6-2008

Effect of different land covers on nitrate-nitrogen leaching and nitrogen uptake in Iowa

Zhiming Qi
Iowa State University

Matthew J. Helmers
Iowa State University, mhelmers@iastate.edu

Peter A. Lawlor
Iowa State University

Effect of different land covers on nitrate-nitrogen leaching and nitrogen uptake in Iowa

Abstract

Nitrate-nitrogen (NO_3-N) loading from subsurface drainage is an environmental concern in the Midwest. The majority of NO_3-N loading occurs in April, May and June when the crops are not planted or just establishing. In this study, NO_3-N leaching was monitored under alternative land covers and in a corn-soybean rotation. Land cover treatments in a 2-year field experiment included: 1) corn-soybean rotation initiated with corn in 2006 and fallow in late fall and early spring (fallow-Corn-fallow-Soybean, fCfS); 2) corn-soybean rotation initiated with soybean in 2006 and fallow in late fall and early spring (fallow-Soybean-fallow-Corn, fSfC); 3) corn-soybean rotation initiated with corn in 2006 with rye cover crop (rye-Corn-rye-Soybean, rCrS); 4) corn-soybean rotation initiated with soybean in 2006 with rye cover crop (rye-Soybean-rye-Corn, rSrC); 5) Corn with established kura clover as a living mulch (kura-Kura-kura-Corn, kKkC); and 6) Pasture as a perennial grass treatment (PP). Subsurface drainage volume and NO_3-N concentration were monitored. Suction lysimeters were installed to extract the soil water solution for NO_3-N analysis. Biomass of spring cover crops was sampled to analyze nitrogen (N) content. The objectives of this study were: 1) to determine NO_3-N loss through subsurface drainage as affected by different land covers; 2) to investigate the NO_3-N concentrations in the soil water under different land covers and 3) to quantify the nitrogen uptake by different cover crops in the spring. The results from the two-year study indicated that the annual average NO_3-N loss for fCfS and fSfC treatments was 37.5 kg N ha^{-1} and that the rCrS and rSrC treatments reduced NO_3-N leaching by 3.8 kg N ha^{-1} during April, May and June. kKkC and PP treatments resulted in 39.7% and 59.9% annual NO_3-N leaching reduction, respectively, when compared to the average NO_3-N loss of fCfS and fSfC treatments. Rye followed by soybean reduced the NO_3-N concentration in the soil solution significantly (56.4%) at the 30- and 60-cm depths, and PP treatment showed the lowest NO_3-N concentration at those two depths. The average nitrogen uptake by rye was 33.3 kg N ha^{-1} at growth termination, and the average N uptake was 59.9 kg N ha^{-1} for kura clover and 33.2 kg N ha^{-1} for pasture in early June. This study suggested that winter rye cover crop, kura clover as a living mulch and perennial pasture land covers have positive effects on NO_3-N loss reduction under the weather condition encountered during this study period in Iowa.

Keywords

winter rye, kura clover, pasture, corn-soybean rotation, subsurface drainage, NO3-N leaching

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

This is an ASABE Meeting Presentation. Paper No. 084806.

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 084806

Effect of different land covers on nitrate-nitrogen leaching and nitrogen uptake in Iowa

Zhiming Qi, Graduate Research Assistant

Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011

Matthew J. Helmers, Assistant Professor

Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011

Peter A. Lawlor, Research Associate

Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011

Written for presentation at the
2008 ASABE Annual International Meeting
Sponsored by ASABE
Rhode Island Convention Center
Providence, Rhode Island
June 29 – July 2, 2008

Mention any other presentations of this paper here, or delete this line.

Abstract. *Nitrate-nitrogen (NO_3-N) loading from subsurface drainage is an environmental concern in the Midwest. The majority of NO_3-N loading occurs in April, May and June when the crops are not planted or just establishing. In this study, NO_3-N leaching was monitored under alternative land covers and in a corn-soybean rotation. Land cover treatments in a 2-year field experiment included: 1) corn-soybean rotation initiated with corn in 2006 and fallow in late fall and early spring (fallow-Corn-fallow-Soybean, fCfS); 2) corn-soybean rotation initiated with soybean in 2006 and fallow in late fall and early spring (fallow-Soybean-fallow-Corn, fSfC); 3) corn-soybean rotation initiated with corn in 2006 with rye cover crop (rye-Corn-rye-Soybean, rCrS); 4) corn-soybean rotation initiated with soybean in 2006 with rye cover crop (rye-Soybean-rye-Corn, rSrC); 5) Corn with established kura clover as a living mulch (kura-Kura-kura-Corn, kKkC); and 6) Pasture as a perennial grass treatment (PP). Subsurface drainage volume and NO_3-N concentration were monitored. Suction lysimeters were installed to extract the soil water solution for NO_3-N analysis. Biomass of spring cover crops was sampled to analyze nitrogen (N) content. The objectives of this study were: 1) to determine NO_3-N loss through subsurface drainage as affected by different land covers; 2) to investigate the NO_3-N concentrations in the soil water under different land covers and 3) to quantify the nitrogen uptake by* *different cover crops in the spring. The results from the two-year study indicated that the annual average NO_3-N loss for fCfS and fSfC treatments was 37.5 kg N ha^{-1} and that the rCrS and rSrC treatments reduced NO_3-N leaching by 3.8 kg N ha^{-1} during April, May and June. kKkC and PP treatments resulted in 39.7% and 59.9% annual NO_3-N leaching reduction, respectively, when compared to the average NO_3-N loss of fCfS and fSfC treatments. Rye followed by soybean reduced the NO_3-N concentration in the soil solution significantly (56.4%) at the 30- and 60-cm depths, and PP treatment showed the lowest NO_3-N concentration at those two depths. The average nitrogen uptake by rye was 33.3 kg N ha^{-1} at growth termination, and the average N uptake was 59.9 kg N ha^{-1} for kura clover and 33.2 kg N ha^{-1} for pasture in early June. This study suggested that winter rye cover crop, kura clover as a living mulch and perennial pasture land covers have positive effects on NO_3-N loss reduction under the weather condition encountered during this study period in Iowa.*

Keywords. winter rye, kura clover, pasture, corn-soybean rotation, subsurface drainage, NO_3-N leaching

Introduction

Iowa Water Quality

Nitrate-nitrogen (NO_3-N) has been deemed a main source of pollutant for both shallow groundwater and surface water bodies. Groundwater serves as drinking water supply for more than 50% of people in the United States (Nolan and Hitt, 2006). NO_3-N has been found to be an important contaminant in drinking water because it appears widely in groundwater with a median value of 2.9 mg N L^{-1} for agricultural areas and 1.5 mg N L^{-1} for urban areas (Nolan, 2004). The National Water-Quality Assessment (NAWQA) of the USGS assessed the water quality of more than 60% of the Nation's drinking water and water for irrigation and industry during 1991-2001. Twenty percent of the shallow wells in agricultural areas exceeded the drinking water standard of 10 mg N L^{-1} for NO_3-N in the sampled wells over the nation (USGS, 2004). A state-wide rural well water survey in Iowa that was conducted in 1988 and 1989 showed that 18% of Iowa's private rural drinking wells surpassed the MCL for NO_3-N 10 mg L^{-1} (Kross et al., 1990).

