ; 30,000 LCMR dollars, 25% time on the project.

Dr. Mike Russell, faculty, Soil, Water and Climate Dept., UM; 0 LCMR dollars, 1% time

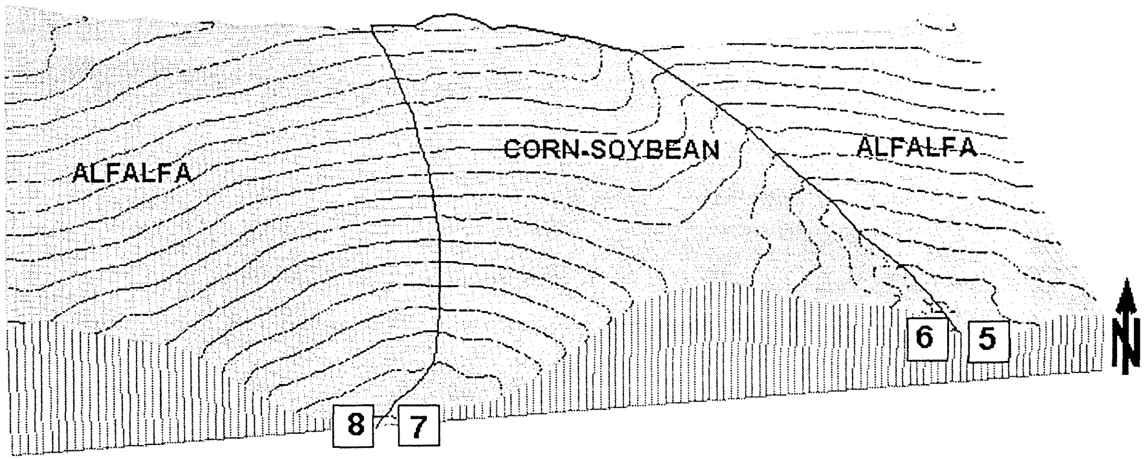
Dr. Edward Nater, faculty, Soil, Water and Climate Dept., UM; 0 LCMR dollars, 1% time

VIII. **LOCATION:** There will be activities in Ramsey, Big Stone, Grant, Douglas, Traverse, Stevens, Pope, Swift, Redwood Lac Qui Parle, Chipewa, Yellow Medicine, Renville, Kandiyohi, Lincoln, and Lion Counties.

IX. **REPORTING REQUIREMENTS:** The next work program progress report will be submitted not later than March of 2000 (if needed). A final work program report and associated products will be submitted by June 30, 2000.

X. APPENDIX FIGURES AND TABLES

WATERSHED STUDY SITE
West Central Research & Outreach Center, Morris, MN



Appendix Fig. 1: Paired watershed study site at West Central Research & Outreach Center Morris, MN. The numbers at the downslope end of each field indicate plot designations and approximate locations of flumes and instrumentation shelter.

Appendix Table 1: Summary of the total amounts of precipitation (rain and snow) recorded during 1996-1998 compared with historical records from West Central Research and Outreach Center at Morris.

Monitored Parameters	1996-97 Mean	1997-98 Mean	1886-1998 Historic Record
	Water Equivalent (mm)		
Rain	491	609	499
Snow	199	104	104
TOTAL	690	712	603

Appendix Table 2: Total runoff, sediment load and sediment load per unit runoff during snowmelt and rainfall-runoff events.

Runoff and Pollutants in Runoff	Season	1996-97 Alfalfa	1996-97 Residue: Corn Crop: Soybean	1997-98 Alfalfa	1997-98 Residue: Soy Crop: Corn	ANOVA Results Factor	ANOVA Results *p*
		(mm)					
Total Runoff	Snowmelt	131	104	70.9	23.7	Rotation	***0.099***
	Rain	2.71	1.97	28.7	20.7	Season	***0.001***
	Total	134	106	100	44	R x S	*0.496*
		(kg ha^{-1})					
Sediment Load	Snowmelt	243	496	223	152	Rotation	*0.155*
	Rain	9.13	26.7	153	637	Season	*0.124*
	Total	252	523	376	789	R x S	*0.335*
		(kg $ha^{-1} mm^{-1}$)					
Sediment / Runoff	Snowmelt	1.85	5.13	3.10	6.58	Rotation	***0.044***
	Rain	2.48	22.6	11.5	31.3	Season	*0.106*
						R x S	*0.458*

Appendix Table 3: Amounts of biochemical oxygen (BOD) and chemical oxygen (COD) demanding materials in the snowmelt and rainfall-runoff water.

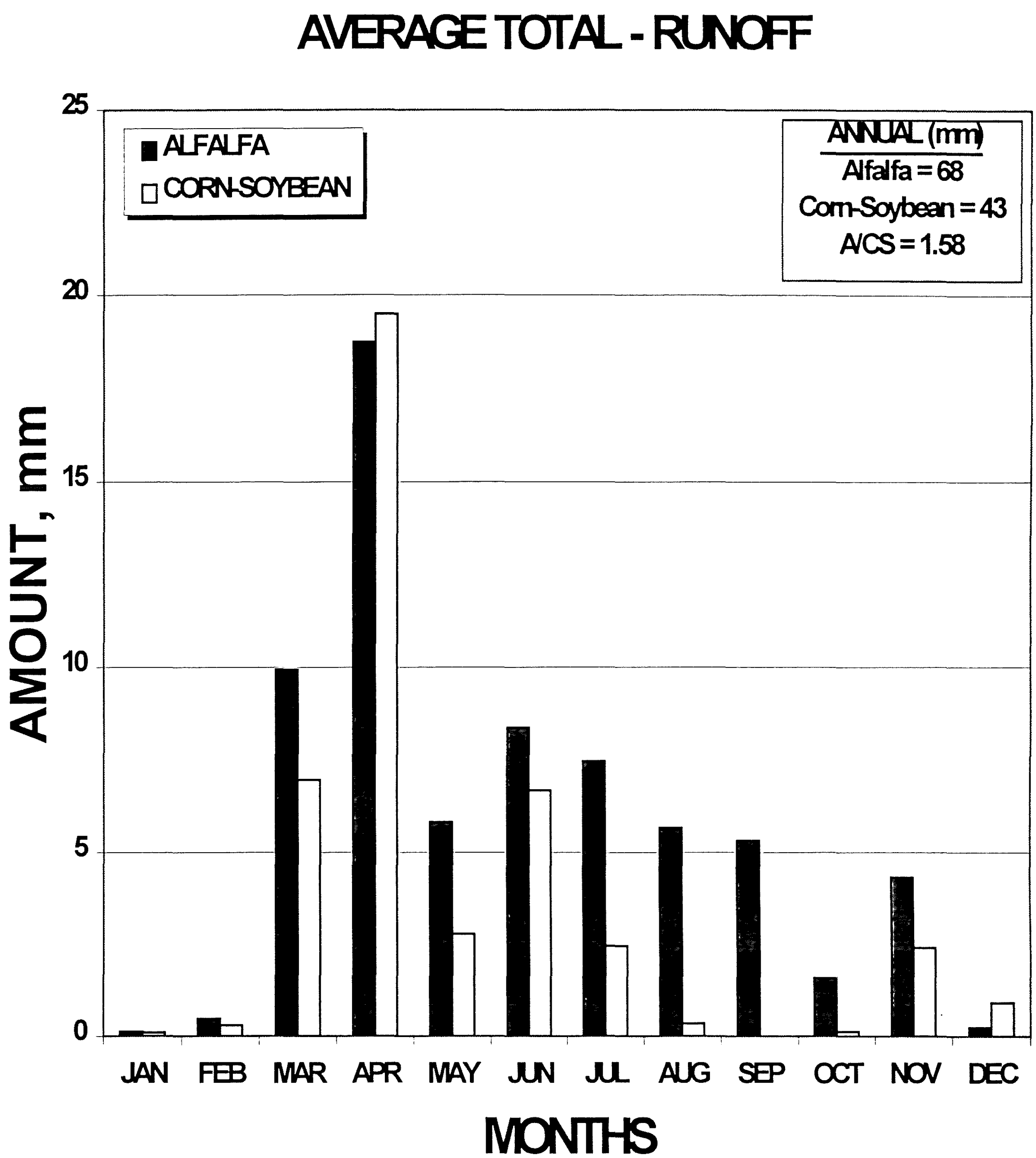
Pollutants in Runoff Water	Season	1996-97 Alfalfa	1996-97 Residue: Corn Crop: Soybean	1997-98 Alfalfa	1997-98 Residue: Soy Crop: Corn	ANOVA Results Factor	ANOVA Results *p*
		(mm)					
COD	Snowmelt	54.2	65.1	136	18.0	Rotation	*0.602*
	Rain	1.78	4.71	48.8	97.0	Season	*0.239*
	Total	56.0	69.8	185	115	R x S	*0.203*
		(kg ha^{-1})					
BOD	Snowmelt	18.7	13.7	42.9	2.62	Rotation	***0.048***
	Rain			3.86	1.58	Season	*0.104*
	Total	18.7	13.7	46.8	4.20	R x S	***0.092***

Appendix Table 4: Loads of total (TP), bioavailable (BP), dissolved (DMRP), and particulate (PP) phosphorus in snowmelt and rainfall-runoff water.

