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Nitrate Losses through Subsurface Tile Drainage in Conservation Reserve Program, Alfalfa, and Row Crop Systems

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ABSTRACT

Subsurface drainage of gravitational water from the soil profile through tiles is a common practice used to improve crop production on poorly drained soils. Previous research has often shown significant concentrations of nitrate-N (NO_3–N) in drainage water from row-crop systems, but little drainage research has been conducted under perennial crops such as those used in the Conservation Reserve Program (CRP). Four cropping systems (continuous corn, a corn-soybean rotation, alfalfa, and CRP) were established in 1988 to determine aboveground biomass yields, N uptake, residual soil N (RSN), soil water content, and NO_3 losses to subsurface tile drainage water as influenced by cropping system. Hydrologic-year rainfall during the 6-yr study ranged from 23% below normal to 66% above normal. In dry years, yields were limited, RSN accumulated at elevated levels in all crop systems but especially in the row-crop systems, soil water reserves and RSN were reduced to as deep as 2.7 m in the alfalfa (*Medicago sativa* L.) and CRP systems, and tile drainage did not occur. Drainage occurred only in the corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] systems in the year of normal rainfall. In years of excess precipitation, drainage from the row-crop systems exceeded that from the perennial crops by 1.1 to 5.3X. Flow-weighted average NO_3–N concentrations in the water during the flow period of this study were continuous corn = 32, corn-soybean rotation = 24, alfalfa = 3 and CRP = 2 mg/L. Nitrate losses in the subsurface drainage water from the continuous corn and corn-soybean systems were about 37X and 35X higher, respectively, than from the alfalfa and CRP systems due primarily to greater season-long ET resulting in less drainage and greater uptake and/or immobilization of N by the perennial crops.

Artificial drainage through subsurface tile lines is a common agricultural practice in large areas of highly productive but poorly drained soils in the USA, particularly in the upper Midwest. Nutrient composition of tile drainage reflects nutrient losses from the field and potential inputs to surface and groundwater. Substantial amounts of sediment and nutrients, and detectable amounts of pesticides are carried in tile drainage (Baker and Johnson, 1981; Buhler et al., 1993; Kladivko et al., 1991). Therefore, monitoring tile effluents is useful for assessing the impact of agricultural management practices on surface and groundwater quality (Hallberg et al., 1986; Kanwar et al., 1987).

Corn has been the crop used in most investigations in the Midwest to determine the role of management on loss of nutrients via subsurface drainage (Baker & Johnson, 1981; Gast et al., 1978; Kanwar et al., 1988; Kladivko et al., 1991; Owens, 1987; Randall and Iragavarapu, 1995). These studies generally have shown marked losses of NO_3 in the drainage water with the magnitude of loss dependent on fertilizer N management. Logan et al. (1980) reported NO_3 losses were highest with N-fertilized corn, intermediate for soybean or systems where other crops were in rotation, and lowest with alfalfa.

Alfalfa effectively reduces NO_3–N concentrations in the soil profile (Mathers et al., 1975; Schertz and Miller, 1972) and has been suggested as a management alternative for removing NO_3–N from the soil below the rooting depth of most crops (Russelle and Hargrove, 1989). Mathers et al. (1975) reported that both NO_3 and soil water apparently were used to a 1.8-m depth in the first year of alfalfa and up to a depth of 3.6 m in the 2nd year in Texas. Robbins and Carter (1980) showed lower NO_3–N concentrations in drainage water with growing alfalfa compared to dry bean (*Phaseolus vulgaris* L.) and corn in Idaho. Nutrient losses in tile drainage in Ontario from alfalfa were highest with continuous corn, intermediate with a corn-oat (*Avena sativa* L.)-alfalfa-alfalfa rotations, and lowest with continuous bluegrass (*Poa pratensis* L.) (Bolton et al., 1970).

Relatively few drainage studies have been conducted with perennial grass crops. A seeding mix of 30% orchardgrass (*Dactylis glomerata* L.) and 70% alfalfa planted in lysimeters that had previously received high rates of N for corn-reduced NO_3–N concentrations in the drainage water from the range of 15 to 40 mg/L to <5 mg/L (Owens, 1990). In Swedish studies, Bergstrom (1987) found much lower drainage volume and NO_3–N concentration and flux with two perennial ley crops, fescue (*Festuca pratensis* L.) and alfalfa, compared to barley (*Hordeum distichum* L.). The fescue and alfalfa leys acted as optimal catch crops, mostly due to their extended growing season. Timothy (*Phleum pratense* L.) and smooth bromegress (*Bromus inermis* L.) were much more effective in removing NO_3–N from the soil compared to corn in Ontario (MacLean, 1977).