Other than contaminating groundwater, NO_3-N also impairs surface water bodies. NO_3-N loading of the Mississippi River is suspected to be a main contributor to the hypoxic zone in the Gulf of Mexico (Rabalais et al., 2001). The main source of NO_3-N in the Mississippi River Basin (MRB) is linked to tile drainage (Lowrance, 1992; David et al., 1997; Zuker and Brow, 1998). Approximately 25% of agricultural land is artificially drained in Iowa (Baker et al., 2004) and subsurface drainage is the main source of NO_3-N loss. From 1980 to 1996, the annual average total N yields were 2750, 2290, 2020, 3090 and 1850 kg N km^{-2} yr^{-1} in the Cedar, Iowa, Skunk, Raccoon, and Des Moines Rivers in the state of Iowa, respectively (Goolsby et al., 2001). Schilling and Zhang (2004) reported that while Iowa accounts for 5% of the area of the MRB it contributes approximately 25% of NO_3-N load (26 kg N ha^{-1}) over a 28-year period from 1972 to 2000. Plot scale experiments measured NO_3-N loss of 26 to 55kg N ha^{-1} $year^{-1}$ in northeast Iowa (Weed and Kanwar, 1996), 27 to 31 kg in central Iowa (Baker et al., 1975; Baker and Johnson, 1981; Kanwar et al., 1983) and 7 to 68 kg N ha^{-1} $year^{-1}$ in northwest Iowa (Lawlor, et al., 2008).

Iowa NO_3-N Leaching Pattern

The mass of NO_3-N loss is closely related to subsurface drainage volume (Baker et al, 1975; Cambardella et al., 1999). Hatfield et al. (1998) documented that the NO_3-N loading had the same pattern as the subsurface drainage discharge in the Walnut Creek watershed in Iowa. Kanwar et al. (2005) observed a linear relationship between annual NO_3-N loss and drainage flow volume (r^2=0.99) in northeastern Iowa under different land covers. Bakhsh et al. (2002) also found a strong linear relationship between drainage and precipitation, and between NO_3-N loss and drainage. April, May and June were found to be the main subsurface drainage period. In these 3 months, nearly 70% of the drainage occurred in north-central Iowa (Helmers et al., 2005), and 71% of the annual drainage and 75% of NO_3-N loss were observed in Minnesota during this period (Randall and Vetsch, 2005). Brouder et al. (2000) found that more than 50% of the annual flow occurred in May and June in central Indiana.

At the plot scale some studies have reported that the mass of NO_3-N loss was positively related to nitrogen application rate (Baker and Johnson, 1981; Lawlor et al., 2008). Additional researchers have found similar NO_3-N concentration between the corn and soybean phase of the rotation system. Randall and Vetsch (2005) showed 54% of NO_3-N was lost in the corn phase and 46% loss in soybean phase in a corn-soybean rotation fertilized every other year.

Zhu and Fox (2003) found that NO_3-N leaching potential was similar in corn and soybean plots with N application rate greater than 100 kg/ha applied to the corn phase of the rotation.

Annual Cover Crop

Annual cover crop, perennial living mulch and perennial grassland have the potential to reduce NO_3-N leaching in the Midwest. An annual cover crop is any living ground cover that is planted into or after a main crop and then commonly killed before the next crop is planted (Hartwig and Ammon, 2002). Annual winter cover crops, which have historically been added into corn-soybean rotation to achieve soil and water conservation benefits in Midwest (Kaspar et al., 2001; Unger and Vigil, 1998), were studied to assess their potential in reducing subsurface drainage volume and NO_3-N concentration in the drain flow thereby decreasing the NO_3-N loss from the soil. Rye is one of the main annual winter cover crops; it is a cereal crop that has super weather hardiness and the ability to grow on soils with marginal fertility (Bushuk, 2001). Rye requires less heat than wheat and it can germinate at temperatures slightly above 0 ºC. Appreciable growth of rye ceases when the mean temperature drops below 5 ºC but resumes growth when the temperatures rise (Leonard and Martin, 1963). It can survive under temperatures of -35 to -25 ºC even with limited snow cover (Stoskopof, 1985), and has performed well during the cold winters in North Dakota and Montana (Leonard and Martin, 1963). In North America, some rye is grown at the northern limit of the Canadian grain belt. Rye is the last crop to stop growing in the fall and the first to start in the spring (Buskuk, 2001).

Strock et al. (2004) found that using rye as a winter cover crop in Minnesota reduced drainage volume by 11% and NO_3-N leaching by 13%. Kessavalou and Walters (1999) reported that winter rye cover crop reduced residual soil N by 18 to 33% in Nebraska. N uptake by rye was reported to be 42-48 kg N ha^{-1} in Nebraska (Kessavalou and Walters, 1999), 21-74 kg N ha^{-1} in Minnesota (DeBruin et al., 2005), 9-34 kg N ha^{-1} in Wisconsin (Andraski and Bundy, 2005), and 35-51 kg N ha^{-1} in Illinois (Ruffo et al., 2004). In Iowa, N uptake by rye was reported to be 5 to 48 kg kg N ha^{-1} with fertilizer rate of 212 to 235 kg N ha^{-1} to the corn phase of the rotation (Kasper et al., 2007; McDonald, et al., 2008). The following main crop yield was lowered by 5 to 22% in cover crop plots (MacDonald et al., 2008). Most researchers reported there was not a significant effect of rye cover crop on the following corn or soybean yield (Strock et al., 2004; De Bruin et al., 2005; Ritter et al., 1998) or even an increase in corn yield (Andrski and Bundy, 2005).

Perennial living mulch

Living mulches are cover crops planted either before or with a main crop and maintained as a living ground cover throughout the growing season (Hartwig and Ammon, 2002). Living mulches can reduce erosion, suppress weeds, and in the case of legumes benefit N cycling. Italian ryegrass, alfalfa, and kura clover are examples of living mulches. Perennial leys, including alfalfa and grasses, had considerably less drainage volumes and NO_3-N loss than the treatments with annual barley (Bergstrom, 1987). Corn in Italian ryegrass was unable to establish a competitive root system thus its growth and yield were reduced in Switzerland (Liedgens et al., 2004). With suppression and careful management, kura clover in corn did not reduce the whole-plant biomass, grain yield (Zemenchik et al, 2000)or corn root density (Eleki, 2003) in North Central USA, especially if herbicide-resistant corn was planted (Affeldt, et al. 2004).

Perennial grassland

Perennial grass covers serve as the most effective nitrogen loss reduction approach because no fertilization is necessary and it has a longer growing period than winter cover crop, however at present there is no economic market for the product. Baker and Melvin (1994) documented that the NO_3-N concentration in the drain tile under alfalfa was much lower than that under corn or soybean. Randall and Mulla (2001) reported that drainage in the perennial alfalfa was 1.1 to 5.3 times less than that from row-crop, and NO_3-N loss were 37 and 35 times less in alfalfa and Conservation Reserve Program (CRP) plots.

Objectives

In Iowa previous research on NO_3-N loss with rye as a winter cover crop were conducted with fairly high N rates (Kaspar et al. 2007; McDonald et al., 2008). Reports on perennial living mulch as an approach of water quality protection is very limited. To get a better understanding on the effects of land covers on NO_3-N loss, a field experiment was conducted in northwest Iowa with winter rye cover crop in corn-soybean rotation, kura clover as a living mulch for corn and a pasture land cover. The objectives of this study were: 1) to evaluate the impact of a different land covers on NO_3-N loss in subsurface drainage under recommended crop fertilization; 2) to investigate the NO_3-N concentrations in the soil water under different land covers and 3) to quantify the N uptake by different cover crops in the spring.