Pollutants in Runoff Water	Season	1996-97		1997-98		ANOVA Results	
		Alfalfa	Residue: Corn Crop: Soybean	Alfalfa	Residue: Soy Crop: Corn	Factor	*p*
		(g ha^{-1})					
Total Phosphorus (TP)	Snowmelt	1829	2417	1070	508	Rotation	*0.987*
	Rain	38	45	798	784	Season	***0.006***
	Total	1867	2462	1868	1292	R x S	*0.600*
Bioavailable Phosphorus (BP)	Snowmelt	1540	2067	719	370	Rotation	*.0966*
	Rain			473	336	Season	***0.020***
	Total	1540	2067	1192	706	R x S	*0.528*
Dissolved Phosphorus (DMRP)	Snowmelt	1605	2153	524	375	Rotation	*0.813*
	Rain	30	9	361	216	Season	***0.002***
	Total	1635	2162	885	591	R x S	*0.700*
Particulate Phosphorus (PP)	Snowmelt	224	264	546	133	Rotation	*0.610*
	Rain	8	37	437	568	Season	***0.052***
	Total	232	301	983	701	R x S	*0.292*

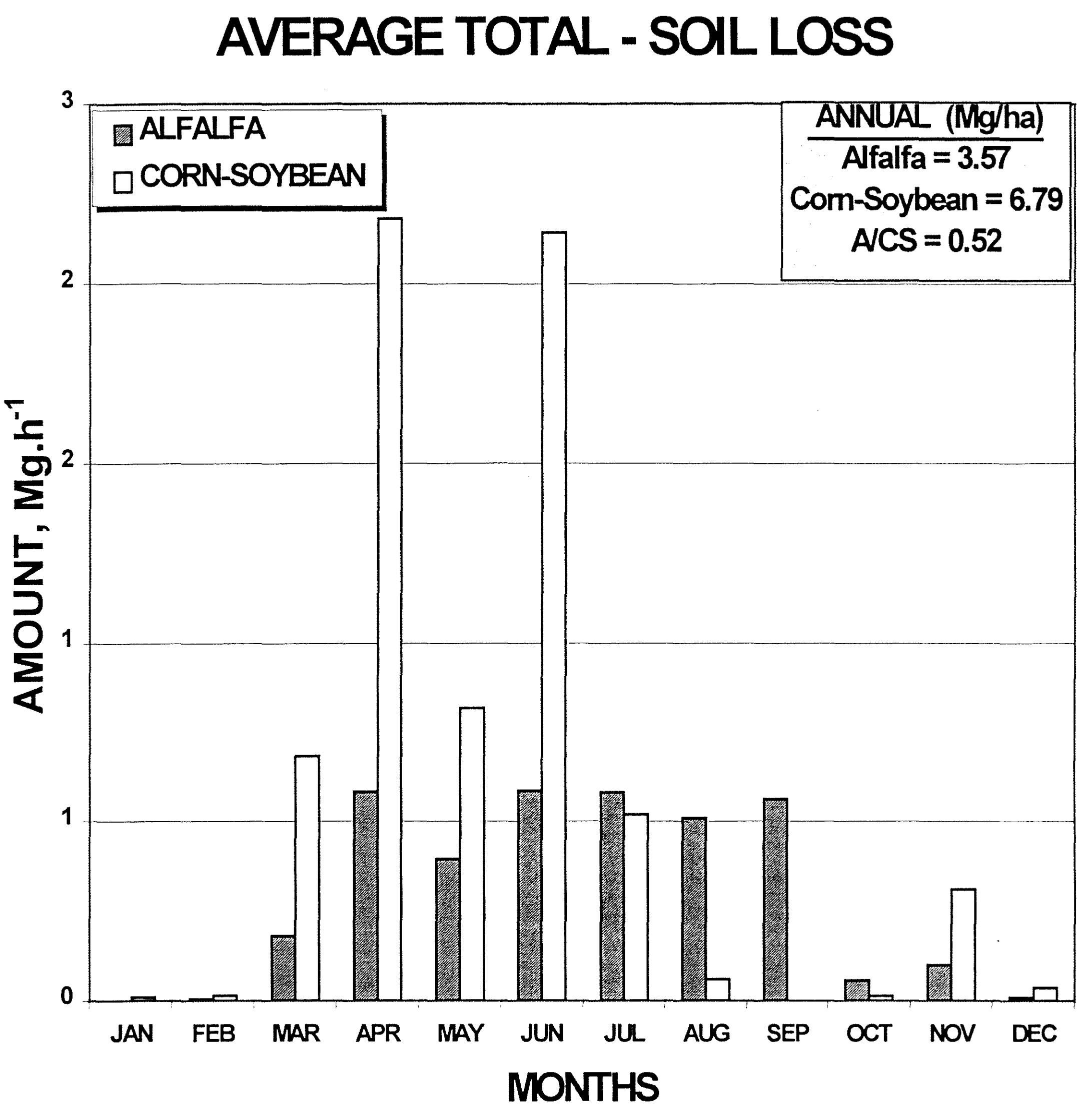
Appendix Table 5: Loads of ammonium, nitrate, and total nitrogen in snowmelt and rainfall-runoff water

Pollutants in Runoff Water	Season	1996-97		1997-98		ANOVA Results	
		Alfalfa	Residue: Corn Crop: Soybean	Alfalfa	Residue: Soy Crop: Corn	Factor	*p*
		(g ha^{-1})					
Ammonium Nitrogen	Snowmelt	6066	263	5528	304	Rotation	***0.019***
	Rain	14	4	375	67	Season	***0.093***
	Total	6081	266	5903	371	R x S	*0.129*
Nitrate Nitrogen (PP)	Snowmelt	2621	7145	1026	6806	Rotation	***0.014***
	Rain	39	45	494	4320	Season	***0.070***
	Total	2660	7190	1520	11126	R x S	*0.366*
Total	Snowmelt	8688	7407	6554	7110	Rotation	*0.606*



Nitrogen	Rain	53	48	869	4387	Season	***0.008***
	Total	8741	7455	7423	11497	R x S	*0.627*

Appendix Fig. 2: EPIC simulated predictions of average monthly runoff from fields cultivated with a six year alfalfa-corn (CAAAAC) vs. corn-soybean (CS) rotation for 48 years on a sloping Barnes loam soil at Morris, MN.



Appendix Fig. 3: EPIC simulated predictions of average monthly soil erosion from fields cultivated with a six year alfalfa-corn rotation (CAAAAC) vs. corn-soybean (CS) rotation for 48 years on a sloping Barnes loam soil at Morris, MN.

Appendix Paper 1:

The Effect of Alfalfa and Corn-Soybean Cropping Systems on Runoff Losses of Solids and Associated BOD and COD from Snowmelt on a Field Scale

P. P. Sharma, J.J. Xia, E.C. Dorsey, J.F. Moncrief, and S.C. Gupta

ABSTRACT

Four field size watersheds were instrumented in the fall of 1996 at Morris, Minnesota to compare the volume of runoff and pollutants coming from alfalfa and corn-soybean fields on a rolling prairie landscape. Runoff water of the snowmelt from each watershed was measured by the height of water in two flumes with overlapping ranges arranged in series. An automatic water sampler collected runoff samples for chemical analysis. The water samples were analyzed for total solids, biochemical oxygen demand (BOD), and chemical oxygen demand (COD). Based on the results of snowmelt events of 1997, 1998, and 1999, the alfalfa fields yielded more runoff than corn-soybean fields while the latter produced more sediment. Runoff from alfalfa fields contained about four times more BOD and two times more COD than corn-soybean fields.

Abbreviations: CS21X, Campbell Scientific data logger model 21X; BOD, biochemical oxygen demand; COD, chemical oxygen demand.

INTRODUCTION

In the upper Mississippi River watershed, the Minnesota River is recognized as one of the major contributors of pollutants from non-point sources. A significant part of the Minnesota River's load of pollutants comes with runoff and sediment entering the river and its tributaries throughout its 4-million-hectare watershed. The watershed consists of gently to moderately sloping rolling prairie landscape predominantly used for row-crop agriculture. Corn and soybean grown in rotation often requires the use of substantial fertilizer, manure, and pesticide inputs. Tillage practices range from conventional moldboard or chisel plow based to high residue systems that eliminate or greatly reduce primary tillage.

Field scale studies of runoff and soil erosion in temperate climates show snowmelt water to be a significant contributor to total annual runoff and soil loss. The partitioning of total snowmelt into runoff and infiltration varies with annual climatic variability of a physiographic region, land use, tillage practices, and spatial variability of soil physical properties. Snowmelt and prolonged occurrence of low-intensity rains especially when the soil is still frozen below the surface are identified as main causes of runoff and soil erosion in high latitude landscapes (Chanasyk and Woytowich 1986; Edward and Burney, 1989). On a frozen silt-loam soil in northern Oregon, Zuzel et al. (1982) estimated infiltration to be about 41 to 91% of total snowmelt. In a similar soil in Fairbanks, Alaska, Kane and Stein (1987) estimated infiltration to be about 53 to 75% of the total snowmelt. In years when soil water contents at freezing were high, infiltration of the snowmelt water decreased to between 24 and 47%. Studies on effect of tillage on runoff and erosion in the Peace River region of Canada (Van Vliet et al., 1993) indicated that mean snowmelt runoff was higher for high residue systems like zero tillage (ZT) compared to frequently tilled conventional tillage (CT) systems while sediment loss was the opposite.