The CRP was initiated in 1985 with the intention of converting highly erodible land to permanent grassland cover while reducing soil erosion and production of row crops. By 1993, 14.8 million ha (36.5 million acres) of highly erodible or environmentally sensitive land were enrolled in CRP (Lindstrom et al., 1994). Lands converted to CRP may influence the water budget and NO_3 accumulation within the soil profile, as soils of long-term grasslands tend to have greater pore continuity and more pores in the size range near field water-holding

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Abbreviations: CRP, Conservation Reserve Program; RSN, residual soil nitrate; ET, evapotranspiration; CC, continuous corn; C, corn; Sb, soybean.

capacity, which can improve water availability for plant growth (Low, 1976).

The effect of perennial cropping systems (e.g., alfalfa and alfalfa-grass mixtures planted on CRP lands) on the loss of NO_3 to subsurface drainage systems has not been compared to annual row-crop systems containing corn and soybean. Our objectives were to determine the effect of cropping systems on (i) aboveground biomass yield and N uptake, (ii) water content and residual NO_3–N in the soil profile (0–3.0 m), and (iii) NO_3–N loss through subsurface tile drainage water.

STUDY METHODS

The study was conducted on a moderately well-drained Normania clay loam (fine-loamy, mixed, mesic Aquic Haplustoll) at the University of Minnesota Southwest Experiment Station at Lamberton, MN from 1988 through 1993. Subsurface tile drainage systems (perforated, plastic 10-cm tubing) were installed in 1972 to 15 individual 13.7 by 15.3-m plots with separate drain outlets. Tile lines were spaced to simulate 28-m spacing and placed 1.2 m deep. Individual plots were isolated to a depth of 1.8 m by trenching and installation of a 12-mil thick plastic sheet. Soil characteristics and a detailed experimental layout were given by Gast et al. (1978).

Corn was planted annually in the entire experimental area starting in 1973. An experiment consisting of various N rates was conducted from 1973 to 1979. Except for 56 kg N/ha annually in 1986 and 1987, N was not applied to corn for the 1980 to 1987 period to reduce the residual effects of the previous treatments. Corn grain was harvested and the plots were moldboard plowed each year.

In the spring of 1988 after secondary tillage, the cropping systems [continuous corn (CC), corn after soybean (C-Sb), soybean after corn (Sb-C), alfalfa, and CRP] were established and replicated three times in a randomized, complete-block design. In the corn-soybean rotation, each crop was present each year in separate plots. Corn and soybean (cv. Hardin at 370 000 seeds/ha)[1] were planted in 76-cm rows perpendicular to the drain tiles. After a single disking on 19 April, the CRP plots were planted to a mixture of alfalfa (6.7 kg/ha), smooth bromegrass (6.7 kg/ha), orchardgrass (2.2 kg/ha), and timothy (2.2 kg/ha) interseeded with a companion crop of oats (36 kg/ha). Alfalfa (cv. Blazer) was seeded at 11.2 kg/ha on 20 April after incorporating Balan at a labeled rate by double disking on 19 April. Annual experimental procedures for all cropping systems are given in Table 1.

Annual N application rates for corn were determined from the NO_3–N content in soil samples taken to a 1.2-m depth in April, previous crop (corn or soybean), and a yield goal of 8800 kg/ha (Rehm and Schmitt, 1989). Urea was broadcast applied for corn each spring and incorporated within 24 h by cultivation. No N was applied to the CRP plots. Fertilizer P and K were not applied to the corn, soybean, or CRP plots because of very high soil tests for the nutrients. Potash was applied annually (1990–1993) to alfalfa after the first cutting at a rate of 112 kg K/ha. Weeds were controlled in the row crops with labeled rates of herbicides and mechanical cultivation. Weeds were not present in the perennial crop systems.