Materials and Methods

Site description

The field study was conducted in 2006 and 2007 on the Agricultural Drainage Water Quality - Research and Demonstration Site (ADWQ-RDS, former Agricultural Drainage Well Site) near Gilmore City in Pocahontas County, northwestern Iowa, which has been described in greater details by Helmers et al. (2005), Singh et al. (2006) and Lawlor et al. (2008). An automatic meteorological station was installed at the site. The size of each plot was 38 m in length and 15.2 m in width. The plots were established after the installation of corrugated plastic drain lines through the center and both boundaries parallel to the long dimension (7.6 m drain spacing) at a depth of 1.06 m. Drainage water from each center line was collected in an aluminum culvert with automatic pumping, volume monitoring and water sampling systems.

A six-treatment experiment was established in a randomized block design. The six land cover treatments in 2006 and 2007 were (Table 1): 1) corn-soybean rotation initiated with corn in 2006 and fallow in spring (fallow-Corn-fallow-Soybean, fCfS); 2) corn-soybean rotation initiated with soybean in 2006 and fallow in spring (fallow-Soybean-fallow-Corn, fSfC); 3) corn-soybean rotation initiated with corn in 2006 with rye cover crop (rye-Corn-rye-Soybean, rCrS); 4) corn-soybean rotation initiated with soybean in 2006 with rye cover crop (rye-Soybean-rye-Corn, rSrC); 5) Corn with established kura clover as a living mulch (kura-Kura-kura-Corn, kKkC); and 6) Pasture as a perennial grass treatment (PP). The plots were blocked by drainage characteristics, resulting in four blocks, high, medium high, medium low and low drainage blocks, based on the long-term drainage performance. One plot in each block was randomly assigned to each treatment (6 treatments×4 blocks×1replication) in this study. This experiment was initiated in 2005 but data presented in this paper started in April 2006.

Table 1. Land cover treatments.

Treatment Notation	Spring, 2006	Summer, 2006	Spring, 2007	Summer, 2007
fSfC	fallow	Soybean	fallow	Corn
fCfS	fallow	Corn	fallow	Soybean
rSrC	rye	Soybean	rye	Corn
rCrS	rye	Corn	rye	Soybean
kKkC	kura clover	Kura clover	kura clover	Corn+kura clover
PP	pasture	Pasture	pasture	Pasture

Agronomic management

Agronomic field activities were completed in a timely manner prior to and during the crop season beginning in October 2004 with plot tillage and rye seeding. Tillage for seedbed preparation for perennial crops was completed in the spring just prior to planting on April 18th 2005. ‘Endura’ kura clover (Trifolium ambiguum) was hand seeded at a rate of 13 kg ha^{-1}, the perennial pasture plots were hand seeded with ‘Duration’ red (Trifolium pratense), and ‘Pinnacle’ ladino (Trifolium repens) clovers with ‘Extend’ orchardgrass (Dactylis glomerata) at 9, 0.6, and 4.5 kg ha^{-1}. A conventional cropping system was used for corn and soybean plots that did not include rye in the system. Corn residue was chopped and chisel plowed in the fall of 2004 followed by disking and field cultivation prior to planting in the spring. Soybean residue was not disked but was field cultivated prior to planting in 2005. In the fall, plots that included rye, corn residue was chopped, disked twice and smoothed with a field cultivator prior to rye planting. Soybean residue was disked once and field cultivated. ‘Rhymin’ rye (Secale cereale) was drill seeded at a rate of 100 kg ha^{-1} in 19 cm rows with a skip row every 76 cm for subsequent corn or soybean planting in the spring. Glyphosate resistant corn (Zea maize) and soybean (Glycine max) were used and planting dates were dictated by field conditions. Seeding rates were 12,150 for corn and 120,000 seed ha^{-1} for soybean. Commercial-grade 28% aqueous ammonia-nitrogen (N) was applied at 140 kg N ha^{-1} in spring closely following corn emergence to corn plots only. N fertilizer was applied mid-row to corn, with a conventional knife applicator. Recommended rates for the study area were 112 to 168 kg N ha^{-1} (Blackmer et al., 1997). Glyphosate was applied at a rate of 239 mL ha^{-1} in the rye/corn system and in rye/soybean plots to terminate rye plant growth. For weed control, it was subsequently applied two more times during the growing season, dictated by weed pressure. See Table 2 for agronomic timing details.

Table 2. Agronomic field activity timing.

Treat-ment	2005	2006					2007			
	rye seeding	rye termination	corn planting	soybean Planting	fertilizer application	rye seeding	rye termination	corn planting	soybean Planting	fertilizer application
fSfC	-	-	-	10-May	-	-	-	14-May	-	5-Jun
fCfS	-	-	4-May	-	18-May	-	-	-	17-May	-
rSrC	11-Oct	16-May	-	10-May	-	12-Oct	30-Apr	14-May	-	5-Jun
rCrS	11-Oct	24-Apr	4-May	-	18-May	12-Oct	23-May	-	17-May	-
kKkC	-	-	-	-	-	-	-	14-May	-	5-Jun
PP	-	-	-	-	-	-	-	-	-	-

Drainage volume monitoring, sampling and analysis

Drainage flow volume was measured by a magnetic flow meter, connected to an electronic data logger. Meter readings were also recorded manually. Samples were collected after approximately every 13 cm of subsurface drainage flow, acidified to pH of 3, and thereafter were stored in a cooler at 4 ºC until analyzed. NO_3-N concentration in the subsurface drainage water samples were analyzed in the Wetland Research Laboratory, Iowa State University through the second-derivative spectroscopy technique. NO_3-N concentration in the suction lysimeter soil water solution samples were analyzed in the Agricultural and Biosystems Engineering Water Quality Laboratory, Iowa State University using a Quickchem 2000 Automated Ion Analyzer flow injection system (Lachet Instruments, Milwaukee, Wisc.).

Soil water solution sampling

Soil water solution was sampled using two suction lysimeters (1 m apart) installed along the midway between the center and boundary lines at the depths of 30 and 60 cm in each of the medium high, medium low and low flow block plots. The suction lysimeter consisted of a porous ceramic cup, connected to 3.8 cm PVC pipe and sealed. Two sections of hard plastic tubing were installed inside the PVC pipe, one for vacuum application and another for solution sampling. Tubing extended 10 cm outside the pipe and with a sealable top to hold vacuum in the lysimeter. To install the suction lysimeter, a soil core was removed vertically by a truck mounted Gidding's probe (#25-SCS Model HDGSRPS, Giddings Machine Company Inc, CO). Fine silica sand was placed in the bottom of the hole and the gap between the ceramic cup and the soil wall. The gap above the ceramic cup was then sealed with granular bentonite. A vacuum of -75 kPa was applied to the suction lysimeters every week and any available soil water solution sample was collected every three to four days. Soil solution samples were processed and analyzed the same as subsurface drainage samples.