The chemical oxygen demand (COD) is an estimate of the total available reduced carbon and other energy sources for oxidation by chemical and biochemical reactions. The COD in the runoff samples should be related to the total substrates of energy in the residue from crops and the sediment load that contains available carbon. The biochemical oxygen demand (BOD) is the amount of oxygen required by bacteria to decompose organic material in the water under aerobic conditions during a five-day incubation. BOD measures the potential source of organic energy substrate that is highly related to the composition of the crops (Martone, 1976) and the amount of runoff.

Usually, when the spring thaw begins in western Minnesota, the soil is still frozen. While a perennial alfalfa crop provides continuous cover to the land surface, sparse evidence in the literature suggests that over-wintering alfalfa biomass may be susceptible to leaching losses of nutrients during snowmelt. The increased amount of biomass may also delay soil thawing. The specific objective of this research was to compare runoff and pollutant loads delivered to the field edge from perennial alfalfa and corn-soybean fields from snowmelt. Analyses of observed runoff and pollutant load data during snowmelt events of 1997, 1998, and 1999 spring are presented in this manuscript.

MATERIALS AND METHODS

Establishment of paired watershed treatments

Four field size watersheds laying east-west and draining south were selected on the east ½ of West Central Research and Outreach Center field E-5 at Morris in Stevens County, Minnesota (T. 125N, R. 41W). The area is dominated by gently sloping to hilly, well-drained Buse *(fine-loamy, mixed Udorthentic Haploborolls*) - Barnes *(fine-loamy, mixed Udic Haploborolls*) - Forman *(fine-loamy, mixed Udic Argiborroll*) soil association that is mostly loam to clay loam in texture.

The general relief of the study site is shown in Figure 1. The dominant soil series at the site includes the well drained, gently (2-6%) to moderately sloped (6 - 12% slopes), Barnes - Buse loam (Lewis et. al, 1971). The corner fields (Plot 5 and 8) are separated from the middle fields by natural grass waterways. A natural ridge line defines the drainage area of the middle fields (Plot 6 and 7). Plots 5 and 7 face southwest while plots 6 and 8 face southeast.

Plot 5 (0.65 ha) and 8 (1.78 ha) were field cultivated for seedbed preparation for alfalfa (figure 1). The total annual alfalfa yield was 4.4 Mg ha^{-1} in 1997, 5.7 Mg ha^{-1} in 1998 and 4.9 Mg ha^{-1} in 1999. The over-wintering biomass of alfalfa measured during the fourth week of October was 1.86 Mg ha^{-1} in 1996, 1.25 Mg ha^{-1} in 1997 and 1.62 Mg ha^{-1} in 1998. The central two watersheds (Plots 6 & 7 both 0.98 ha) were seeded with corn (*Zea mays*, L.) in 1996 and 1998, and soybean in 1997 and 1999. An aggressive soil and water conservation tillage approach was employed for the corn and soybeans production. All tillage, anhydrous ammonia injection, and planting was done perpendicular to the slope. Following soybean harvest in the fall anhydrous ammonia was injected. This was the only fall tillage. In the spring watersheds were field cultivated and planted to corn. Corn at 60cm height was row cultivated once for weed control. Following corn harvest in the fall stalks were chopped and watersheds were chisel plowed. Watersheds were field cultivated and planted to narrow row soybeans (25cm) the next spring.

Measurement of runoff and collection of water samples

Two flumes arranged in series (a 15-cm Parshall flume and a 10-cm Palmer Bowlus flume) were used to measure runoff at each field. The 10-cm Palmer Bowlus flume can measure range of water flow between 0.047 and 3.412 liters per second while 15-cm Parshall flume can measure from 1.496 liter up to 107 liter per second. The overlaps of the measured ranges from two flumes guarantee that we didn't miss any runoff. A specially constructed nearby instrument shelter housed a data logger and a water sampler. A pressure sensor connected to a N-gas-bubbling device and gage tube at each flume measured the height of water in the flumes. A CS21X Campbell Scientific data-logger was programmed to read the instruments every 30 seconds. Whenever the smaller Palmer Bowlus flume recorded a flow height >5 mm, the program triggered the water sampler to collect about 110-ml of runoff at a set time interval (15-20 minutes). Eight 110-ml samples were collected in each of 24 1L bottles. This resulted in a composite sample representing two to three hours of runoff. Each day, the collected runoff samples were transported in a cooler to the University of Minnesota, Soil Water & Climate laboratory at St. Paul and stored at 4 °C for determination of chemical constituents (phosphorus and nitrogen results will be discussed in a separate paper). Along with retrieval of water samples, stored flow data were transferred to a personal computer by connecting a RS-232 cable with the storage module and using communication software provided by the data-logger vendor.

Analysis of runoff water

Standard laboratory practices prescribed by US-EPA (1989) were followed to analyze sediment load, BOD, and COD as parameters of water quality. Sediment concentration was determined by evaporating a known volume of sub-sample by oven drying at 104 °C. The COD was determined using a spectrophotometer after oxidization with premixed COD reagents (US-EPA, 1989). For BOD, the water samples collected at the sites were stored at 4 °C and analyzed for oxygen within 24 hours. The samples were diluted 2, 6, and 10 times and incubated for five days. The comparison of oxygen remaining in the samples to its original content was used to calculate the BOD.

The amount of sediment, BOD and COD load for a runoff event are calculated by multiplying the flow volume with the corresponding concentrations measured in the laboratory. The runoff volume and sediment load are normalized on a unit area basis by dividing with the respective field sizes in hectares. Since the snowmelt period during the three years extended from February to April, and there was intermittent rain and sleet during the period, runoff volumes and the other loads were cumulated for the entire period.

Year, crop, aspect, and watershed pair are potential factors affecting the runoff and the other loads. As a preliminary evaluation, we used one-way ANOVA to assess the effects of each of these factors on runoff. This analysis showed little or no effect of watershed location and the aspect. Further analysis and interpretation of data are based on two-way analysis of variance conducted to evaluate the effects of year and crop on runoff and load of pollutants.

RESULTS AND DISCUSSION

Snowmelt runoff during winters of 1996-97, 1997-98, and 1998-99

The distribution of temperature and rainfall during the snowmelt periods of March 21 to April 6 in 1997 (Fig. 2), February 15 to April 5 in 1998 (Fig. 3), and February 8 to March 20 in 1999 (Fig. 4) are shown. The effect of temperature and rain on average cumulative runoff from alfalfa and corn-soybean fields is also shown. Continuous above freezing days resulted in the ripening of the snow pack and initiation of runoff. Rainfall water during the melting period added to the volume of total runoff.

The 1997 snowmelt started on March 21 with a small flow rate during the day and freezing temperatures during the night (Fig. 2). During March 26 to 29 when daytime temperature increased, the rate of runoff increased with occasional freezing during early morning hours. The temperature decreased below freezing again during March 30 and early morning hours of March 31. Snowmelt and runoff started on March 31 and continued until April 6 when both day and night temperatures remained above freezing. Fifty mm of rain on April 5-6 further added to the runoff volume. The total runoff was 131mm from alfalfa fields compared with 104mm from the corn fields. The accelerated snowmelt of a record snow pack and the rainfall-runoff water rapidly moving through previously frozen waterways was one of the causes of the historical flooding in the Minnesota and Red River Valleys in the spring of 1997.

Compared to 1997, the snowmelt events of 1998 and 1999 spring were rather uneventful (Figs. 3 and 4). After about 24 hours of continuous above freezing temperatures, snowmelt started on February 16 in 1998 and February 9 in 1999. The continuous above freezing temperatures combined with occasional rain and sleet accelerated the snowmelt process. Most of the winter snow cover was gone within a week of the initiation of the snowmelt in 1998. The snowmelt of 1999 was continuous and controlled by several warmer events over a longer period of time. The total runoff was 71mm and 38mm from the alfalfa fields, and 34mm and 0.3mm from the corn-soybean fields in 1998 and 1999 respectively.

Alfalfa fields yielded more snowmelt runoff than corn-soybean fields (figure 5). During the high precipitation year of 1997 (199mm during snowmelt season), total runoff due to snowmelt and rainfall from alfalfa fields was about 30 mm more than corn fields. In the more normal year of 1998 (105mm) and less normal year of 1999 (55mm), alfalfa produced 47 and 38 mm more runoff than soybean and corn fields, respectively.

Water Balance

The precipitation through the snowmelt periods of 1997, 1998, and 1999 in both alfalfa and corn-soybean fields is summarized in table 1. Total precipitation of 199 mm was recorded at the Research Center's weather monitoring site in the winter of 1996-97 while 105 and 55 mm precipitated as snow and rain during the winters of 1997-98 and 1998-99 respectively. The differences in the amounts of total precipitation and snow on the ground (due to drifting) before the melt events from year to year resulted in significantly different runoff events in 1997 compared to the later two years (fig. 5). The year by crop interaction was also significant with alfalfa consistently showing higher average total runoff than either corn or soybean watersheds.

