CROPPING SYSTEM EFFECTS ON NO_3–N LOSS WITH SUBSURFACE DRAINAGE WATER

A. Bakhsh, R. S. Kanwar, T. B. Bailey, C. A. Cambardella, D. L. Karlen, T. S. Colvin

ABSTRACT. *An appropriate combination of tillage and nitrogen management practices will be necessary to develop sustainable farming practices. A six–year (1993–1998) field study was conducted on subsurface–drained Clyde–Kenyon–Floyd soils to quantify the impact of two tillage systems (chisel plow vs. no tillage) and two N fertilizer management practices (preplant single application vs. late–spring soil test based application) on nitrate–nitrogen (NO_3–N) leaching loss with subsurface drain discharge from corn (*Zea mays *L.) soybean (*Glycine max *L.) rotation plots. Preplant injected urea ammonium nitrate solution (UAN) fertilizer was applied at the rate of 110 kg ha^{-1} to chisel plow and no–till corn plots, while the late–spring N application rate averaged 179 and 156 kg ha^{-1} for the no–till and chisel plow corn plots, respectively. Data on subsurface drainage flow volume, NO_3–N concentrations in subsurface drainage water, NO_3–N loss with subsurface drainage flow, and crop yield were collected and analyzed using a randomized complete block design. Differences in subsurface drainage flow volume due to annual variations in rainfall significantly (P = 0.05) affected the NO_3–N loss with subsurface drainage flows. High correlation (R^2 = 0.89) between annual subsurface drainage flow volume and the annual NO_3–N leaching loss with subsurface drainage water was observed. The flow–weighted average annual NO_3–N concentrations varied from a low of 6.8 mg L^{-1} in 1994 to a high of 13.9 mg L^{-1} in 1996. Results of this study indicated that NO_3–N losses from the chisel plow plots were 16% (16 vs. 19 kg–N ha^{-1}) lower in comparison with no–till plots, while corn grain yield was 11% higher in the chisel plow plots (8.3 vs. 7.5 Mg ha^{-1}). Late–spring N application applied as a sidedress resulted in 25% lower NO_3–N leaching losses with subsurface drainage water in comparison with preplant single N application and also significantly (P = 0.5) higher corn grain yield by 13% (8.4 vs. 7.4 Mg ha^{-1}). These results clearly demonstrate that chisel plow tillage with late–spring soil test based N application for corn after soybean can be a sustainable farming practice for the northeast part of Iowa.*

***Keywords**. Tillage, Nitrogen management, Nitrate leaching, Water quality.*

Water drained from croplands in the midwestern parts of the U.S. has been identified as a potential nonpoint source of surface water contamination with nitrate–nitrogen (NO_3–N), which may have adverse effects on human and animal health (Kanwar et al., 1999; Jaynes et al., 1999; Cambardella et al., 1999; Bjorneberg et al., 1998; Gentry et al., 2000). Recently, the development of a hypoxic zone in the Gulf of Mexico has also been attributed to the increased loadings of nitrates in the Mississippi River (Rabalais et al., 1999). The higher NO_3–N concentrations in the Mississippi River have been linked to the stream tributaries and extensive subsurface drainage systems in the upper Midwest (Davis et al., 2000; Randall, 1998). Therefore, monitoring and evaluation of subsurface drainage water quality and quantity for various cropping systems can provide information useful to assess and improve the impact of farming practices on soil and water quality (Bakhsh et al., 2000a; Kanwar et al., 1999; Andraski et al., 2000).

Tillage practices have been reported to affect the way that water and nitrates infiltrate into the soil (Bakhsh et al., 2000b; Drury et al., 1993; Weed and Kanwar, 1996). Chisel plowing alters the soil structure and slows downward water movement when compared with no–till (Smith and Cassel, 1991). No–till does not alter the soil structure and thus maintains cracks, holes, and worm burrows to a depth of up to 1 m (Dick et al., 1991; Singh and Kanwar, 1991). Such cracks and holes induce preferential movement of water and thus affect the solute transport processes in the soil profile (Kanwar et al., 1997).

Conservation tillage practices usually leave a significant amount of crop residue on the soil surface, which can affect water movement below and above the soil surface (Serem et al., 1997). Chisel plow tillage can leave as low as 30% of the crop residue as surface cover compared with as high as 90% left with no–till (Andraski et al., 1985). The higher residue levels maintained with no–till can affect the water distribution components by increasing infiltration and reducing runoff and erosion (Kenimer et al., 1987; Edwards et al., 1988). Chisel plow mixes crop residue with the soil during its

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operation, so there will be a different soil water regime than that maintained in the soil with a no–till system (Green et al., 1995). The decomposition rates of crop residue may differ for both systems of tillage because of the different physical, chemical, and biological processes taking place in the soil. The soil water content and soil temperature, which are affected by tillage systems, change C and N dynamics (Torbert et al., 1998). The N transformation processes, such as nitrification or denitrification, have been reported to be different for soils treated with different tillage systems (Doran, 1980). Groffman (1985) reported higher nitrification and denitrification activities in the top 50 mm of no–till soils than in conventional tillage soils and a reverse pattern for the lower depths. Bjorneberg et al. (1996) reported that low NO_3–N concentrations from no–till and ridge till systems might have resulted from greater bypass flow, denitrification, and immobilization under nonplowed systems.