Biomass sampling and N analysis

Rye shoots were sampled weekly from early spring (April 12 in 2006, March 29 in 2007) until chemically terminated with Roundup herbicide. Weekly kura clover and pasture shoots sampling coincided with rye and continued until late June (in 2007). After June, corn, soybean, kura clover and pasture were sampled once in three weeks until early October. Rye, corn and soybean were sampled along a 30-cm long section at four randomly selected locations; Kura and pasture were sampled by a $30 \times 30\ cm^2$ area randomly selected at three locations in each plot. Samples were dried at 60 ºC for a week in ovens at the Agricultural Engineering Farm of Iowa State University. Dry matter weight was recorded.

Total nitrogen (TN) content was analyzed for all samples obtained from rye plots, two occasions for Kura clover and pasture, and two occasions for corn soybean plots. Total nitrogen analysis was conducted in Soil Plant Analysis Laboratory at Iowa State University by the combustion method.

Subsurface drainage volume, flow-weighted NO_3-N concentration in the subsurface drainage, NO_3-N loss and NO_3-N concentration in the suction lysimeter were analyzed as a completely randomized block design using PROC GLIMMIX procedure in SAS software. Because subsurface drainage may not be observed in some plots while subsurface flow occurred in other plots during a month, the NO_3-N concentration data could be unbalanced. The GLIMMIX is a new procedure which can test the significance of difference for unbalanced data. Means were grouped using a least significant difference test at $p=0.05$ ($LSD_{0.05}$).

Results

Climate data

Daily precipitation and temperature for the study period are presented in Fig 1. The annual precipitation in 2006 and 2007 was 549 and 856 mm respectively, with 536 and 843 mm in the drainage season from March to November. The long term average rainfall in the drainage season for Pocahontas, Iowa, is 722 mm (Lawlor et al., 2008). Precipitation during April, May and June were 167 and 217 mm, accounting for 31% and 26% of the precipitation during the drainage season in 2006 and 2007, respectively. The year of 2007 was much wetter especially in August and October when 334 and 107 mm rainfall occurred, which were three and two times greater than the long term normal rainfall in these two months, respectively.

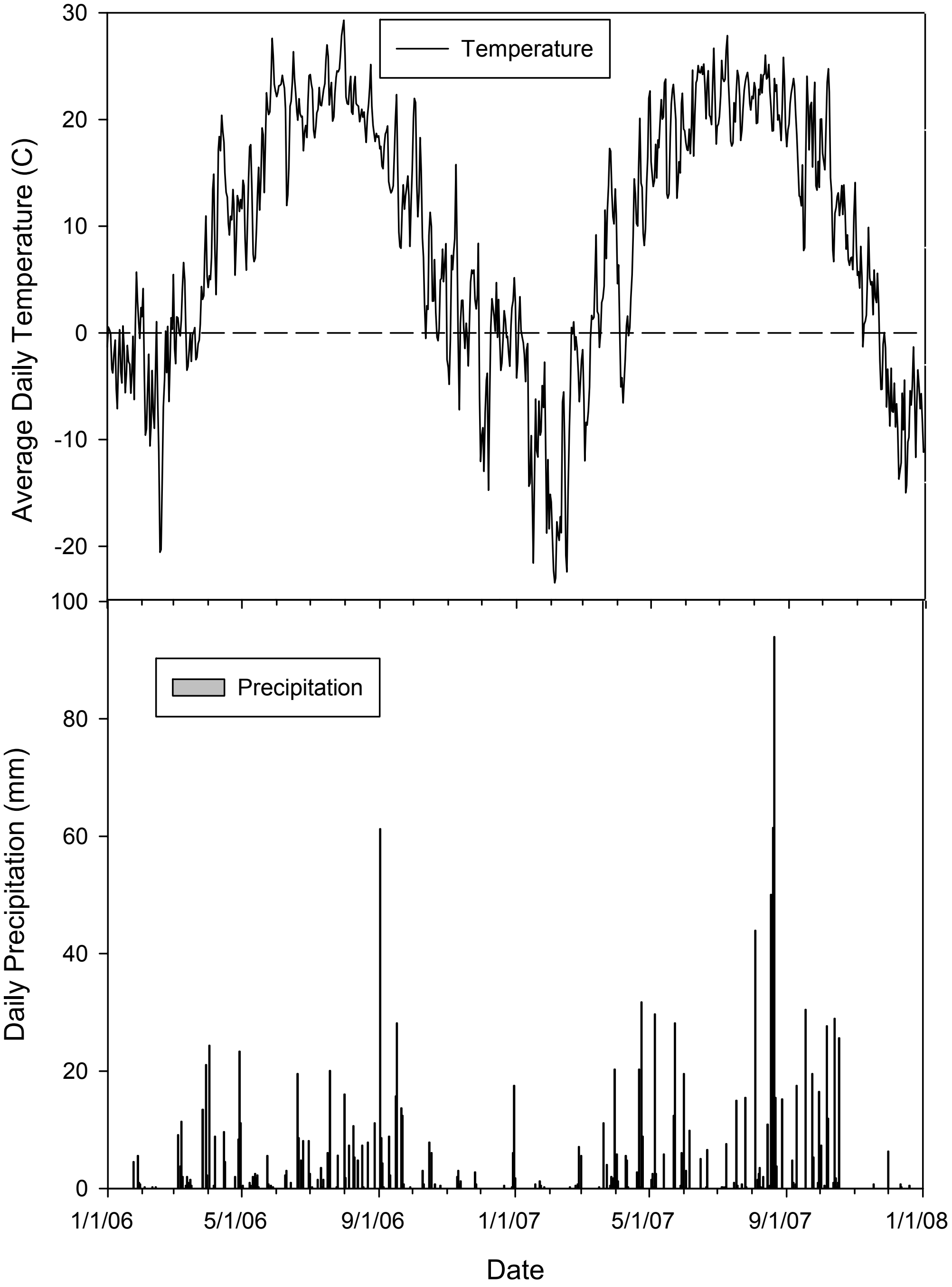

Figure 1. Daily temperature, solar radiation and precipitation: 2006-2007.

The long-term monthly average temperatures during the rye growing season in March, April, and May are 1.0, 8.6 and 15.6 °C. The temperatures during these three months in 2006 were 1.3, 11.7 and 15.8 °C which were higher than the long term average. However, in 2007, the average temperatures in March and May were 3.8 and 18.1 °C which were higher than the average, but in April the average temperature was 7.4 °C, lower than the long-term average in April. Cold weather was observed in early April of 2007 with the average temperature of -0.9 °C in the first 10 days and -5.1 °C on average from April 4 through April 7, 2007 with the lowest temperature observed (-10.0 °C) on April 7.

Drainage and NO_3-N leaching

The annual discharge for the 24 plots varied from 30.3 to 239.8 mm for 2006 and 103.9 to 1010.2 mm for 2007 (Table 3 and Table 4). The average annual drainage of all land cover treatments was 301.9 mm during the two years, which represented 43.7% of the rainfall during the drainage season. The total average drainage in April, May and June was 125.8 mm which accounted for 41.7% of the annual drainage. During these three months, the equivalent of 65% rainfall exited via the subsurface drainage system. There was no significant difference ($p<0.05$) in monthly or annual drainage volume due to land cover treatments except that the drainage of kKkC in May 2007 was significantly lower than fSfC, fCfS, and rSrC treatments.