Assuming the total precipitation recorded at the Research Center's weather observation site fairly represents the expected precipitation at the watershed study site, watershed scale infiltration was estimated by subtracting the measured runoff from the total water (water equivalent of snow on ground + rainfall) available for runoff on the surface. The corn-soybean fields had infiltration about two times higher than that of the alfalfa fields (fig.5).

The average surface cover with crop residue measured after the snowmelt period and before tillage operations in the spring is also shown in table 1. The alfalfa fields had slightly higher surface cover than that provided by the corn-soybean residues. However, due to aggressive soil-conservation practices followed during tillage operations, both corn and soybean fields retained very high surface cover. During both the high and low snow years, alfalfa produced more runoff than either corn or soybean fields. The fall tillage done on the contour in the corn-soybean fields (chisel plowing following corn and anhydrous ammonia injection following soybeans) provided soil fracture zones and surface storage while also providing high levels of soil cover with crop residues that maximized infiltration of snow melt. Soil cover was similar on alfalfa fields but the fractured soil and surface storage was not present which reduced infiltration and increased runoff.

Sediment Load

While alfalfa fields generated more runoff each year, runoff water coming from alfalfa fields contained less suspended sediments (fig. 6). Runoff from corn residue covered fields in 1997 and 1999 generated more sediment load than alfalfa due to exposed soil. The sediment load from soybean covered residue fields in 1998 was lower than that from alfalfa fields due to more continuous cover between anhydrous injection zones. As a result, for the three years of observations, the main effect of crop on total sediment load was insignificant. Unit sediment load (or weighted average sediment concentration) was calculated by dividing the total sediment load with the total runoff for each year. Corn-soybean fields had about 2 to 3 times higher concentration of suspended sediments in runoff than runoff coming from alfalfa fields (fig. 6).

Load of BOD and COD

The estimates of the total load of biochemical and chemical oxygen demanding materials in the snowmelt runoff water are shown in figure 7. Averaged over three years, water coming from alfalfa fields carried about four times more BOD than corn-soybean fields. This is attributed to a higher volume of standing biomass for alfalfa and greater runoff volume. The above ground alfalfa biomass goes through a sequence of freezing at the first frost and then drying. The ruptured cells release nutrients during the next leaching rainfall or snowmelt runoff event (Timmons et al., 1970). On the other hand, the corn or soybean residue has already dried during senescence in the fall and is partially incorporated into the soil due to tillage. The leaching of cell contents in runoff water as measured by BOD depends upon time of year, time of precipitation, freezing-thawing and wetting-drying frequency, and crop stage.

While BOD measures the very labile energy substrate, COD measures total organic C, which could potentially be oxidized. When BOD values are lower relative to COD there usually is a good correlation with soil loss and associated organic matter. During the heavy snow accumulation year of 1997, runoff from the corn fields yielded slightly more COD than from the alfalfa fields due to the greater amount of soil loss. During the low snow accumulation years of 1998 and 1999, alfalfa fields yielded higher COD than either soybean or corn fields. The three-year average load of COD from alfalfa fields was twice that from corn-soybean fields.

SUMMARY

Observations of snowmelt during springs of 1997, 1998, and 1999 show alfalfa fields yielding more runoff than corn-soybean fields with aggressive soil and water conservation practices. The corn-soybean fields resulted in more sediment loss in 1997 and 1999 following corn and less sediment loss in 1998 following soybeans. From the results of three years, runoff water from alfalfa fields resulted in a four times higher load of BOD and a twice the load of COD compared to corn-soybean fields.

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Table: Total precipitation during the snowmelt season and surface cover for the three years of observation

	Year	Alfalfa	Corn-Soybean
		(mm)	
Total Precipitation1 (Snow + Rain)	1997	199	199
	1998	105	105
	1999	55	55
		(%)	
Surface cover After snowmelt	1997	79	64
	1998	78	63
	1999	79	60
	Mean	79	62

WATERSHED STUDY SITE
West Central Research & Outreach Center, Morris, MN

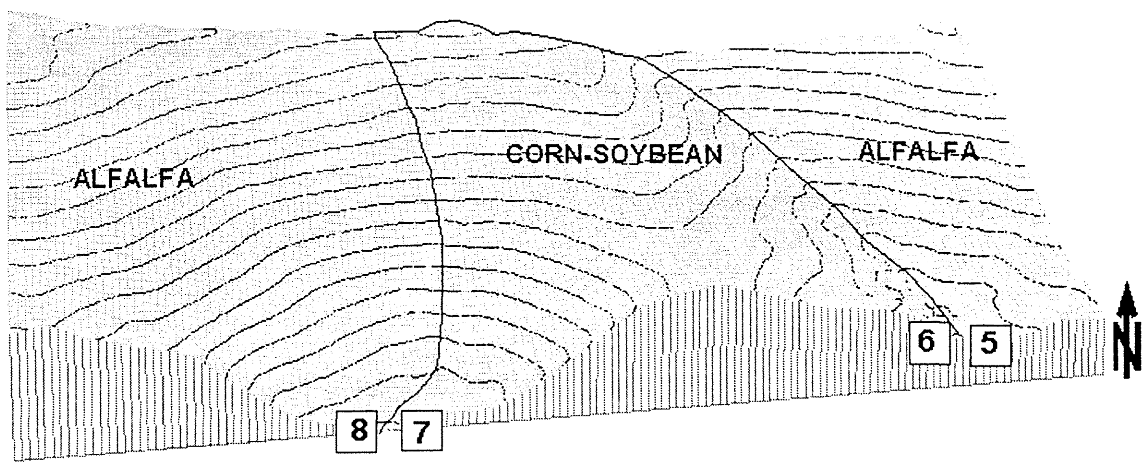


Fig. 1. General relief of the watershed study site at Morris, MN. The numbered boxes indicate plot designations and approximate location of instruments for measuring flow and sample runoff from each watershed.

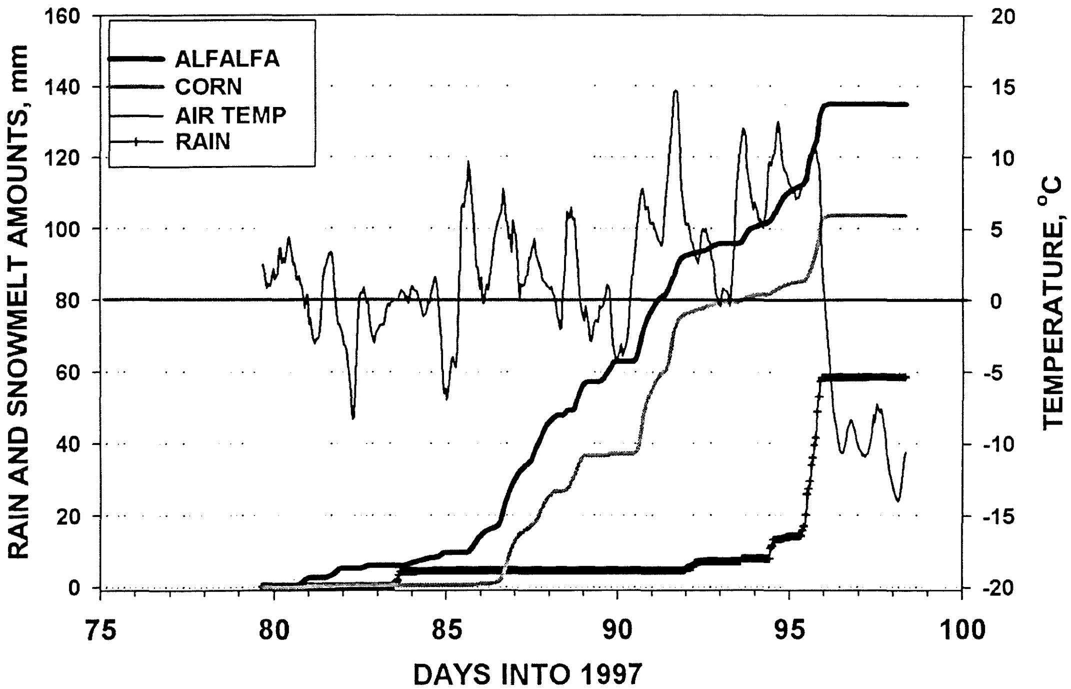


Fig. 2. Cumulative rain, average hourly temperature, and average cumulative runoff from alfalfa and corn-residue fields during snowmelt season in 1997.