A crop rotation such as corn (*Zea mays* L.) after soybean (*Glycine max* L.) can also influence the leaching of NO_3–N because this system of crop production has an impact on the input and output of N from the root zone. Soybean also does not usually receive any N fertilizer applications during its phase of production. Moreover, the low C/N ratio of soybean residue may influence rates of N mineralization and immobilization (Katupitiya et al., 1997). Soil and crop management practices can be used to reduce the potential negative environmental effects of agriculture while maintaining the crop yield levels (Karlen et al., 1998).

The leaching losses of NO_3–N from the root zone can be affected by the concentrations of NO_3–N in the soil profile at the time of percolation of water from the root zone. The time between supply of the available form of nitrogen in the soil and plant uptake of N can affect the leaching of NO_3–N. Bjorneberg et al. (1998) reported that much of the pre–plant N fertilizer and mineralized N in the soil may have denitrified or leached from the soil profile before it could be used by the corn. Milburn and Richards (1994) and Bjorneberg et al. (1996) reported that 50% to 85% of the annual drain flow and 45% to 85% of the annual NO_3–N losses occurred when crops were not actively growing. The plant uptake of N may offer an alternative for reducing soil nitrate levels to reduce the leaching of nitrates and maintain crop productivity. The duration, during which soil nitrates are prone to leaching, can be changed by N application methods. The split application of N fertilizer based on late–spring nitrate test (LSNT) can reduce the leaching time and can increase the plant uptake of N. A single pre–planting application of N fertilizer can provide more time for its leaching, particularly when applied at the time of less N requirement by the plants (Blackmer et al., 1989; Meisinger et al., 1992; Bjorneberg et al., 1998). These studies, however, have not reported the integrated effects of tillage when combined with single or split N applications for corn–soybean rotation plots on the leaching losses of NO_3–N with subsurface drainage water. This study was designed to quantify the impact of two tillage systems (no–till vs. chisel plow), two N management practices (single vs. late–spring applications), and their interaction on the leaching losses of NO_3–N with subsurface drainage water for corn–soybean rotation plots using six years (1993–1998) of field–measured and laboratory data.

Materials and Methods

Experimental Site and Treatments

The experimental site for this study was located at Iowa State University's Northeastern Research Center, Nashua, Iowa, on a predominantly Kenyon loam (fine–loamy, mixed, mesic Aquic Hapludoll) with 2% to 3% organic matter (USDA–SCS, 1982). These soils have a seasonally high water table and benefit from improved subsurface drainage. Sixty meters of pre–Illinoian till typically overlies a carbonate aquifer, although bedrock is near the surface in some areas.

The Nashua water quality research site has thirty–six 0.4–ha plots (each 58.5 × 67 m in size), with fully documented tillage and cropping records for the past 21 years. These plots had been managed under a randomized complete block design with four tillage systems (chisel, ridge, moldboard, and no–till) since 1979 (Bjorneberg et al., 1996). In 1993, new farming systems were initiated at this site with two options of N management treatments under two tillage systems (chisel and no–till).

Of these 36 plots, 24 plots were used for eight experimental treatments:

- CCPLS: corn after soybean received sidedress late–spring application of UAN fertilizer using late–spring nitrate test developed by Blackmer et al. (1989) under chisel plow.
- CCPSA: corn after soybean received a single N applica–tion of UAN fertilizer under chisel plow for a total of 110 kg–N/ha.
- CNTLS: corn after soybean received sidedress late–spring application of UAN fertilizer under no–till.
- CNTSA: corn after soybean received a single N applica–tion of UAN fertilizer under no–till for a total of 110 kg–N/ha.
- SCPLS: soybean after corn in plots with late–spring application of UAN fertilizer to corn under chisel plow.
- SCPSA: soybean after corn in plots with single N application of UAN fertilizer to corn under chisel plow.
- SNTLS: soybean after corn in plots with late–spring application of UAN to corn under no–till.
- SNTSA: soybean after corn in plots with single N application of UAN to corn under no–till.

Each treatment was replicated three times in a randomized complete block design. Treatment means were separated using SAS (1989) with least significant difference (LSD; tests the difference, significant among all the treatment means) and contrast (tests the difference, significant between the specified treatment means) methods at the 5% probability level.