Table 3. Average drainage volume, flow-weighted NO_3-N concentrations and NO_3-N losses in 2006.

Month	Land cover treatments					
	fSfC	fCfS	rSrC	rCrS	kKkC	PP
Drainage mm						
April	66.5 a	70.9 a	70.6 a	46.8 a	66.2 a	81.4 a
May	44.7 a	39.5 a	35.8 a	31.7 a	20.7 a	23.3 a
July	12.5 a	8.2 a	9.2 a	19.4 a	4.4 a	3.5 a
Annual	123.7 a	118.6 a	115.5 a	97.8 a	91.3 a	108.2 a
Flow weighted NO_3-N concentration mg L^{-1}						
April	14.4 a	11.9 a	13.0 ab	13.2 ab	7.0 c	8.4 bc
May	16.3 ab	16.2 a	12.4 bc	13.4 ab	5.3 d	8.1 cd
July	14.6 ab	10.2 a	9.6 b	21.1 ab	8.3 b	6.0 b
Annual flow-weighted average	15.1 a	13.2 ab	12.6 b	14.8 a	6.7 c	8.2 bc
NO_3-N loss kg ha^{-1}						
April	9.6 a	8.4 a	9.2 a	6.2 a	4.6 a	6.8 a
May	7.3 a	6.4 ab	4.5 abc	4.2 abc	1.1 c	1.9 c
July	1.8 a	0.8 a	0.9 a	4.1 a	0.4 a	0.2 a
Annual	18.7 a	15.7 ab	14.5 ab	14.5 ab	6.1 b	8.9 ab

Means within a row followed by the same letter were not significantly different at p=0.05. Significance was tested by month and year across treatments.

NO_3-N concentration in the tile drainage water samples varied from 3.5 to 21.9 mg N L^{-1} during 2006 and 1.0 to 25.3 mg N L^{-1} in 2007. The average annual flow-weighted NO_3-N concentration of fSfC and fCfS treatments was 13.7 mg N L^{-1}. In the corn-soybean rotation plots either with or without winter rye as a land cover, monthly flow-weighted NO_3-N concentration in April, May and June consistently exceeded the 10 mg N L^{-1} maximum contaminant limit set by the USEPA for drinking water. Treatments with rye followed by soybean, namely rSrC in 2006 and rCrS in 2007, showed the lowest annual flow-weighted NO_3-N concentration for the corn-soybean rotation with a NO_3-N concentration 21.7% lower than the treatments with fallow-soybean. Rye followed by soybean treatments also showed the lowest monthly concentration for the treatments with corn-soybean rotation with only one exception, April, 2006. Although significant annual NO_3-N concentration reduction by rye was only observed in rSrC for 2006, the reduction of monthly NO_3-N concentration was observed in some cases during April, May and June. In 2007, monthly flow-weighted NO_3-N concentration of rSrC treatment was significantly lower than fSfC treatment in April and May; monthly flow-weighted NO_3-N concentration of rCrS was significantly lower than fCfS in May ($p<0.05$). The annual flow-weighted NO_3-N concentration from the rSrC and rCrS treatments was reduced by14.8% and 26.3% compared with their fallow controls in 2007.

Table 4. Average drainage volume, flow-weighted NO_3-N concentrations and NO_3-N losses in 2007.

Month	Land cover treatments					
	fSfC	fCfS	rSrC	rCrS	kKkC	PP
			Drainage mm			
March	6.6 a	5.1 a	6.1 a	12.0 a	16.0 a	9.2 a
April	118.1 a	94.2 a	132.0 a	111.6 a	143.5 a	111.4 a
May	37.8 ab	38.3 ab	43.4 a	16.9 bc	11.1 c	29.7 abc
June	9.4 a	3.0 a	4.6 a	1.6 a	2.3 a	4.0 a
August	182.5 a	119.5 a	182.8 a	259.9 a	237.6 a	175.5 a
Steptember	4.5 a	4.1 a	3.9 a	0.2 a	2.1 a	8.4 a
October	129.2 a	119.1 a	172.1 a	174.7 a	125.2 a	98.4 a
Annual	488.1 a	383.3 a	544.9 a	576.9 a	537.8 a	436.7 a
			Flow weighted NO_3-N concentration mg L^{-1}			
March	13.0 a	12.7 a	11.2 a	9.3 a	3.0 a	6.4 a
April	14.3 a	13.2 ab	11.7 b	10.6 b	2.9 c	5.0 c
May	16.1 a	16.0 a	13.1 b	12.7 b	3.1 c	4.6 c
June	16.3 a	13.5 abc	13.1 ab	11.8 ab	3.9 c	4.9 bc
August	12.3 a	12.9 a	9.6 a	8.9 a	11.1 a	5.2 b
Steptember	11.4 a	10.5 a	7.5 a	5.8 a	5.8 a	3.3 a
October	13.5 a	12.0 ab	12.9 a	9.2 b	5.8 c	3.9 c
Annual flow-weighted	13.5 a	12.9 ab	11.5 ab	9.5 bc	7.2 cd	4.8 d
			NO_3-N loss kg ha^{-1}			
March	0.9 a	0.7 a	0.7 a	1.1 a	0.5 a	0.6 a
April	16.9 a	12.4 ab	15.4 a	11.9 abc	4.2 c	5.5 bc
May	6.1 a	6.1 a	5.7 a	2.1 b	0.3 b	1.4 b
June	1.5 a	0.4 b	0.6 ab	0.2 b	0.1 b	0.2 b
August	22.5 a	15.4 a	17.5 a	23.2 a	26.5 a	9.1 a
Steptember	0.5 a	0.4 a	0.3 a	0.0 a	0.1 a	0.3 a
October	17.4 ab	14.3 abc	22.2 a	16.0 ab	7.3 bc	3.9 c
Annual	65.8 a	49.6 ab	62.4 a	54.5 ab	39.0 ab	21.0 b

The average annual flow-weighted NO_3-N concentration from the drain tile of the kKkC and PP treatments was 7.0 and 6.5 mg N L^{-1} respectively, below the 10 mg N L^{-1} of USEPA limit for drinking water. The annual flow-weighted NO_3-N concentration for kKkC treatments, even when fertilizer application was in June, 2007, was found to be significantly lower than the fSfC and fCfS treatments ($p<0.05$). NO_3-N concentration in PP treatment decreased from 2006 to 2007 and was significantly lower than all treatments with corn-soybean rotation in 2007 ($p<0.05$). The lowest annual flow-weighted concentration was observed in PP treatment during 2007. The NO_3-N loss of kKkC and PP treatments during April, May and June were 5.2 and 7.9 kg N ha^{-1}, which were 72.3% and 57.9% lower than the NO_3-N loss from fSfS and fCfS in the same period.

The monthly NO_3-N loss of kKkC and PP was significantly lower than fSfC and fCfS treatment in May of the two years ($p<0.05$).