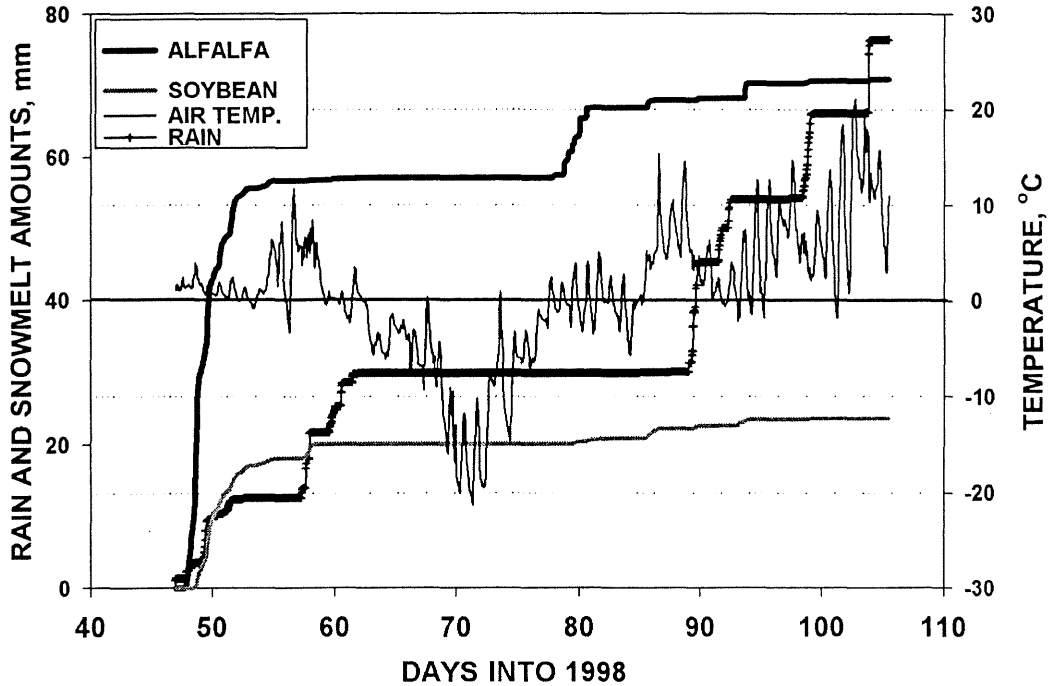


Fig. 3. Cumulative rain, average hourly temperature, and average cumulative runoff from alfalfa and soybean-residue fields during snowmelt season in 1998

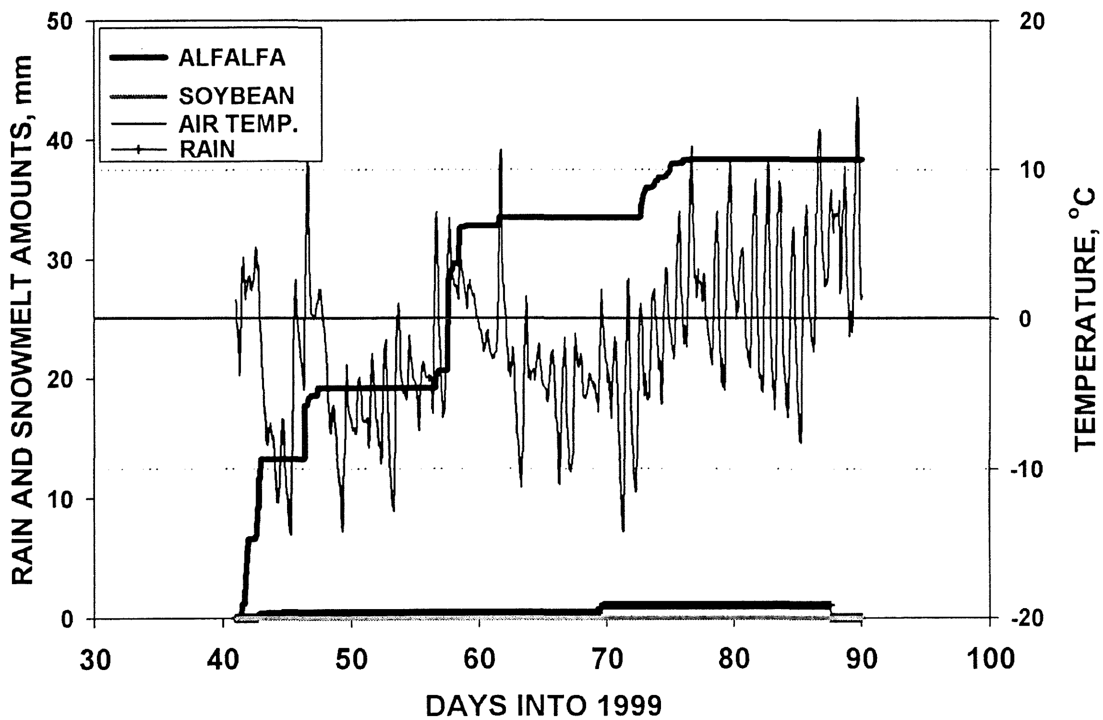
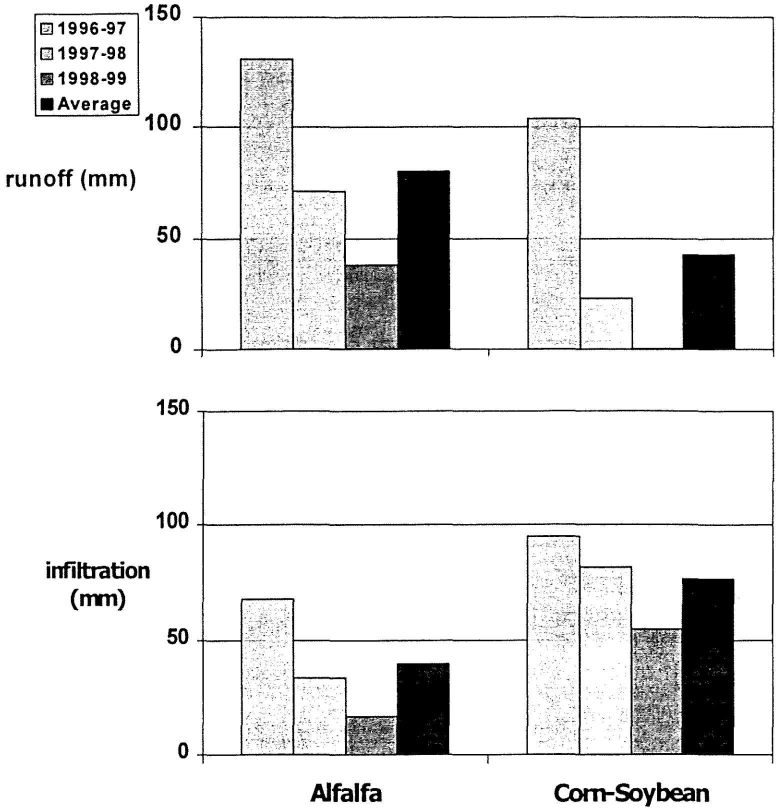


Fig. 4. Cumulative rain, average hourly temperature, and average cumulative runoff from alfalfa and soybean-residue fields during snowmelt season in 1999.