The same varieties of corn (Golden Harvest 2343) and soybean (Sands of Iowa) were grown in these plots during the six–year (1993–1998) study (Bakhsh et al., 2000b). Corn, whether fertilized with preplant single or late–spring N applications, was planted in 750–mm rows into a seedbed prepared by fall chiseling and field cultivating in the spring (table 1). Soybean was drilled in 200–mm rows directly into corn stover from the previous year, and no fertilizer was applied. A single UAN application of 110 kg–N ha^{-1} was made before planting with a spoke injector, which injected

Table 1. Schedule of management activities of the study area at the northeast research center, Nashua, Iowa.

Field Operations	1993	1994	1995	1996	1997	1998
Spring fertilizer application	14 May	24 April	12 May	3 May	12 May	1 May
Primary tillage (chisel plow)	20 Nov.	15 Nov.	20 Nov.	17 Nov.	12 Nov.	17 Nov.
Corn planting	17 May	2 May	16 May	21 May	12 May	5 May
Soybean planting	26 May	17 May	22 May	30 May	16 May	18 May
Sidedress fertilizer application	7 July	17 June	22 June	24 June	19 June	15 June
Cultivation (corn plots)	21 July	2 June	14 June	24 June	19 June	4 June
Approximate corn maturity	1 Sept.	2 Sept.	7 Sept.	5 Oct.	30 Sept.	10 Sept.
Corn harvest	25 Oct.	28 Sept.	22 Sept.	21 Oct.	10 Oct.	22 Sept.
Soybean harvest	7 Oct.	6 Oct.	11 Oct.	8 Oct.	2 Oct.	1 Oct.

Table 2. Nitrogen application rates for various cropping systems from 1993 to 1998.

Application Rates	1993		1994		1995		1996		1997		1998		Average	
	NT	CP	NT	CP	NT	CP	NT	CP	NT	CP	NT	CP	NT	CP
LSNT	144	93	169	160	193	16011	195	169	187	171	189	186	179	156
Single	110	110	110	110	110	0	110	110	110	110	110	110	110	110

LSNT = late–spring nitrate fertilizer application rates for corn after soybean, includes 30 kg–N/ha applied with planter.
NT = no–till system; CP = chisel plow system.

UAN at about 200–mm intervals, 250–mm from corn rows (Baker et al., 1989). The late–spring UAN applications were determined based on the late–spring NO_3–N test (LSNT) developed for Iowa soils (Blackmer et al., 1989), in addition to 30 kg–N ha^{-1} applied with the corn planter (Bjorneberg et al., 1998). Based on LSNT, UAN was injected to increase the soil NO_3–N concentrations in the top 300 mm of the soil profile to 25 mg kg^{-1}. The amount of N applied for the LSNT treatment varied from 93 to 195 kg–N ha^{-1} during the 6–year period of this study (table 2). Corn and soybean yield were measured from each plot using a modified commercial combine. The statistical analyses were conducted separately for corn and soybean yield data using ANOVA (analysis of variance) procedures and a randomized complete block design. Details on the statistical procedures are given in Bakhsh et al. (2000b).

Subsurface Drainage System and Sampling Procedure

The subsurface drainage system was installed in 1979 at the Nashua water quality research site. Each plot is drained separately and has subsurface drainage lines installed in the center of the plot at a depth of 1.2 m below the ground surface with a drain spacing of 28.5 m. Cross contamination of each plot was avoided by installing subsurface drainage lines on the northern and southern borders of the plot and isolating the eastern and western borders with berms (Kanwar et al., 1999). The central subsurface drainage lines are intercepted at the end of the plots and are connected to individual sumps for measuring drainage effluents and collecting water samples for chemical analysis. The sumps are equipped with a 110–volt effluent pump, water flow meter, and an orifice tube to collect water samples. Data loggers, connected to the water flow meters, record subsurface drainage flow continuously as a function of time. Composite water samples were collected for NO_3–N analysis using an orifice tube located on the discharge pipe of the sump pump. Approximately 0.2% of the water pumped from the sump flowed through a 5–mm diameter polyethylene tube to a water–sampling bottle located in the collection sump each time the pump operated. Cumulative subsurface drain flows were recorded, and sampling bottles were removed two times per week beginning from mid–March to the beginning of December during the entire study period. A more detailed description of the automated subsurface drainage system installed at the site can be found in Kanwar et al. (1999).

The water samples collected for NO_3–N analysis were analyzed spectrophotometrically using a Lachat Model AE ion analyzer (Lachat Instruments, Milwaukee, Wisc.). The NO_3–N loss with subsurface drainage water in kg–N ha^{-1} was calculated by multiplying the NO_3–N concentrations in mg L^{-1} with the drainage effluent in mm and dividing it by 100 (conversion factor) for each interval of sampling (i.e., two times per week). The cumulative NO_3–N loss and drainage effluent for the entire monitoring season were used to calculate the flow–weighted average NO_3–N concentrations for each year (Bjorneberg et al., 1998).