The annual NO_3-N loss of the 24 plots varied from 8.1 to 63.4 kg N ha^{-1} for 2006 and from 7.3 to 107.8 kg N ha^{-1} for 2007. The average annual NO_3-N loss was 37.5 kg N ha^{-1} for fSfC and fCfS treatments, and 36.5 kg N ha^{-1} for rSrC and rCrS treatments. The NO_3-N loss during April, May and June was 18.8 kg N ha^{-1} for fSfC, 50.0% of the annual NO_3-N leaching. The differences in annual NO_3-N loss between rye-corn or soybean treatment and fallow-corn or soybean treatment were not significant. However, while not significantly different there was a slight reduction in NO_3-N loss during April, May and June for the winter rye cover crop treatment. In these three months, the average NO_3-N loss for fSfC and fCfS was 18.8 kg N ha^{-1} and 15.0 kg N ha^{-1} for rSrC and rCrS. The rye treatment reduced NO_3-N loss by 3.8 kg N ha^{-1} during the period from April to June, which was 20.1% of the average NO_3-N loss of fSfC and fCfS treatments during this three months and 10.0% of the average annual NO_3-N loss for fallow treatments. Rye followed by soybean grew around 20 days longer than that followed by corn due to the later planting date for soybean. Treatment of rye followed by soybean, namely rSrC for 2006 and rCrS for 2007, showed 2.6 kg N ha^{-1} (15.8%) less NO_3-N loss than rye followed by corn treatments, although not significantly different.

Table 5 lists the average drainage, flow-weighted NO_3-N concentration and NO_3-N loss for 2006 and 2007. The average drainage volume was not significantly different. The two-year flow weighted NO_3-N concentration of kKkC and PP treatments were significantly lower than other treatments. The average annual NO_3-N loss of kKkC and PP treatments were 22.4 kg N ha^{-1} and 15.0 kg N ha^{-1}, and were 39.7% and 59.9% lower the annual NO_3-N loss from fSfC and fCfS treatments. The average annual NO_3-N loss of PP treatment was significantly lower than all corn-soybean treatments with or without rye ($p<0.05$).

Table 5. Average annual drainage, flow-weighted NO_3-N concentrations and NO_3-N losses in 2006 and 2007.

Year	Land cover treatments					
	fSfC	fCfS	rSrC	rCrS	kKkC	PP
----- Drainage mm -----						
2006	123.7 a	118.6 a	115.5 a	97.8 a	91.3 a	108.2 a
2007	488.1 a	383.3 a	544.9 a	576.9 a	537.8 a	436.7 a
Average	305.9 a	251.0 a	330.2 a	337.4 a	314.6 a	272.5 a
----- Flow weighted NO_3-N concentration mg L^{-1} -----						
2006	15.1 a	13.2 ab	12.6 b	14.8 ab	6.3 c	8.2 bc
2007	13.5 a	12.9 ab	11.5 ab	9.5 bc	7.2 cd	4.8 d
Two-year flow-weighted average	13.8 a	13.0 a	11.6 a	10.2 a	7.1 b	5.5 b
----- NO_3-N loss kg ha^{-1} -----						
2006	18.7 a	15.7 ab	14.5 ab	14.5 ab	5.8 b	8.9 ab
2007	65.8 a	49.6 ab	62.4 a	54.5 ab	39.0 ab	21.0 b
Average	42.3 a	32.7 ab	38.5 ab	34.5 ab	22.4 bc	15.0 c

When averaged across all six treatments, 13.0 kg N ha^{-1} was exported through the subsurface drainage tile in 2006. However, this number increased to 48.7 kg N ha^{-1} in 2007, which was 2.7 times higher than that in 2006. The annual drainage volume was 109.2 mm for 2006 and 494.6 mm for 2007. The drainage volume of 2007 was 3.5 times higher than that of 2006. Drainage, NO_3-N concentration, and NO_3-N loss significantly differed in various years (not included in Table 6, $p<0.01$) which indicated that subsurface drainage volume and NO_3-N loss were dependent on the weather conditions.

Table 6. NO_3-N concentration in suction lysimeters at 30-cm and 60-cm depths in 2007.

Date	Land Cover Treatments					
	fSfC	fCfS	rSrC	rCrS	kKkC	PP
30-cm depth						
April	21.4	25.1	14.8	10.7	8.5	
May	12.2	15.2	13.0	7.5	2.3	1.1
June	8.7	16.6	17.7	4.1	2.9	5.0
July	13.6	17.9	11.0	8.3		
August	5.0	2.0	2.8	3.9	24.9	0.2
September	16.0	6.7	7.5	5.6	23.2	0.0
Average [1]	*12.8*	*13.9*	*11.1*	*6.6*	*12.4*	*1.6*
60-cm depth						
April	19.8	30.8	7.3	19.3		1.0
May	17.6	26.6	11.7	12.2	2.8	0.2
June	15.3	27.6	10.1	4.7	2.0	2.1
July	13.4	21.4	10.0	4.6	0.6	
August	4.2	8.2	4.1	3.2	22.4	0.6
September	8.7	7.1	12.4	4.5	38.3	0.1
Average [1]	*13.2*	*20.3*	*9.2*	*8.1*	*13.2*	*0.8*
Overall average [2]	13.0 ab	17.1 a	10.2 bc	7.4 c	12.8 b	1.2 d

[1]. Average over all observed values; [2]. Average over all monthly values.

Suction Lysimeter NO_3-N Concentration

Nitrate-nitrogen concentrations in the shallow soil solution ranged from 0.1 to 33.4 mg N L^{-1} for fSfC, 0.4 to 38.1 mg N L^{-1} for fCfS, no detection ($\leq$0.01 mg N L^{-1}) to 26.6 mg N L^{-1} for rSrC, no detection to 22.1 for rCrS, no detection to 77.6 for kKkC, and no detection to 15.0 mg N L^{-1} for PP.

Monthly average NO_3-N concentrations of soil solution at 30-cm and 60-cm depths are listed in Table 6. On average, NO_3-N concentration in the soil solution of rCrS treatment was significantly lower than the fCfS treatment by 56.4% ($p<0.05$). Although not significant, NO_3-N concentration in rSrC treatment was 21.5% lower than that in fSfC treatment. The PP treatment significantly ($p<0.05$) reduced the NO_3-N content in the shallow soil solution compared with any other treatments.

NO_3-N-nitrogen concentrations at 30-cm were not significantly different than those at 60-cm depth, indicating that NO_3-N concentration was not stratified at these two depths. However, in the PP plots, the average NO_3-N concentration in the soil solution at 30- and 60-cm was 1.2 mg N L^{-1}, 72.9% lower than the flow-weighted NO_3-N concentration in the tile line (106 cm deep). For the corn-soybean rotation treatments, no matter with or without rye as a winter cover, the NO_3-N concentrations at 30- and 60-cm were generally higher than that in the tile flow in spring and early summer but lower in August and September. Moreover, in the corn-soybean and pasture treatment plots, the NO_3-N concentration in the soil solution in April, May and June were lower than those in August and September. An inverse pattern was observed in kKkC treatment, which reflected the fertilizer application in June, 2007 and little uptake of N fertilizer due to poor corn growth.

Biomass and N uptake of spring land covers

Biomass and nitrogen uptake of spring land covers was lower in 2007 than in 2006 (Tables 7 and 8). Winter rye cover crop growing in the rye-soybean treatment was chemically desiccated in the middle to late May and the rye in the rye-corn treatment was killed in the late April with a difference of about twenty days. At termination of growth, the average rye biomass was 1479.1 kg ha^{-1}. The average biomass of rye followed by soybean was 2338.6 kg ha^{-1}, while rye biomass followed by corn was 619.6 kg ha^{-1}. Within the twenty days after the rye followed by corn was terminated, rye followed by soybean accumulated 79.8% of the biomass in 2006 and 77.9% of the biomass in 2007. In early June, observed biomass was 3922.7 kg ha^{-1} for Kura clover and 3033.4 kg ha^{-1} for pasture.