Corn grain yields were taken at physiological maturity by hand-harvesting two 6.1-m long rows, shelling the grain, and determining grain moisture content. Corn stover yields were measured on one 6.1-m long row. Two soybean rows each 12.2-m long were harvested with a plot combine to determine seed yield. Soybean stover yields were taken by collecting all leaves, petioles, and stems within a wire-caged 1-m length of row within each plot. Two samples per plot, each 0.91-m wide by 6.1-m long, were used to determine alfalfa yield. Aboveground biomass of CRP was determined each September by hand-clipping three, 1-m^2 areas within each plot, separating the material into alfalfa and grass, and drying the forage in a forced-air dryer at 60°C. The remainder of the CRP plots were never harvested. Plots where corn was grown were moldboard

[1] The use of the name by the USDA and the Univ. of Minnesota implies no approval of the product to the exclusion of others that may also be suitable.

Table 1. Experimental procedures used in the establishment year (1988) and in the following years for each of the cropping systems.

		Year					
Cropping systems	Procedures	1988	1989	1990	1991	1992	1993
Cont. corn and corn-Sb†	Hybrid	Pioneer 3732	Pioneer 3732	Pioneer 3615	Pioneer 3615	Pioneer 3615	Pioneer 3563
	Planting rate, pl/ha	64 250	64 250	68 450	68 450	71 660	71 660
	Planting date	25 April	25 April	25 April	10 May	4 May	14 May
	Insecticide	Furadan	Furadan	Lorsban	Counter	Furadan	Counter
	Herbicides	Eradicane + Bladex (PPI)	Eradicane + Bladex (PPI	Lasso + Bladex (PPI)	Lasso + Bladex (PPI)	Lasso + Bladex (PPI)	Lasso + Bladex (PPI)
	N appl. date	1 June	7 June	12 June	3 June	5 June	28 June
	Cultivation date(s)	17 May and 2 June	24 May and 7 June	12 June	3 and 18 June	5 and 22 June	15 and 28 June
	Harvest date	4 Oct.	11 Oct.	5 Oct.	30 Sept.	9 Oct.	13 Oct.
Cont. corn	N rate, kg/ha‡	180	145	35	135	175	155
Corn-Sb† only	N rate, kg/ha§	180	145	130	120	135	105
Soybean-C¶	Planting date	9 May	11 May	10 May	22 May	5 May	14 May
	Herbicides	Treflan, Amiben, and Pursuit	Lasso, Amiben, and Pursuit	Lasso, Amiben, and Pursuit	Lasso (PRE)	Lasso (PPI) and Pursuit	Lasso (PPI) and Pursuit
	Cultivation date(s)	2 and 16 June	7 June	12 June	27 June	22 June	15 June
	Harvest date	5 Oct.	29 Sept.	9 Oct.	7 Oct.	13 Oct.	5 Oct.
Alfalfa	Harvest dates	9 Sept.	8 June and 20 July	7 June, 13 July, and 31 Aug.	8 June, 12 July, and 27 Aug.	4 June, 7 July, and 1 Sept.	14 June, 26 July, and 2 Sept.

† Corn following a previous crop of soybean.
‡ Rate based on 0–1.2 m soil samples taken in April from continuous corn plots.
§ Rate based on 0–1.2 m soil samples taken in April from plots where soybean was grown the previous year except in 1988 when corn was the previous crop.
¶ Soybean following a previous crop of corn.

Table 2. Hydrologic year and growing season precipitation at Lamberton, MN, during the study period.

Years	Hydrologic year†	Growing season‡	Month						
			April	May	June	July	Aug.	Sept.	Oct.
	1961–1990 Normal, mm								
	647	530	69	79	88	94	71	76	52
	% of normal								
1987–1988	77	64	96	48	22	23	159	102	1
1988–1989	78	73	84	18	61	109	135	84	0
1989–1990	94	99	49	145	106	75	180	40	97
1990–1991	124	122	160	130	192	37	107	187	19
1991–1992	106	113	92	52	117	129	184	70	167
1992–1993	166	166	94	227	320	141	190	78	50

† October to September.
‡ April to October.

plowed each fall after harvest while those planted to soybean were not fall-tilled but were field cultivated prior to planting corn the next spring.

The experiment was conducted under ambient precipitation. Daily precipitation data were collected at a site 700 m from the experimental plots and were summarized from 1988 through 1993 (Table 2).