Results and Discussion

Subsurface Drainage Flows

Cropping systems effects on the subsurface drainage volumes and NO_3–N losses with subsurface drainage water were determined using the analysis of variance approach, which compared variability induced by the treatments to the natural variability due to spatial and lithological characteristics of the soils and also due to the experimental error (table 3). Cropping system effects on subsurface drainage water on a yearly basis were found to be non–significant (P = 0.05) because of highly significant year effects (P = 0.01) (table 4) due to weather differences over these years. However, the 6–year average treatment effects on subsurface drainage flows were found to be significant at the 0.10 probability level, which has also been reported as a criteria of significance (Weed and Kanwar, 1996; Torbert et al., 1998). The effects of season (years) and their interaction with treatments on subsurface drainage flows were found to be highly significant (P = 0.01) and significant (P = 0.05), respectively, partly due to rainfall patterns changing over the years, which also affected the subsurface drainage flow volume from year to year (table 4). The growing season (March through November) rainfall varied from a low of 680 mm in 1996 to a high of 1030 mm in 1993. The rainfall in both years affected the subsurface drainage flow volumes because a significant (P = 0.05) correlation between the annual subsurface drainage flow volume and the growing

Table 3. Analysis of variance for subsurface drainage flow and nitrate loss with subsurface drainage flow on yearly basis.

Sources of Variability	df[a]	1993	1994	1995	1996	1997	1998
		P > F[b] (subsurface drainage flow)					
Blocks (blk)	2	0.48	0.74	0.47	0.56	0.66	0.82
Cropping systems (trt)	7	0.06	0.26	0.19	0.17	0.12	0.32
Error (blk × trt)	14						
		P > F (NO_3–N concentrations in subsurface drainage water)					
Blocks (blk)	2	0.04	0.13	0.06	0.08	0.11	0.18
Cropping systems (trt)	7	<0.01	0.02	<0.01	0.54	<0.01	0.65
Error (blk × trt)	14						
		P > F (NO_3–N loss with subsurface drainage water)					
Blocks (blk)	2	0.68	0.76	0.76	0.88	0.78	0.96
Cropping systems (trt)	7	0.43	0.14	0.24	0.12	0.26	0.43
Error (blk × trt)	14						

[a] df = degrees of freedom.
[b] P > F = probability values.

Table 4. Analysis of variance for annual subsurface drainage flow and nitrate loss with subsurface drainage flows from 1993 to 1998.

Sources of Variability	df[a]	Subsurface Drainage Flow (P > F)[b]	NO_3–N Concentrations[c] (P > F)	NO_3–N Loss with Subsurface Drainage Flow (P > F)
Blocks (blk)	2	0.52	<0.01	0.97
Treatments (trt)	7	0.09	<0.01	0.15
Error a	14			
Year	5	<0.01	<0.01	<0.01
Year × trt	35	0.02	<0.01	0.80
Error b	80			

[a] df = degrees of freedom.
[b] P > F = probability values.
[c] Flow–weighted average annual NO_3–N concentrations in subsurface drainage water.

season rainfall (R^2 = 0.89) was found for the study site. The year 1993 was wet, having rainfall 23% greater than the 30–year average annual rainfall of 840 mm (Voy, 1995). Other years' rainfall amounts (750 mm for 1994, 800 mm for 1995, and 750 mm for 1997) were lower than the 30–year average annual rainfall except 980 mm for 1998, which was 17% more than the 30–year average annual rainfall. The 6–year average subsurface drainage flow showed that about 20% of the average growing season rainfall (832 mm) contributed as subsurface drainage flow (168 mm) for this area (table 5).

Tillage and N management effects on subsurface drainage flows showed that tillage effects varied from year to year and were significant (P = 0.05) under single N application for both corn and soybean plots. The yearly subsurface drainage flow volumes followed the pattern of rainfall and varied from a low of 66 mm in 1996 to a high of 390 mm in 1993. When averaged across all six years, the no–till system with single N applications resulted in significantly (P = 0.05) higher subsurface drainage flows than the chisel plow system under the same N management with a two–fold increase (246 vs. 122 mm) for both corn and soybean rotation plots (table 5). Bjorneberg et al. (1998), studying the same site, also reported similar results and argued that the longer history of the no–till plots from 1978 to 1992 may have partly contributed to higher subsurface drainage flow volumes for these plots. Randall and Iragavarapu (1995) reported from a study in southeastern Minnesota that increased drain flow under no–till plots was attributed to the combined effects of reduced evapotranspiration and increased infiltration in this system. In addition, no–till might have induced preferential movements of water in the soil profile because of a better connected network of macropores compared to chisel plow,

Table 5. Cropping system means[a] for annual subsurface drainage flow (mm) on yearly basis.