Table 7. Biomass, nitrogen content and nitrogen uptake by rye, kura clover, and pasture in the spring of 2006.

Date	Biomass (kg ha^{-1})		N content (%)		N uptake (kg N ha^{-1})	
	rCrS	rSrC	rCrS	rSrC	rCrS	rSrC
4/12/06	248.2	198.1	4.4	4.1	10.9	8.1
4/19/06	676.5	383.5	3.8	3.8	26.1	13.9
4/26/06	909.2	604.1	3.4	3.2	31.1	18.9
5/10/06		1972.4		2.5		50.1
5/17/06		2992.5		1.9		58.8
	kKkC	PP	kKkC	PP	kKkC	PP
4/26/06	1787.5	1962.1	3.8	3.1	33.1	31.2
6/5/06	6193.0	5794.2	2.4	1.7	75.9	39.2

Table 8. Biomass, nitrogen content and nitrogen uptake by rye, kura clover, and pasture in the spring of 2007.

Date	Biomass (kg ha^{-1})		N content (%)		N uptake (kg N ha^{-1})	
	rCrS	rSrC	rCrS	rSrC	rCrS	rSrC
3/29/07	55.3	55.9	5.7	6.0	3.2	3.3
4/5/07	63.1	95.3	4.8	5.0	3.0	4.8
4/13/07	71.9	96.6	5.1	5.2	3.7	5.1
4/19/07	111.6	100.2	4.5	4.9	5.1	4.9
4/27/07	197.1	236.9	4.3	4.5	8.4	10.6
4/30/07	372.1	329.9	3.3	3.4	12.2	11.3
5/10/07	691.5		2.9		19.8	
5/17/07	1091.9		2.3		24.4	
5/25/07	1684.1		1.9		31.8	
	kKkC	PP	kKkC	PP	kKkC	PP
4/27/07	967.8	179.2	4.7	3.6	45.5	6.4
6/7/07	1652.4	2072.6	2.6	1.3	43.9	27.2

With the accumulation of above ground biomass, nitrogen content in the grass and legume shoot decreased during the sampling period from late March to early June. Nitrogen content declined from 5.7% on March 29 to 1.9% on May 25 for the rye followed by soybean in 2007. At the rye growth termination, the average nitrogen uptake by rye was 33.3 kg N ha^{-1}. In early June, the cumulative nitrogen uptake was 59.9 kg N ha^{-1} for kura clover and 33.2 kg N ha^{-1} for pasture.

Conclusion

This study evaluated the impacts of various land covers in NO_3-N concentration and leaching losses in Iowa. In total, 43.7% of the annual rainfall exited through the subsurface drainage system. April, May and June were the main drainage months with 41.7% of the annual drainage. From the six different land cover treatments over two years, there was no significant differences among annual drainage volume.

The average annual flow-weighted NO_3-N concentration in the fallow corn or soybean treatments was 13.7 mg N L^{-1}. NO_3-N concentration in the drainage flow from the corn-soybean treatments during April, May and June consistently exceeded the 10 mg N L^{-1} limit set by USEPA for drinking water. Rye followed by soybean was found to significantly reduce annual flow-weighted NO_3-N concentration for 2006 and resulted in 21.7% lower annual flow-weighted NO_3-N concentration in the tile flow compared with fallow-soybean plots over the two years. The average annual flow-weighted NO_3-N concentration from the drain tile of the kKkC and PP treatments was 7.0 and 6.5 mg N L^{-1} respectively, below the 10 mg N L^{-1} of USEPA limit for drinking water.

Annual NO_3-N loss of corn soybean treatments without winter land cover was 37.5 kg N ha^{-1}; which 50.0% of this amount occurred in April, May and June. When rye was utilized as a winter cover crop, the annual NO_3-N leaching was reduced by 3.8 kg N ha^{-1} during April, May and June, and was 10.0% of the annual NO_3-N loss from the fallow corn and soybean treatments. Rye followed by soybean showed 15.8% less NO_3-N leaching than rye followed by corn treatment. Compared with corn-soybean without spring land cover treatments, kura clover as a living mulch and perennial pasture treatments resulted in a 39.7% and 59.9% reduction in annual NO_3-N leaching, respectively.

Rye followed by soybean reduced the NO_3-N concentration in the soil water solution significantly (56.4%) at the 30- and 60-cm depths. Pasture treatment showed significantly lower NO_3-N concentrations than all other treatments in the soil solution at these depths. At the termination of rye growth, the average nitrogen uptake by rye was 33.3 kg N ha^{-1}. In early June, the cumulative nitrogen uptake was 59.9 kg N ha^{-1} for kura clover and 33.2 kg N ha^{-1} for pasture.

Overall, this study indicates that winter rye cover crop, kura clover as a living mulch and perennial pasture land covers had positive effects on reducing NO_3-N leaching under the weather conditions present during these two years in Iowa. Weather conditions showed a significant effect on NO_3-N loss. Severe cold weather in April 2007 retarded the growth of rye, kura clover and pasture. Additional data over several years with differing weather conditions is important to draw broader conclusions on the impacts of various land covers.

Acknowledgements

The authors appreciate Mr. Carl Pederson in the Department of Agricultural and Biosystems Engineering, Iowa State University for helping in agronomic management. Mr. Loren Shiers in the Water Quality Laboratory of Iowa State University is thanked for water sample analysis. The authors' gratitude also goes to Ms. Delise Lockett, Mr. Bradley Bond and Ms. Rachel Chellm for helping in field work.

References

Affeldt, R.P., K.A. Albrecht, C.M. Boerboom, and E.J. Bures. 2004. Integrating herbicide-resistant corn technology in a kura clover living mulch system. *Agron. J.* 96:247-251

Andraski, T.W., and L.G. Bundy. 2005. Cover crop effects on corn yield response to nitrogen on a irrigated soil. *Agron. J*. 97:1239-1244.

Baker, J.L. and H.P. Johnson. 1981. NO_3-N-nitrogen in tile drainage as affected by fertilization. *J. Environ. Qual*. 4: 519-522.

Baker, J.L., and S.W. Melvin. 1994. Chemical management, status, and findings. P.27-60. In Agricultural drainage well research and demonstration project—annual report and project summary. Iowa Dep.of Agric. And Land Stewardship, Des Moines. IA.

Baker, J.L., K.L. Campbell, H.P. Johonson, and J.J. Hanway. 1975. NO_3-N, phosphorus, and sulfate in subsurface drainage water. *J. Environ. Qual*. 4: 406-412.

Baker, J.L., S.W. Melvin, D.W. Lemke, P.A. Lawlor, W.G. Crumpton, and M.J. Helmers. 2004. Subsurface drainage in Iowa and the water quality benefits and problem. Drainage VIII Proceedings of the Eighth International Symposium. ASAE Meeting Paper No. 701P0304. St. Joseph, MI.

Bakhsh, A., R.S. Kanwar, T.B. Bailey, C.A. Cambardella, D.L. Karlen, and T.S. Colvin. 2002. Cropping system effects on NO_3-N loss with subsurface drainage water. *Trans. ASAE*. 45(6):1789-1797.