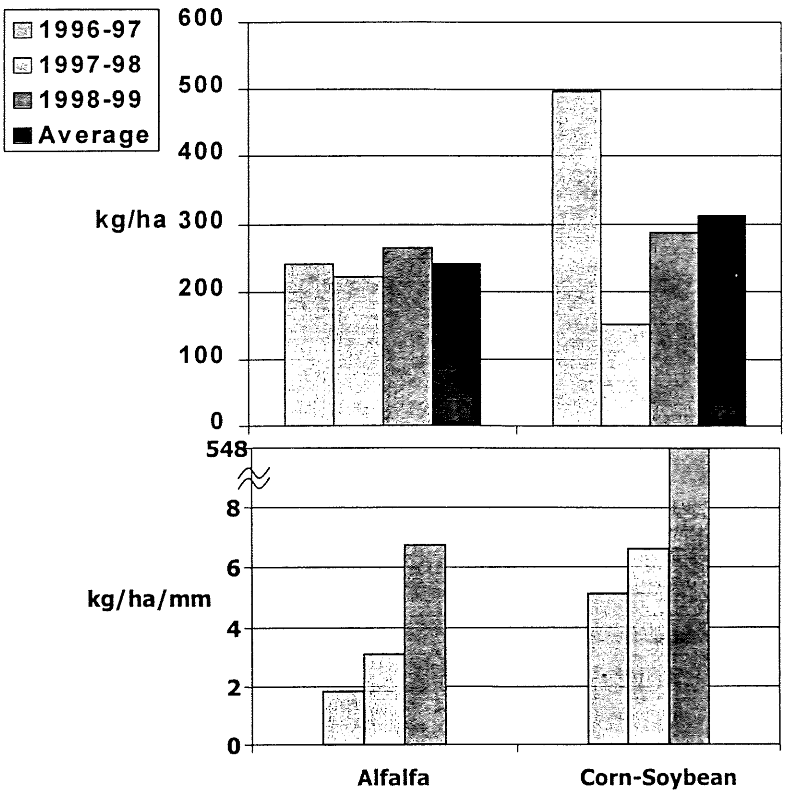
ANOVA Results

Factor	P
Year	0.019
Crop	0.098
Rotation x Year	0.750

ANOVA Results

Factor	P
Year	0.025
Crop	0.018
Rotation x Year	0.328

Fig. 5 Snowmelt Runoff and Infiltration in Alfalfa and Corn-Soybean Fields



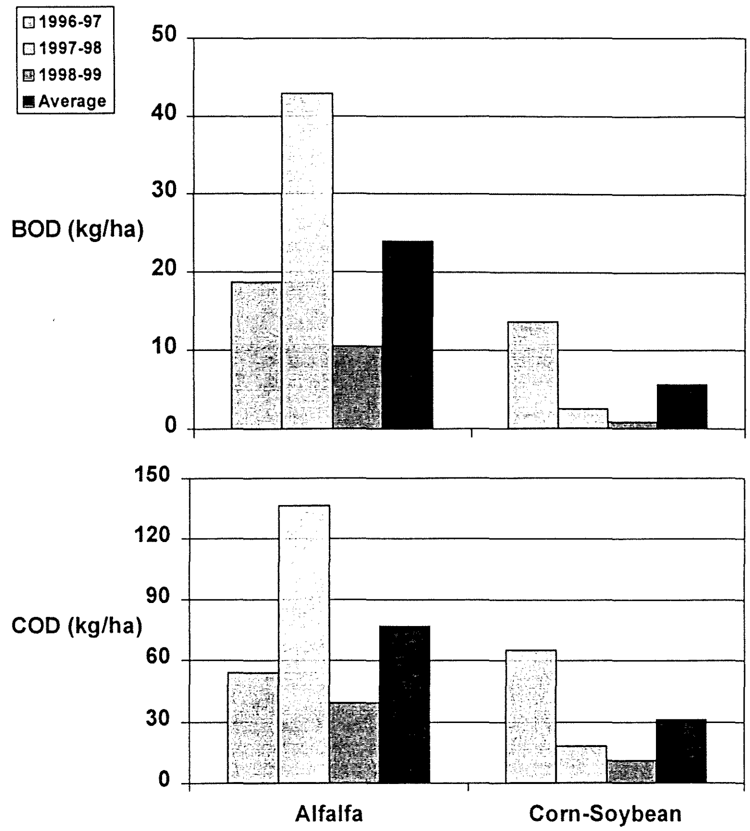
ANOVA Results

Factor	P
Year	0.102
Crop	0.651
Crop x Year	0.026

ANOVA Results

Factor	P
Year	0.083
Crop	0.098
Crop x Year	0.477

Fig. 6 Sediment Load and Sediment Load Per Unit Runoff in Alfalfa and Corn-Soybean Fields



ANOVA Results

Factor	P
Year	0.386
Crop	0.092
Rotation x Year	0.352

ANOVA Results

Factor	P
Year	0.192
Crop	0.122
Rotation x Year	0.240

Fig. 7. BOD and COD in Snowmelt Runoff from Alfalfa and Corn-Soybean Fields

The Effect of Alfalfa and Corn-Soybean Cropping Systems on Runoff Losses of Phosphorus and Nitrogen from Snowmelt on a Field Scale

P. P. Sharma, J.J. Xia, E.C. Dorsey, J.F. Moncrief, and S.C. Gupta

ABSTRACT

Annual cultivation of row crops with an aggressive soil and water conservative system was compared to a perennial alfalfa crop. Phosphorus and nitrogen losses from snowmelt runoff were measured from 1-2 hectare fields. While the P loads in runoff from both alfalfa and corn-soybean fields were highly related to the amount of snow, there were no differences in total load of P between the two cropping systems. The over-winter residues in the watersheds were a major source of P in the snowmelt runoff. Compared to a corn-soybean rotation, alfalfa significantly reduced the loss of nitrate nitrogen but had higher losses of ammonium nitrogen, which was likely leached from the residue during the spring snowmelt. Crop effects on total N loss were small and not significant.

Abbreviations: TP, total phosphorus; BP, bioavailable phosphorus; DMRP, dissolved molybdate reactive phosphorus.

INTRODUCTION

Nitrogen (N) and phosphorus (P) carried in surface runoff from agriculture lands can be a major source of pollution of surface waters. Sources of N and P in agricultural runoff include commercial fertilizer, manure, and release from soil and plant tissue. Plant residues left on the soil surface for improved snow catch to minimize winter kill of alfalfa and for erosion control for corn and soybeans are a potential source of N and P.

Cover crops have a number of potential beneficial effects including reduction in soil erosion, improvement of soil structure and prevention of NO_3-N leaching (Lal et al., 1991). Since the runoff from the snowmelt is often greater than rainfall runoff in the upper Midwest, the leaching from crop residue may yield significant amounts of nutrient losses during snowmelt runoff. Nutrients can be leached from the plant tissue after senescence or frost and increase the concentrations in runoff (Sharpley and Smith, 1991). This is of particular concern for P, but also, to a lesser extent, for N (Miller et al., 1994).

The available P may include both dissolved and some fraction of the sediment-bound forms. Wendt and Corey (1980) observed higher losses of dissolved molybdate reactive phosphorus (DMRP) from established or newly seeded alfalfa fields in the fall after the foliage had been killed by frost. The largest DMRP loss occurred in October after a frost had killed the vegetation and was due primarily to high concentrations of DMRP rather than large runoff volumes. The amounts of P leached from alfalfa tissue samples taken at various times (October 0.45 μg/ml, April 0.01μg/ml, July 0.06 μg/ml) suggests that differences in P leached from plant tissue accounted for much of the variation in DMRP losses. While the fraction of total P lost as DMRP was greater for alfalfa than for corn, the greatest P losses were associated with highest sediment loads observed on corn plots (Wendt and Corey, 1980).

Schomberg et al. (1994) studied the decomposition and nitrogen dynamics of alfalfa, grain sorghum and winter wheat. Decomposition coefficients were greater for alfalfa than for wheat or grain sorghum and were greater for buried than for surface residues. Rate coefficients increased linearly with water applied.

The crops from this study include alfalfa, corn, and soybean. The contribution of the nutrients loss from these crops to surface runoff, and the desiccation and freezing effects for the nutrition leaching from plant tissue is estimated.

MATERIALS AND METHODS

Study Site

Four field size watersheds were selected on the east ½ of West Central Research and Outreach Center field E-5 at Morris in Stevens County, Minnesota as described in the accompanying paper. All four plots were under wheat (*Triticum aestivum* L.) in 1994 and soybean (*Glycine max* L.) in 1995. Liquid manure was applied in February 1996. The manure application supplied approximately 114 kg ha^{-1} of P_2O_5.

The results of soil tests from grid soil samples (0-15cm depth) taken during June of 1998 to assess pH, organic matter, P and K levels in the soil are shown in table 1. The P and K levels were estimated using Bray-P and ammonium-acetate-extractable K methods. Due to manure application, the average soil P levels were elevated in 1996. Phosphorus fertilizer was not applied during this study.

The over-wintering alfalfa residue measured during the fourth week of October was 1.86 Mg ha^{-1} in 1996, 1.25 Mg ha^{-1} in 1997 and 1.62 Mg ha^{-1} in 1998. The corn and soybean residue in the fields after the harvest is estimated based on grain yield and a harvest index of .50 were 3.0 Mg ha^{-1} in 1996, 2.3 Mg ha^{-1} in 1997 and 4.99 Mg ha^{-1} in 1998.

Analysis Of Runoff Water

Standard laboratory practices described by US-EPA (1989) were used to analyze phosphorus and nitrogen from snowmelt runoff. Water samples for three forms of phosphorus, dissolved (DMRP), bioavailable (BP), and total (TP) were tested. The DMRP measures phosphorus in solution, and the TP measures both the dissolved and sediment-adsorbed phosphorus. The BP is an estimate of phosphorus (both dissolved and adsorbed) that would be potentially available for growth of algae in waterways. After filtration of water samples with a glass fiber membrane filter, the DMRP was determined using Molybdate blue method (US-EPA, 1971). The total phosphorus (TP) was determined by digesting with HNO_3 and $HClO_4$ and neutralization with NaOH (Olson, and Sommers, 1982). The bioavailable phosphorus was determined by mixing thoroughly with NaOH and neutralization with H_2SO_4 (Sharpley et al., 1992). Ammonium and nitrate were determined by the gas diffusion-conductivity method of Carlson et al. (1990).

The calculation and statistical analysis for various forms of N and P is similar for sediment, BOD, and COD described in the accompanied paper.

Laboratory leaching experiment

Alfalfa, Corn and Soybean residues were collected from the watersheds four times in 1997 and 1998 (table 2) for determining the concentration of N and P in the plant tissue and estimating the potential leaching of the nutrition from the crops. For the water exaction experiment in the laboratory, fresh, dry and frozen alfalfa tissue and fresh and dry corn tissue were used. Fresh samples were extracted right after collection, dry samples were first heated in an oven at 40°C and then extracted. Frozen samples were first frozen at –20°C and then extracted. A 0.6g tissue sample of either alfalfa or corn was shaken with 200ml deionized water in a 1,000ml plastic bottle, and repeated two more times with the final ratio of the plant to water 1g/L, which is close the ratio of the residue to the snow pack. All water samples were analyzed for DMRP, TP, NH_4-N and NO_3-N (US-EPA, 1989, Olson and Sommers, 1982, Carlson et al., 1990). The total N and P concentrations in the alfalfa and the corn were measured by Kjeldahl method.

RESULTS AND DISCUSSION

Water extracted nutrients from Alfalfa and Corn tissue

Total and water extractable N and P from the crop residues collected four times within two years are shown in table 2. The accumulation of total precipitation after frost is also provided for each sampling in the table 2. The quantity of each plant nutrient leached from the crop residue depends on the solubility and quantity present. Leaching by rain after plant senescence of frost reduces the quantity soluble potential pollutants in the tissue during snowmelt.