Cropping Systems[b]	1993	1994	1995	1996	1997	1998	1993–1998 Average
	Years						
CCPLS	258 c	123 ab	81 b	71 abc	61 b	304 ab	150 ab
CCPSA	352 abc	29 b	67 b	49 abc	50 b	187 ab	122 b
CNTLS	265 c	62 ab	94 ab	53 abc	59 b	164 b	116 b
CNTSA	492 ab	164 a	201 ab	114 a	133 ab	372 a	246 a
SCPLS	501 ab	68 ab	203 ab	45 bc	151 ab	191 ab	193 ab
SCPSA	282 bc	56 ab	95 ab	38 c	55 b	206 ab	122 b
SNTLS	391 abc	61 ab	109 ab	51 abc	70 b	195 ab	146 ab
SNTSA	572 a	109 ab	249 a	106 ab	211 a	264 ab	252 a
Avg.	390	84	138	66	99	235	168
C.V.	33	75	67	57	72	46	39
S.E.	74	37	53	22	41	63	15
$LSD_{(0.05)}$	225	111	161	65	125	191	43

[a] Treatment means with different letters are significantly (P = 0.05) different from each other.
[b] Refer to the Appendix for definitions of abbreviations.

Table 6. Cropping system means[a] for flow–weighted average NO_3–N concentrations (mg L^{-1}) in subsurface drainage flow.

Cropping Systems[b]	Years						1993–1998 Average
	1993	1994	1995	1996	1997	1998	
CCPLS	11.4 a	8.8 ab	13.5 ab	13.9 a	10.5 b	12.1 a	11.7 ab
CCPSA	9.3 b	9.3 a	15.5 a	13.0 a	12.4 ab	12.7 a	12.0 a
CNTLS	9.4 b	8.1 ab	10.9 cd	15.3 a	12.6 c	11.8 a	11.4 ab
CNTSA	9.3 b	6.3 bc	12.7 bc	12.8 a	12.3 ab	10.9 a	10.7 ab
SCPLS	6.3 c	6.7 abc	10.3 cd	12.9 a	7.6 c	11.1 a	9.2 cd
SCPSA	11.5 a	6.2 bc	10.9 cd	15.1 a	6.8 c	11.9 a	10.4 bc
SNTLS	5.9 c	4.6 c	8.5 d	15.7 a	7.9 c	11.8 a	9.1 cd
SNTSA	6.5 c	4.8 c	9.0 d	12.4 a	7.3 c	9.7 a	8.3 d
Avg.	8.7	6.8	11.4	13.9	9.7	11.5	10.3
C.V.	12.4	23.3	12.4	16.9	11.9	15.9	14.5
S. E.	0.6	0.9	0.8	1.4	0.7	1.0	0.3
$LSD_{(0.05)}$	1.9	2.8	2.5	4.1	2.0	3.2	1.4

[a] Treatment means with different letters "a, b, c," are significantly (P = 0.05) different from each other.

[b] Refer to the Appendix for definitions of abbreviations.

and therefore might have resulted in higher subsurface drainage flow volumes than in plots under chisel plow (Kanwar et al., 1997; Bakhsh et al., 2000b).

Flow–Weighted Average NO_3–N Concentrations

Flow–weighted average NO_3–N concentrations (FWANC) have been reported to be a better indicator of overall contamination potential, particularly when stream flow can join a drinking water source (Jaynes et al., 1999). The cropping system effects on FWANC varied from year to year but were found to be significant (P = 0.05) in 1993, 1994, 1995, and 1997 (table 3). However, the analysis of variance based on 6–year average FWANC (table 4) showed that treatment, block (replication), and year effects were found to be highly significant (P = 0.01). The significant effects of blocks on FWANC show the influence of spatial and lithological variability in the hydraulic properties of the soil profile within given treatment plots. The infiltration and deep percolation of water in the root zone are governed by the hydraulic properties of the soil profile. Any layer in the soil profile having the lowest hydraulic conductivity can control the deep percolation and ultimately subsurface drainage flow, which can affect the FWANC. The levels of NO_3–N concentrations depend on the volume of drainage effluents and can also change due to dilution effects (Cambardella et al., 1999; Jaynes et al., 1999).

The FWANC varied from a low of 6.8 mg L^{-1} in 1994 to a high of 13.9 mg L^{-1} in 1996 (table 6). The lower levels of FWANC in 1994 may be due to excessive flushing of NO_3–N from the soil profile due to heavy rainfall in 1993 (Kanwar et al., 1997; Jaynes et al., 1999). The higher values of FWANC in 1996 may be due to the lowest amounts of rainfall in 1996 among all the six years, resulting in increased FWANC values in subsurface drainage water due to decreased subsurface drainage flow volumes. Higher FWANC values in 1996 may also be the result of lower crop yields in 1995 due to heavy hail storm damage, which reduced the plant N uptake and left more residual soil nitrate (Bjorneberg et al., 1998; Bakhsh et al., 2000b). Randall (1998) also reported significant effect of wet/dry weather on NO_3–N concentration in subsurface drainage water. The lower rainfall resulted in higher FWANC values, and higher rainfall gave lower FWANC values (fig. 1). A significant (P = 0.05) linear relationship (R^2 = 0.89) between growing season rainfall and subsurface drainage flow volume was found.