Bergstrom, L. 1987. NO_3-N leaching and drainage from annual and perennial crops in tile-drained plots and lysimeters. *J. Enivron. Qual*. 16:11-18.

Blackmer, A.M., R.D., Voss, and A.P. Mallarino. 1997. Nitrogen fertilizer recommendations for corn in Iowa. PM-1714. Ames, Iowa: Iowa State University Extension Service.

Brouder, S., B. Hofmann, E. Kladivko, R. Turco, and A. Bongen. 2000. Interpreting NO_3-N concentration in tile drainage water. Purdue Extension. AY-318-W.

Bushuk, W. 2001. Rye: Production, Chemistry, and Technology. Second Edition. Published by the American Association of Cereal Chemists, Inc. St. Paul, Minnesota, USA.

Cambardella, C.A., T.B. Moorman, D.B. Jaynes, T.B. Parkin, and D.L. Karlen. 1999. Water quality in Walnut Creek watershed: NO_3-N in soils, subsurface drainage water and shallow groundwater. *J. Environ. Qual*. 28:25-34.

David, M.B., L.E. Gentry, D.A. Kovacic, and K.M. Smith. 1997. Nitrogen Balance in and Export from an Agricultural Watershed. *J. Environ. Qual.* 26: 1038-1048

De Bruin, J.L., P.M. Porter, and N.R. Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the upper Midwest. *Agron. J.* 97:587-598.

Eleki, K. 2003. Corn/kura clover living mulch system effects on root growth, soil loss, runoff water and water quality. Iowa State University.

Goolsby, D.A., W.A. Battaglin, B.T. Aulengach, and R.P. Hooper. 2001. Nitrogen input to the Gulf of Mexico. *J. Environ. Qual*. 30:329-336.

Hartwig, N., and H.U. Ammon. 2002. Cover crops and living mulches. *Weed Sci*, 50: 688-699.

Hatfield, J.L., J.H. Prueger and D. B. Jaynes. 1998. Environmental impacts of agricultural drainage in the Midwest. p.28-35. In Drainage in the 21st century: Food production and the environment. Proc. Annu. Drainage Symp. 7th, Orlando, FL. 8-10 Mar. 1998. Am. Soc. Of Agric. Eng., St. Joseph, MI.

Helmers, M. J., P.A. Lawlor, J. L. Baker, S. Melvin, D. Lemke. 2005. Temporal subsurface flow patterns form fifteen years in North-Central Iowa. ASAE Meeting Paper No. 05-2234. St. Joseph, MI.

Kanwar, R.S., H.P. Johnson, J.L. Baker. 1983. Comparison of simulated and measured NO3-N loss in tile effluent. *Trans. ASAE*. 26(5): 1451-1457.

Kanwar, R.S., R.M. Cruse, M. Ghaffarzadeh, A. Bakhsh, D.L. Karlen, and T.B. Bailey. 2005. Corn soybean and alternative cropping systems effected on NO_3-N leaching losses in subsurface drainage water. *Appl. Eng. Agric.* 21(2):181-188.

Kaspar, T.C., D.B. Jaynes, T.B. Parkin, and T.B. Moorman. 2007. Rye cover crop and gamagrass strip effects on NO_3 concentration and load in tile drainage. *J. of Environ. Qual.* 36:1503-1511.

Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. *J. Soil Water Cons*. 56:160-164.

Kessavalou, A., and D.T. Walters. 1999. Winter rye cover crop following soybean under conservation tillage: residual soil NO_3-N. *Agron. J.* 91:643-649.

Kross, B.C., G.R. Hallberg, D.R.Bruner, R.D. Libra and others. 1990. The Iowa state-wide rural well-water survey: Water quality data: Initial analysis. Iowa Department of Natural Resources, Geological Survey Bureau, Technical Information Series 19.

Lawlor, P.A., M.J. Helmers, J.L. Baker, S.W. Melvin, and D.W. Lemke. 2008. Nitrogen application rate effect on NO_3-N-nitrogen concentration and loss in subsurface drainage for a corn-soybean rotation. *Trans. ASABE*. 51(1): 83-94.

Leonard, W.H., and J.H. Martin. 1963. *Cereal Crops*. The Macmillan Company, NY.

Liedgens, M,, A. Soldati and P. Stamp. 2004. Interactions of maize and Italian ryegrass in a living mulch system: (1) Shoot growth and rooting patterns. *Plant Soil*. 191-203.

Lowrance, R. 1992. Nitrogen outputs from a field-size agricultural watershed. *J. Environ. Qual.* 21:602-607

McDonald, P.B., J.W. Singer, and M.H. Wiedenhoeft. 2008. Self-seeded cereal cover crop effects on interspecific competition with corn. *Agron. J.* 100:440-446

Nolan B.T., and K.J. Hitt. 2006. Vulnerability of shallow groundwater and drinking water wells to NO_3-N in the United States. *Environ. Sci. Technol*. 40: 7834-7840

Nolan, B. 2004. Update on NO_3-N in water resources of the United States. *Epidemiology.* 15(4): S109.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman, Jr. 2001. Hypoxia in the Gulf of Mexico. *J. Environ. Qual.* 30:320-329.

Randall, G.W., and J.A. Vetsch. 2005. NO_3-N losses in subsurface drainage from a corn-soybean rotation as affected by fall and spring application of nitrogen and nitrapyrin. *J. Environ. Qual.* 34*:*590-597.

Randall, G.W., and D.J. Mulla. 2001. Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. *J. Environ. Qual*. 30:337-344.

Ritter, W.F., R.W. Scarborough, A.E.M. Chirnside. 1998. Winter cover crop as a best management practice for reducing nitrogen leaching. *J. Contam. Hydrol*. 34:1-15.

Ruffo, M.L., D. G. Bullock, and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. *Agron. J*. 96: 800-805.

Schilling, K.E. and Y.K. Zhang, 2004. Baseflow contribution to nitrate-nitrogen export from a large, agricultural watershed, USA. *J. Hydrol*. 295: 305-316.

Singh, R., M.J. Helmers, and Z. Qi. 2006. Calibration and validation of DRAINMOD to design subsurface drainage systems for Iowa's tile landscapes. *Agric. Water Manage*. 85(2006)221-232.

Strock, J.S., P.M. Porter, and M.P. Russelle. 2004. Cover cropping to reduce NO_3-N loss through subsurface drainage in the northern U.S. Corn Belt. *J. Environ. Qual*. 33:1010-1016.

Unger, P.W., and M.F. Vigil. 1998. Cover crop effects on soil water relationships. *J. Soil Water Cons*. 53: 200-207.

USGS. 2004. Water Quality in the Nation's Streams and Aquifers-Overview of Selected Findings, 1991-2001.

Weed, D.A.J., and R.S. Kanwar. 1996. NO_3-N and water present in and flowing from root-zone soil. J. Environ. Qual. 25: 709-719.

Zemenchik, R.A., K.A. Albrecht, C.M. Boerboom, and J.G. Lauer. 2000. Corn production with Kura Clover as a living mulch. *Agron. J.* 92:698-705.

Zhu, Y. and R.H. Fox. 2003. Corn-soybean rotation effects on NO_3-N leaching. *Agron. J.* 95:1028-1033.