Tile flow rates were determined daily except Saturday and Sunday (unless significant precipitation occurred over the weekend) by measuring the amount of water running from each tile line during a 1-min interval and converting to liters per plot per day. Water samples for NO_3–N analysis were collected manually in 250-mL plastic bottles three times a week (Monday, Wednesday, and Friday) when tile flow exceeded 0.25 mm d^{-1} (30 mL min^{-1}). Water samples were stored frozen until subsequent laboratory analysis. Nitrate was analyzed by the colorimetric Cd-reduction method; therefore, concentration data included nitrite-nitrogen (NO_2–N), which was assumed to be extremely small. Total NO_3–N flux through the tile drains was calculated by multiplying NO_3–N concentration for each sample by total calculated flow for the same period. Flow-weighted average NO_3–N concentrations were calculated by dividing total NO_3–N flux for the period of interest by total flow volume.

Nitrogen content of corn and soybean grain, corn and soybean stover, alfalfa, and CRP biomass was determined by grinding subsamples to pass a 1-mm sieve and analyzing for total N (Technicon Industrial Method, no. 325-74W Sept. 1974; Ammoniacal Nitrogen/BD Acid Digests; Technicon Industrial Systems, Tarrytown, NY 10591). After harvest and when the soil temperatures were below 10°C, soil cores (4.1-cm diam.) were collected with a hydraulic probe to a 3.0-m depth in 30-cm increments. The holes were backfilled with soil not kept for analysis, and the surface was closed to prevent inflow. Two cores were taken from each plot and composited into a single sample at each depth. Soil samples for water content were weighed wet, oven-dried at 105°C, and weighed dry. Soil samples for NO_3–N analysis were air-dried, ground to pass a 2-mm sieve, and analyzed for NO_3-N using the colorimetric Cd-reduction method.

Table 3. Residual NO_3–N in the 0 to 1.2-m soil profile in April of each year as influenced by cropping system.

Year	Current year cropping system					LSD (0.05)
	CC	C-Sb	Sb-C	Alf	CRP	
	NO_3–N, kg ha^{-1}					
1988	66	56	55	56	58	NS
1989	74	52	69	13	26	25
1990	177	75	146	47	34	53
1991	115	67	73	ND†	ND	39
1992	86	61	63	ND	ND	NS
1993	91	64	40	ND	ND	43

† ND = not determined.

RESULTS

Annual and Growing Season Precipitation

Hydrologic year (October through September of following year) and growing season precipitation (April through October) varied greatly during the 6-year period (Table 2). Rainfall during the 7-month growing season in 1988 and 1989 was only 64 and 73% of normal, respectively. These abnormally dry conditions limited crop yields, prevented tile drainage, and reduced stored soil water reserves. In 1990, precipitation returned to normal and some tile flow occurred in late May and June when rainfall exceeded normal. Above-normal precipitation in the last 3 yr resulted in good crop yields (except 1993 when the average temperature for the growing season was 3°C below normal), soil-water recharge of the profile, and plentiful tile drainage.

Spring Soil Nitrate

Residual soil NO_3–N in the 0- to 1.2-m soil profile in April varied among years and among cropping systems (Table 3). Samples taken in 1988 contained relatively low amounts of RSN and indicated no remaining evidence of the previous (1973–1979) fertilizer treatments. Highest RSN levels occurred in 1990 after the second consecutive dry year. Application of 145 kg N/ha in 1989 to both continuous corn (CC) and corn after soybean (C-Sb) plots resulted in 177 and 146 kg NO_3–N/ha, respectively, in the 0- to 1.2-m profile in April 1990. Much of the NO_3 was found in the top 0- to 0.6-m layer, indicating an apparent carryover of the unused fertilizer applied in 1989. When soybean was grown in 1989, only one-half as much NO_3–N/ha was found in the soil profile as after fertilized corn. Based on these RSN data, recommended application rates of N for corn in 1990 were 36 kg/ha for CC and 130 kg/ha for C-Sb.

Spring RSN levels were always highest with CC, while RSN following corn in the Sb-C system was highly variable among years, ranging from 44 to 93% of that in CC.The RSN values following soybean showed little year-to-year variability, ranging from 52 to 75 kg NO_3–N/ha. The influence of alfalfa and CRP on reducing RSN was apparent within 12 mo after crop establishment.

Table 4. Crop yields for each cropping system.