The single N application resulted in higher FWANC values in comparison with late–spring N application treatment under the chisel plow system for both corn after soybean (12 vs. 11.7 mg L^{-1}) and soybean after corn plots (10.4 vs. 9.2 mg L^{-1}), but these differences were mostly non–significant (table 6). The chisel plow system resulted in significantly (P = 0.05) higher FWANC values in comparison with the

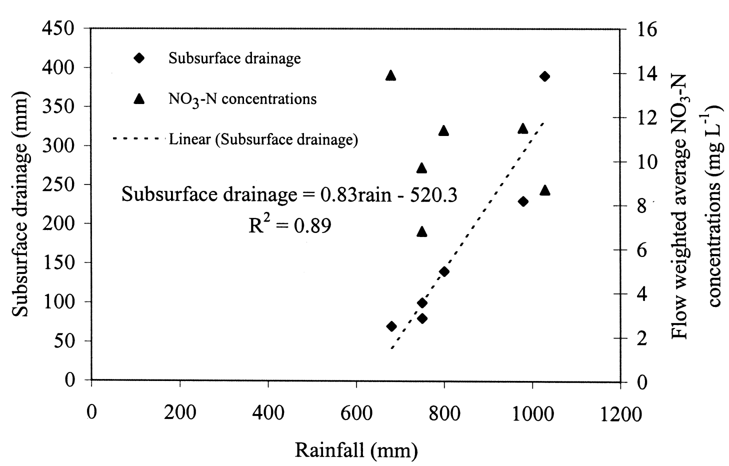

Figure 1. Relationship of subsurface drainage and flow–weighted average NO_3–N.

Table 7. Cropping system means[a] for annual nitrate loss with subsurface drainage flow (kg–N ha^{-1}).

Cropping Systems[b]	Years 1993	1994	1995	1996	1997	1998	1993–1998 Average
CCPLS	32 ab	9 ab	12 ab	8 ab	7 ab	34 ab	17 ab
CCPSA	33 ab	3 b	10 ab	6 b	6 ab	24 ab	14 b
CNTLS	25 ab	5 ab	10 ab	8 ab	7 ab	20 b	13 b
CNTSA	46 a	10 a	25 a	14 a	17 a	40 a	25 a
SCPLS	30 ab	5 ab	18 ab	6 b	11 ab	23 ab	16 ab
SCPSA	32 ab	3 b	10 ab	6 b	4 b	24 ab	13 b
SNTLS	23 b	3 b	9 b	8 ab	6 ab	23 ab	12 b
SNTSA	37 ab	6 ab	23 ab	13 a	16 ab	26 ab	20 ab
Avg.	32	5	15	9	9	27	16
C.V.	37	69	61	43	75	42	40
S. E.	7	2	5	2	4	6	2
$LSD_{(0.05)}$	21	6	15	6	12	19	10

[a] Treatment means with different letters are significantly (P = 0.05) different from each other.
[b] Refer to the Appendix for definitions of abbreviations.

no–till system (10.4 vs. 8.3 mg L^{-1}) for soybean after corn plots under preplant single N applications to corn, which may be due to dilution effects for no–till plots. These results were consistent with those reported by Kanwar et al. (1988), Patni et al. (1996), and Bjorneberg et al. (1998). Higher concentrations of NO_3–N with conventional tillage compared with no–till can be associated with increased net N mineralization in this system (Randall and Irgavarapu, 1995). Kanwar et al. (1997) found that lower NO_3–N concentration in subsurface drainage water from no–till plots may have resulted from more water moving through macropores than the soil matrix and lower N mineralization rates.