Leaching of N and P from the plant tissue by precipitation removed N and P between the sampling dates (figure 1). Up to 80% of P and 33% of N in alfalfa can be leached out as DMRP and NH_4 based on the leaching experiment (table 2), which is close to the result of Timmons and Holt (1970). For the two samples collected in 1997, after the alfalfa had experienced about six cm rain after frost, the N and P content in the crop dropped from 40.9 to 31.9g/kg, and 4.7 to 2.8g/kg respectively. The laboratory water extractable P (DMRP) decreased almost one half (from 80 to 42.5%), and N (NH_4) about 99% (from 32.5 to 0.5%). In the leaching experiment for 1998 samples, the alfalfa was treated by drying and freezing, and the corn was treated only by drying. Corn tissue samples were taken after plant senescence. The amounts of P leached from different conditions of alfalfa (fresh, oven dry and frozen) and corn (field moisture level after senescence and oven dry) in the laboratory are shown in figure 2(a). The alfalfa tissue resulted in large differences in water extractable P between fresh, dry, and frozen conditions, 2.0, 31.8 and 138.5 mg/kg respectively. The fresh alfalfa tissue (70% water) ruptured by freezing and released the highest amount of water extractable P. Corn tissue at the field moisture level and oven dry resulted in about the same amount of water extractable DMRP (about 114mg/kg), slightly less than that from frozen alfalfa tissue (138.8mg/kg). Since corn tissue was dead and relatively dry when sampled there was little difference in further oven drying.

Ammonia and nitrate concentrations in both alfalfa and corn from the leaching experiment are shown in figure 2(b). Most of the water extractable N was in the ammonium form. The relative amounts of water extractable ammonium between treatments were similar to the P results.

As early as 1967, Heber (1967) suggests that the dehydration that accompanies freezing alters the permeability of biological membranes. He states it has long been observed that the membranes bordering the protoplasm are no longer intact in frost killed cells. This implies that nutrients would be more readily leached from plant cells after they have been killed by frost or have been dehydrated by severe water stress.

Phosphorus from snowmelt runoff

The DMRP and BP load in snowmelt runoff decreased over successive years but were similar between alfalfa and corn-soybean fields (fig. 3). Particulate phosphorus losses were much lower and consistent for the three years. Snowmelt runoff (see previous paper) also decreased over the three years suggesting that P losses are correlated with runoff volume. The BP and DMRP data closely matched each other indicating that dissolved P in snowmelt runoff is the major contributor to bioavailable P. Averaged over the three years there was no significant crop effect on P loss from snowmelt (fig. 3).

Nitrogen from snowmelt runoff

The total load of ammonium and nitrate nitrogen in snowmelt runoff from alfalfa and corn-soybean fields is shown in figure 4. Alfalfa fields yielded significantly more ammonium and the corn-soybean fields yielded more nitrate in snowmelt runoff. The presence of ammonium in runoff from alfalfa fields is due to lack of residence time since the release of nutrients from alfalfa residue. Release of excess ammonium in surface runoff may accentuate downstream water quality problems. The laboratory crop residue leaching results show that there is potential for twice as much ammonium from the alfalfa than from corn. There is little nitrate from both alfalfa and corn residue. It is likely that the nitrate in snowmelt runoff from the corn-soybean fields is likely contributed by anhydrous Ammonia application after soybean harvest.

On a total N loss basis, perspective higher NH_4 losses from alfalfa fields and higher NO_3 losses from corn-soybean fields offset each other resulting in no statistical difference between the two cropping systems (Fig. 4).

Potential N and P loss from crop residue compared with measured levels in runoff

The leaching experiment suggests that alfalfa and corn-soybean crops are large pools of N and P, and could be sources for N and P in snowmelt runoff. The amount of plant biomass and its N and P content were measured after plant senescence or frost and leaching rainfall. This is compared with P loss from snowmelt runoff in table 3. Apparent N or P concentration in runoff from plant tissue were calculated by the load of the N or P in the runoff divided by the content of the N or P in the residue. Up to 80% P and 32% N in snowmelt runoff could potentially be from crop residue based on the amount of water extractable levels in field biomass at freeze up (table 2). This is also supported by other studies (Timmons and Holt, 1977). Comparing the P and N contents in the both alfalfa and corn-soybean residues, less than half of the P and 20% of N were lost in snowmelt runoff. The highest apparent residue P in the runoff from the both crops fields was in the spring of 1997. This appears to be related to heavy snowfall in that year. The large snow pack allowed for thorough leaching of crop residues. Although the P concentration in the alfalfa crop is twice as that in either corn or soybean (table 2), the average total P loss was not significantly difference. This may be partially because the amount of residue in the corn-soybean fields is about twice that in the alfalfa fields (table 3).

The comparison of crop residue NH_4 to that in runoff shows a different trend. The highest percentage of apparent N from crop residue in the runoff from the alfalfa fields is in spring of 1998. There appears to be more NH_4 load in the snowmelt runoff from the soybean residue than from the corn residue. Based on the crop residue leaching results, NH_4 seems more readily leached. Based on the field runoff data it also is not as strongly related to the quantity of the runoff water as was P.

SUMMARY

The loss of phosphorus in snowmelt runoff varied from year to year and was related to the runoff volume. There was no difference in loss between alfalfa and a corn/soybean rotation. The over-winter crop residue can be a major source of phosphorus in the snowmelt runoff. Any evaluation of the effectiveness of crop residues in reducing the impact of a cropping system on water quality must also consider this potential detrimental effect. In snow melt runoff from alfalfa fields ammonium-N was correlated with crop residue levels. Corn-soybean fields resulted in nitrate-N runoff losses that were poorly correlated with crop residue levels. The effect of crop on total N loss was not statistically significant.

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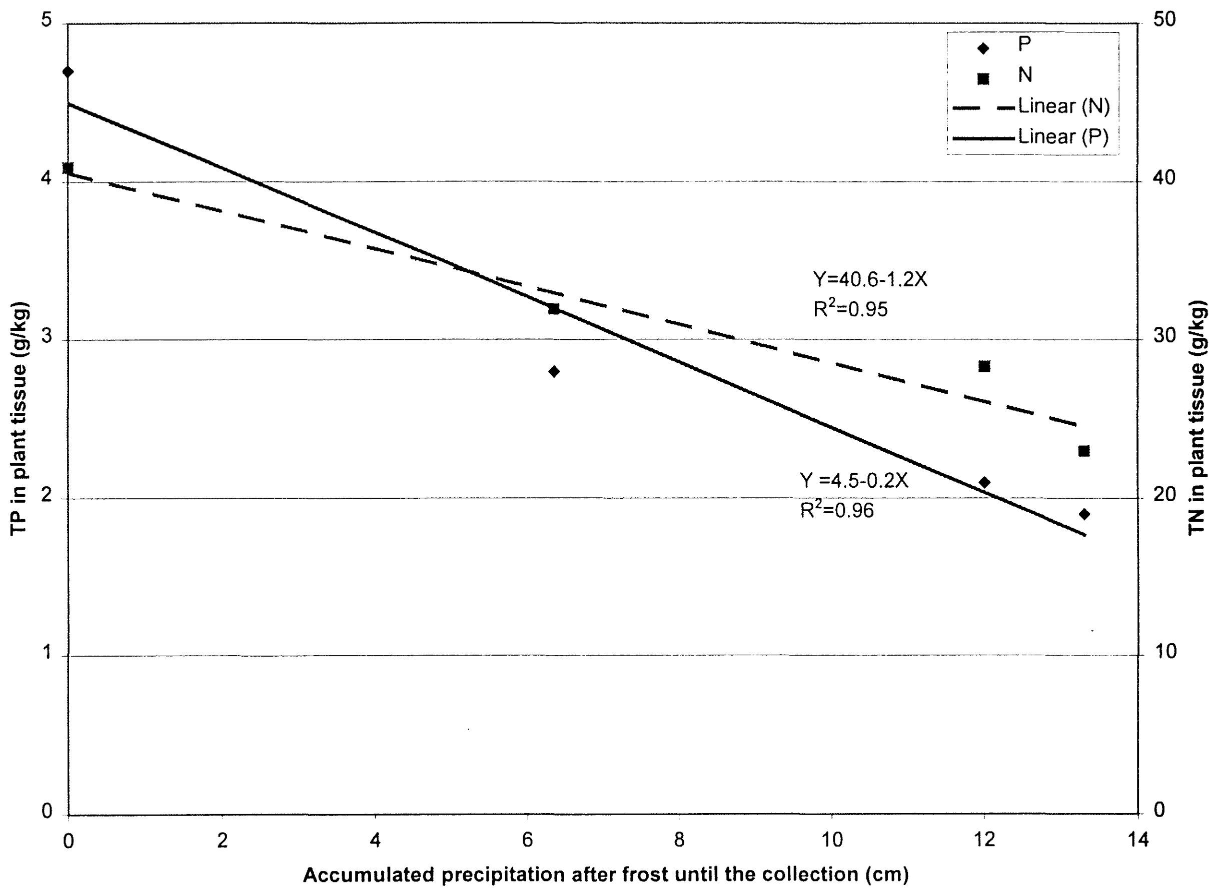


Fig. 1 Relations between TP, TN in plant tissue and accumulated precipitation after frost before the samling