Cropping system	Plant part	Year 1988	1989	1990	1991	1992	1993
		dry matter, kg ha^{-1}					
Cont. corn	Grain	2 730	5 880	6 370	7 780	8 280	5 180
	Stover	2 130	4 430	3 580	3 000	6 500	5 280
Corn-Sb	Grain	2 410	5 710	6 520	9 040	7 090	5 590
	Stover	1 800	4 300	4 130	4 080	6 240	5 630
Soybean-C	Grain	1 270	2 690	2 720	2 540	2 120	1 990
	Stover	2 800	ND†	7 460	4 300	2 530	5 630
Alfalfa	Herbage	3 090	3 780	11 610	11 900	11 480	10 270
CRP	Grass	2 230	ND	2 960	3 600	5 250	5 120
	Alfalfa	390	ND	2 490	390	<100	<100

† ND = not determined.

Crop Yields, Nitrogen Uptake, and Nitrogen Removal

Growing season precipitation had a profound influence on the yields of all crops during this 6-yr study. Crop yields were substantially below normal in 1988 when dry and hot weather caused severe stress on the plants (Table 4). Insufficient early season precipitation in 1989 limited corn and alfalfa yields, but soybean yields appeared to be unaffected, presumably because of above-normal July and August rainfall. Yields of all crops were good from 1990 to 1992, when growing season precipitation was normal to above normal. Due to excess rainfall and cool temperatures, corn and soybean yields were below normal in 1993.

Plant species composition within the CRP system apparently was influenced by precipitation, too, although we cannot rule out other factors that may have affected species composition. Five months after establishment in 1988, 85% of the biomass consisted of grasses (Table 4). In September of the following year, after two very dry growing seasons, visual examination showed the CRP plots to be dominated by alfalfa (species composition data were not obtained). Alfalfa, with its deep-rooting system, apparently was able to out-compete the grass species for limited water. By September 1990, after normal growing season rainfall, more grass herbage was present than alfalfa herbage. Grasses (primarily smooth bromegrass) became progressively more dominant while alfalfa almost disappeared during the wet years of 1991 through 1993.

Total N uptake in aboveground biomass was influenced greatly by both cropping system and growing season rainfall, that is, years (Table 5). With the exception of the two dry years during which alfalfa was becoming established, N uptake was highest for alfalfa, intermediate with soybean, and lowest with corn. Nitrogen uptake in the CRP system was very low, especially in years when grasses dominated. During the 6-yr period, annual N uptake in the aboveground biomass averaged 114, 146, 260, and 68 kg N/ha for the CC, C-Sb rotation, alfalfa, and CRP systems, respectively. Total N removal in the 6-yr period ranged from 1560 kg N/ha with alfalfa to 0 for the CRP system.

Fall Soil Nitrate

Residual soil nitrate-N in the 0- to 1.5-m and 1.5- to 3.0-m profile in late October also was influenced greatly by cropping system and precipitation. Generally, RSN in both profile layers was highest after two dry years, intermediate after the year of normal precipitation (1990), and lowest following the three wet years (Table 6). During the 6-yr period, highest RSN levels in both depth increments consistently occurred with CC. Using the CC system as a base, RSN amounts in the 0- to 1.5-m profile were reduced by 17, 64, and 65% with the C-Sb rotation, alfalfa, and CRP systems, respectively. Cropping system also affected RSN amounts in the 1.5- to 3.0-m depth, with reductions ranging from 22% in the C-Sb rotation to 47% with alfalfa and CRP compared to CC.

Distribution of RSN throughout the 0- to 3.0-m profile for each of the years is shown in Fig. 1. In October 1989, after two successive dry years, RSN amounts throughout the 3.0-m profile were substantially lower for those cropping systems dominated by alfalfa compared to the corn and soybean systems. In the top 1.5-m profile and especially in the top 0.3 m, RSN levels were higher for cropping systems that received fertilizer N. Ranking from highest to lowest RSN in the top 1.5 m generally was: CC = C-Sb > Sb-C > alfalfa = CRP. Following a wet year, RSN amounts in 1991 were much lower than in 1989, but still exhibited the same general ranking among cropping systems. The same pattern continued throughout the 3.0-m profile in 1993 following a very wet growing season.

Soil Water

Cropping systems had large impacts on the soil water content, especially in the dry years. Plant available water (defined as water between -0.3 bar and -15 bars) in the top 1.5-m profile at the end of the growing season was

Table 5. Total N in the aboveground plant biomass for each cropping system.

Cropping system	Year 1988	1989	1990	1991	1992	1993
	N, kg ha^{-1}					
Cont. corn	66	113	106	136	157	108
Corn-Sb	54	102	119	151	122	106
Soybean-C	105	161†	228	227	187	187
Alfalfa	88	100	375	380	344	272
CRP	31	ND‡	130	91	52	36

† Only in the grain.
‡ ND = not determined.