NO_3–N Losses with Subsurface Drainage Water

Cropping systems effects on NO_3–N losses with subsurface drainage water varied from year to year (table 3) and were found to be non–significant (P = 0.05) primarily due to weather differences. The NO_3–N loss with subsurface drainage water ranged from a low of 5 kg–N ha^{-1} in 1994 to a high of 32 kg–N ha^{-1} in 1993 (table 7), which was the result of variability in rainfall during these years. The NO_3–N losses with subsurface drainage water were affected significantly (P = 0.05) with subsurface drainage flow volume (fig. 2). The years having higher subsurface drainage flow volume, such as 1993, resulted in higher NO_3–N losses with subsurface drainage flow, indicating that NO_3–N losses with subsurface drainage water were directly proportional to subsurface drainage flow volumes in a given year. Similar results have been reported by Jaynes et al. (1999) and Cambardella et al. (1999) for subsurface drainage drained fields in central Iowa. Higher NO_3–N losses with subsurface drainage water in 1993 also affected the corn growth and resulted in the lowest corn grain yields (6.1 Mg ha^{-1}) for that year (table 8). The lower corn grain yield data observed in 1995 was due to hail, which severely damaged the crop growth that year (Bakhsh et al., 2000b; Bjorneberg et al., 1998). The linear relationships between annual rainfall, annual subsurface drainage flow volume, and annual NO_3–N losses with subsurface drainage flow were found to be significant (P = 0.05) with R^2 = 0.89 (figs. 1 and 2). The effect of season on NO_3–N losses was found to be highly significant (P = 0.01) when averaged across 1993 to 1998 due to differences in the subsurface drainage flow volume (table 4).

Despite yearly differences in NO_3–N losses with subsurface drainage water, tillage and N management effects were significant for some of the years (table 7). In 1993 (the first year of the experiment), single N applications to corn plots resulted in 84% higher (46 vs. 25 kg–N ha^{-1}) NO_3–N loss in comparison with the late–spring N applications under the no–till system. This was not the result of N treatment effects but was due to the fact that twice as much subsurface drainage flow occurred from single N application plots in comparison to late–spring test plots (492 vs. 265 mm). This effect of higher NO_3–N losses with subsurface drainage flow under

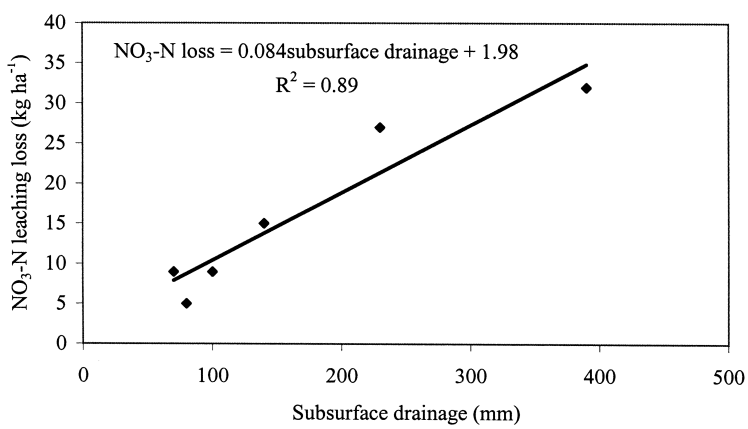

Figure 2. Relationship of NO_3–N leaching loss with subsurface drainage for 1993 to 1998.

Table 8. Cropping system effects on corn grain yield[a] ($Mg\ ha^{-1}$).

Cropping Systems[b]	Years 1993	1994	1995	1996	1997	1998	1993–1998 Average
CCPLS	7.7 a	8.2 a	6.1 a	9.2 a	10.1 a	10.7 a	8.6 a
CCPSA	5.1 b	7.9 a	6.0 a	8.8 b	9.8 bc	9.7 b	7.9 b
CNTLS	7.3 a	7.3 b	5.3 a	9.1 ab	9.9 ab	9.6 b	8.1 b
CNTSA	4.3 b	6.3 c	5.1 a	8.4c	9.5 c	8.1 c	6.9 c
Avg.	6.1	7.4	5.6	8.9	9.8	9.6	7.9
C.V.	7.9	2.2	14.2	1.9	1.3	3.7	5.3
S. E.	0.3	0.1	0.5	0.1	0.1	0.2	0.1
$LSD_{(0.05)}$	0.9	0.3	1.6	0.3	0.3	0.7	0.2

[a] Treatment means with different letters are significantly (P = 0.05) different from each other.

[b] Refer to the Appendix for definitions of abbreviations.

no–till with single N application also resulted in the lowest corn grain yield in 1993 among all the years by 41% (4.3 vs. 7.3 Mg ha^{-1}) when compared with late–spring N application under the no–till system (table 8). In addition, the quantities of NO_3–N leaching may vary between fields and within a field because of variability in soil properties and their effects on N mineralization and water movement through the soil profile (Bakhsh et al., 2001; Power et al., 1998). The role of macropore flow becomes more important when rainfall exceeds the evapotranspiration rates, especially after harvesting the crops (Bjorneberg et al., 1998).