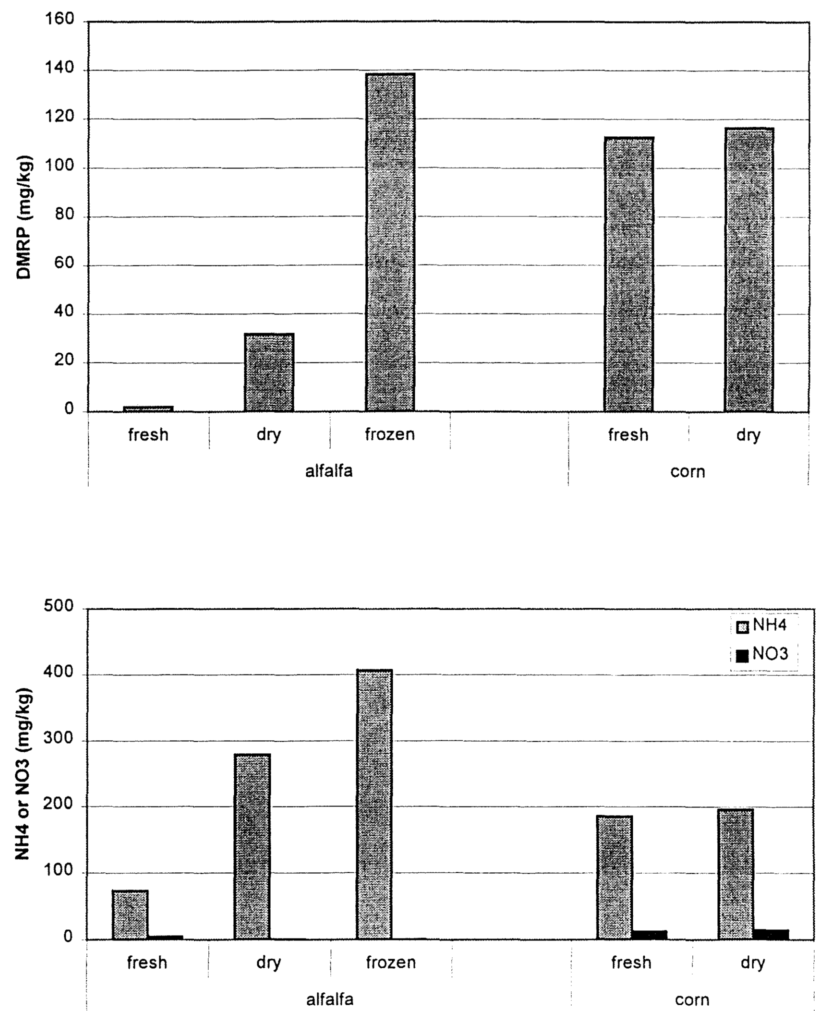
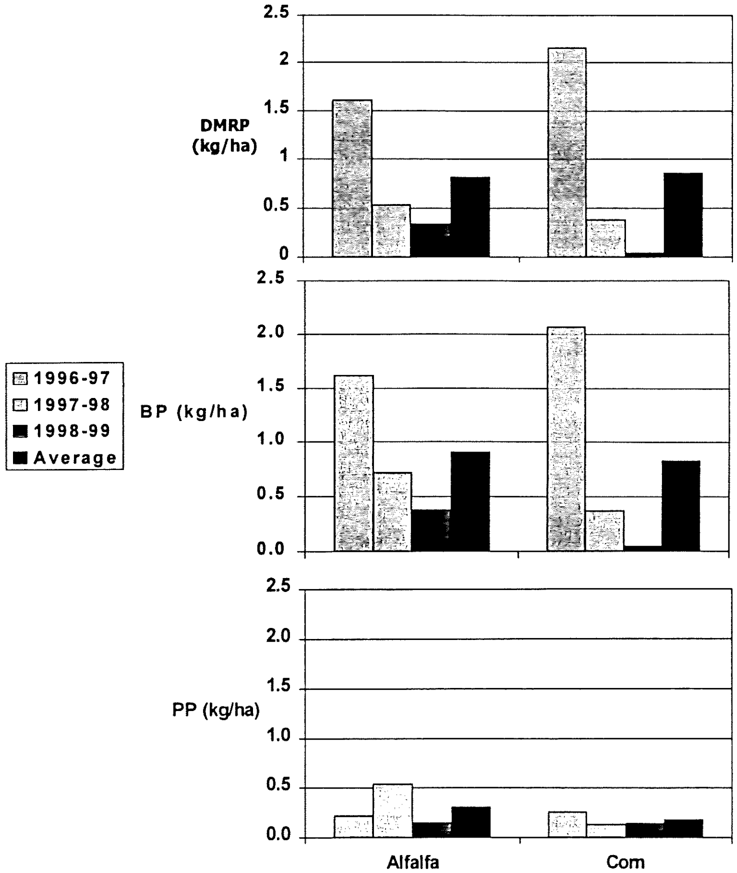


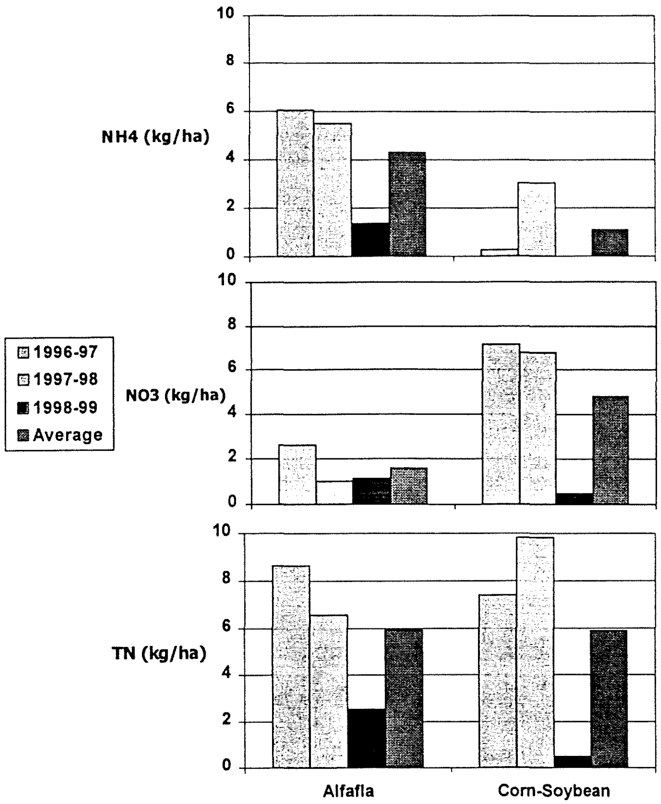
Fig. 2 The laboratory leaching results of alfalfa and corn as DMRP, NH_4 and NO_3 concentration leached from the plant tissue.



ANOVA Results

Factor	P
Year	0.0007
Crop	0.9387
Crop x Year	0.6951
Year	0.0028
Crop	0.8587
Crop x Year	0.7194
Year	0.0004
Crop	0.9106
Crop x Year	0.6367

Fig. 3: Phosphorus analysis results of three years from the snowmelt runoff, Morris, Minnesota.



ANOVA Results

Factor	P
Year	0.2647
Crop	0.048
Crop x Year	0.4187

Year	0.1055
Crop	0.0055
Crop x Year	0.0123

Year	0.0141
Crop	0.4168
Crop x Year	0.8975

Fig. 4: Nitrogen analysis results of three years from the snowmelt runoff, Morris, Minnesota.

Table 1: Soil test results from Morris Watersheds in June 1998

Crop	depth (cm)	pH	O.M. (%)	Olsen-P (ppm)	K (ppm)
Alfalfa	0-5	7.5	6.0	51	294
	5-15	7.6	5.7	35	170
	0-15	7.6	5.8	40	211
Corn-soybean	0-5	7.0	5.8	79	443
	5-15	7.0	5.4	54	259
	0-15	7.0	5.5	62	320

Table 2: Nitrogen and phosphorus in the crops and water extractable from the crops

Crops	Collecting date date	Precipitation after frost cm	Plant tissue TP g/kg	TN g/kg	Water extractable DMRP %	NH4 %	NO3 %
Alfalfa	9/19/97	0	4.7	40.9	80	32.5	0
	10/25/97	6.35	2.8	31.9	42.5	0.5	0
	10/27/98	12.01	2.1	28.3	6	1.5	0
	11/4/98	13.31	1.9	23	0.5	0.6	0
Corn	10/27/98	12.01	1.3	8.5	14.5	4.2	0
	11/4/98	13.31	1	6.3	4.5	0.4	0
Soybean	10/25/97	6.35	1.2	6.1	38	4	0

Table 3: Comparing of DMRP and NH4 from snowmelt runoff with P and N from the residues

Crop	Year	Residue kg/ha	P in residue kg/ha	DMRP in runoff kg/ha	Apparent in runoff %	N in residue kg/ha	NH4 in runoff kg/ha	Apparent in runoff %
Alfalfa	1996-7	1860	7.07	2.14	30.28	87.98	9.30	10.57
	1997-8	1250	3.50	0.56	16.00	54.25	7.65	14.10
	1998-9	1620	3.08	0.40	13.00	45.85	1.50	3.27
Corn	1996-7	3000	2.70	1.45	53.70	41.28	0.31	0.75
Soybean	1997-8	2300	3.22	0.26	8.07	14.72	3.12	21.20
Corn	1998-9	4990	5.84	0.06	1.03	76.33	0.01	0.01