Table 6. Residual NO_3–N in the soil profile in October as influenced by cropping system.

Cropping system	Profile	1988	1989	1990	1991	1992	1993
	m	NO_3–N, kg ha^{-1}					
Cont. corn	0–1.5	46 (10)†	252 (37)	180 (25)	94 (16)	107 (33)	70 (26)
	1.5–3.0	47 (10)	246 (40)	175 (36)	91 (29)	134 (66)	98 (26)
Corn-Sb	0–1.5	44 (5)	264 (40)	169 (16)	96 (45)	66 (9)	48 (6)
	1.5–3.0	82 (25)	233 (18)	160 (7)	45 (8)	72 (8)	57 (7)
Soybean-C	0–1.5	57 (5)	187 (14)	156 (19)	63 (7)	49 (16)	59 (9)
	1.5–3.0	29 (6)	250 (19)	131 (11)	75 (5)	36 (9)	73 (7)
Alfalfa	0–1.5	11 (2)	95 (6)	101 (9)	18 (4)	18 (10)	28 (5)
	1.5–3.0	41 (4)	149 (22)	147 (–)‡	36 (7)	22 (7)	23 (5)
CRP	0–1.5	12 (3)	93 (9)	106 (12)	15 (4)	11 (5)	24 (10)
	1.5–3.0	61 (28)	192 (53)	154 (19)	50 (16)	20 (7)	23 (7)

† (SE) = Standard error of the mean.
‡ Only one core taken.

reduced significantly by the perennial cropping systems compared to the row crops in 1988 to 1991 (Table 7). Although differences in water content were not as great, there was still an indication of greater water use by the perennial crops compared to corn and soybean after the second consecutive wet year (1992). Available soil water was not different among the cropping systems after the third consecutive wet year.

The depth to which each cropping system affected soil water is shown in Fig. 2. In 1989, soil water content was reduced to the 2.4-m depth by both alfalfa and CRP, which was dominated by alfalfa in that year. At the end of a year with normal precipitation (1990), alfalfa showed depletion of soil water reserves to the 3.0-m depth while reserves under CRP were affected to the 2.4-m depth. In 1991, a wet year, alfalfa and CRP reduced the soil water content to depths of 2.1 and 1.5 m, respectively. Soil water differences among cropping systems were much less apparent in 1992, another wet year; however, both perennial systems showed some additional water usage within the top 1.0 m.

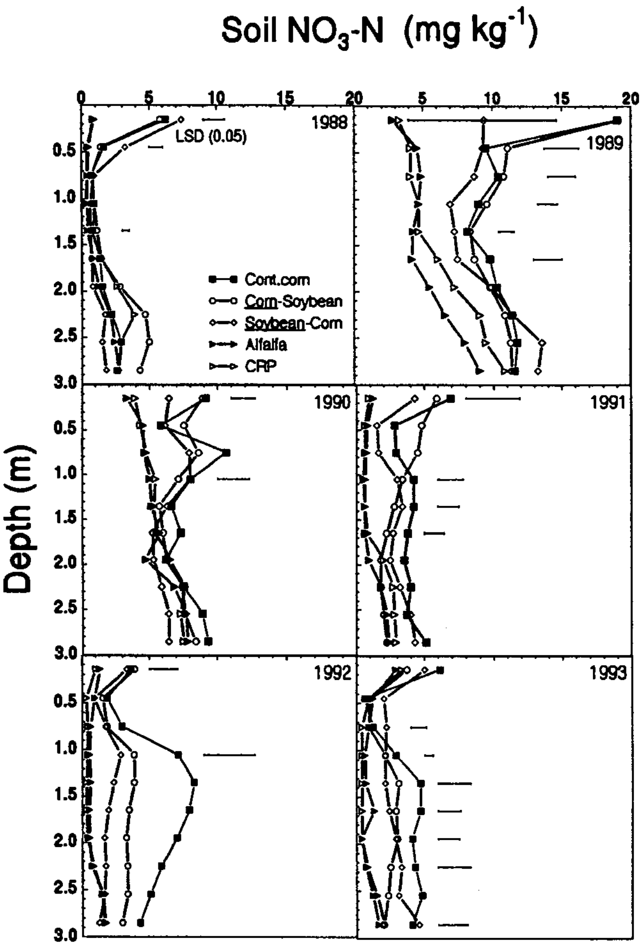

Fig. 1. Residual soil nitrate distribution in October in the 0 to 3.0-m profile in all years as influenced by cropping system.