The single N application treatments resulted in higher NO_3–N losses with subsurface drainage water under the no–till system because of the longer rainfall period available to flush the NO_3–N from the soil profile to the subsurface drainage drain when compared with late–spring N application. The significant effect of tillage (no–till vs. chisel) on subsurface drainage flow and NO_3–N loss with subsurface drainage water has also been reported in earlier studies conducted at this site (Kanwar et al., 1997). Data on 6–year average NO_3–N losses with subsurface drainage water showed that the no–till system receiving single N applications resulted in about two–fold higher (25 vs. 14 kg–N ha^{-1}) NO_3–N loss in comparison with the chisel plow system with single N applications for corn after soybean plots (table 7). These higher NO_3–N losses with subsurface drainage flow under no–till with single N application also resulted in significantly (P = 0.05) lower corn grain yield by 14% (6.9 vs. 7.9 Mg ha^{-1}) when compared to the chisel plow system (table 8). The higher NO_3–N leaching losses with subsurface drainage flow not only increased environmental concerns but also adversely affected the corn grain yield. On the average, chisel plowing gave lower NO_3–N losses with subsurface drainage flow (16 vs. 19 kg–N ha^{-1}) and significantly (P = 0.05) higher corn grain yield (8.3 vs. 7.5 Mg ha^{-1}) than the no–till system. Similarly, the late–spring soil test based N application to corn also resulted in lower NO_3–N losses (15 vs. 20 kg–N ha^{-1}) with subsurface drainage flow and higher corn grain yield (8.4 vs. 7.4 Mg ha^{-1}) than preplant single N application.

The 6–year average NO_3–N losses with subsurface drainage water from soybean after corn plots were not found to be statistically different (15 vs. 17 kg–N ha^{-1}) from those observed under corn after soybean plots (table 7), and no N fertilizer was applied to soybean. This shows that plots under soybean were able to leach NO_3–N with subsurface drainage flow as much as corn plots. A soybean crop typically accumulates 25% to 50% of its N from atmospheric N_2 fixation (Johnson et al., 1975; Harper, 1987) and uses the residual N and mineralized N from the soil for the majority of its N requirement (Olsen et al., 1970). Cambardella et al. (1999) reported that substantial quantities of applied N fertilizer become incorporated in soil organic matter and remineralize in the subsequent years. Therefore, N applied from fertilizer and N derived from mineralization can create high inorganic N pools, particularly after a poor growing season (Gentry et al., 1998). The release of N from inorganic N pools might have made it possible for soybean plots to leach as much NO_3–N as has leached from corn plots (table 7). Therefore, an assessment of the buildup of inorganic N pools for soils having a corn–soybean rotation system, subsurface drainage, and fertilized with N over a longer period may be needed for examining NO_3–N loading with subsurface drainage flow. Gentry et al. (1998) also reported that an appropriate N credit needs to be assessed to the soybean crop to reduce N application rates in the following year.

CONCLUSIONS

Based on the analysis of six years (1993–1998) of field–measured flow data and laboratory analysis of drainage water samples for no–till and chisel plowed plots with a corn–soybean rotation system, the following conclusions were drawn:

- The difference in annual cumulative subsurface drainage flow volume due to rainfall created a significant effect on NO_3–N losses with subsurface drainage water (P = 0.05) and also showed a high correlation (R^2 = 0.89) between annual subsurface drainage flow volume and the annual NO_3–N leaching losses with subsurface drainage water.
- Chisel plowing, on average, resulted in 16% lower NO_3–N losses with subsurface drainage water in comparison with no–till (16 vs. 19 kg–N ha^{-1}) and 11% higher corn grain yields (8.3 vs. 7.5 Mg ha^{-1}). Similarly, late–spring N application, on average, resulted in 25% lower NO_3–N leaching losses with subsurface drainage water in comparison with preplant single N application (15 vs. 20 kg–N ha^{-1}) and 13% higher corn grain yield (8.4 vs. 7.4 Mg ha^{-1}).
- The 6–year average NO_3–N losses with subsurface drainage water from soybean–corn rotation plots were not statistically different from those observed from corn–soybean rotation plots.

- The results of this study indicate that chisel plowing with late–spring soil test based N applications can reduce NO_3–N leaching losses with subsurface drainage water and can also increase crop yields.

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APPENDIX

NT	= no–till
CP	= chisel plow
Avg.	= average
S.E.	= standard error
$LSD_{(0.05)}$	= least significant difference at the 5% probability level
C.V.	= coefficient of variation (%)
FWANC	= flow–weighted average nitrate concentrations
CS	= corn after soybean rotation
SC	= soybean after corn rotation
UAN	= urea–ammonium–nitrate solution fertilizer
LSNT	= late–spring nitrate test
CCPLS	= corn after soybean, chisel plow, late–spring soil test based N application
CCPSA	= corn after soybean, chisel plow, single preplant N application
CNTLS	= corn after soybean, no–till, late–spring soil test based N application
CNTSA	= corn after soybean, no–till, single preplant N application
SCPLS	= soybean after corn, chisel plow (late–spring N application to corn phase only)
SCPSA	= soybean after corn, chisel plow (single N application to corn phase only)
SNTLS	= soybean after corn, no–till (late–spring N application to corn phase only)
SNTSA	= soybean after corn, no–till (single N application to corn phase only)