Tile Flow

Annual tile water discharge was influenced greatly by both annual precipitation and cropping system (Table 8). No flow occurred in the dry years of 1988 and 1989. In 1990, a year of normal precipitation, tile lines in the row-crop systems flowed intermittently during a 26-d period from late May through June. No drainage occurred in the perennial-crop plots. In 1991, tile discharge was 5.3X higher with the row crop systems than the perennial crops. Drainage occurred during a 102-d period (late March–early July) from the row crops and at much lower rates in a 95-d period (late March–late June) for the CRP plots and a 77-d period (mid-April–late June) for alfalfa. In 1992, some tile water discharge occurred each month from early March through October (except September) with the row crops, whereas flow occurred only from early March through early May in the perennial systems. As a result, annual total flow was 2X higher with the row crops compared to the perennial crops. In 1993, when precipitation was >60% above normal, tile flow was abundant from all cropping systems during mid-March through mid-August. Discharge volume was similar for the row crop and CRP

Table 7. Plant available water content of the 0 to 1.5 m soil profile in late October as influenced by cropping system.

Cropping system	1988	1989	1990	1991	1992	1993
	cm					
Cont. corn	10.4	5.3	19.4	11.0	14.2	20.5
Corn-Sb	11.5	5.4	17.6	11.3	14.4	18.0
Soybean-C	10.2	7.3	16.9	10.2	15.5	18.8
Alfalfa	−0.5	−7.1	2.3	2.8	12.8	17.2
CRP	6.0	−4.7	3.0	5.7	11.9	19.0

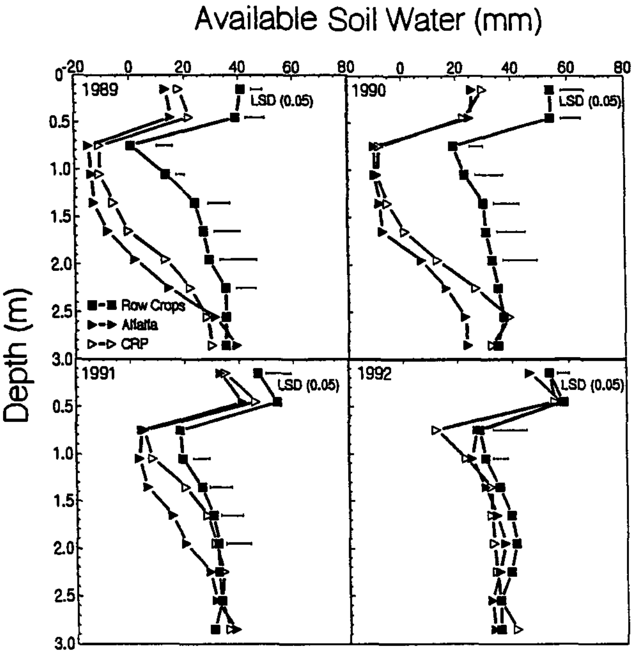

Fig. 2. Plant available water in October within the 0 to 3.0-m profile as influenced by cropping system in four successive years.

systems but one-third less under alfalfa. During the 6-yr period, total tile flow was 1.6X higher with row crop systems compared to perennial crop systems.

The relationship between rainfall and tile flow from the cropping systems for 1991 and 1993 is shown in Fig. 3. In 1991, tile flow closely paralleled rainfall for the row crops. The increase in tile flow from alfalfa in June was likely due to lower ET losses in the 2-wk period following harvest on 8 June. In 1993, drainage volume from both the row and perennial crops closely paralleled monthly rainfall until July when ET from all cropping systems exceeded drainage.

Nitrate-Nitrogen Concentrations in Tile Water

Highest flow-weighted annual NO_3–N concentrations were found consistently in water draining from the CC system (Table 9). This was consistent with the RSN values found in the 0 to 1.2-m profile in April (Table 3). Rotating soybean with corn reduced the NO_3–N concentrations slightly; however, when soybean was grown, NO_3–N concentrations were close to that from CC in 2 of 4 yr. Substantially lower NO_3–N concentrations were found in drainage from the alfalfa and CRP systems. Average NO_3–N concentrations in the drainage water during the flow period of this study were CC = 32, C-Sb = 23, Sb-C = 26, alfalfa = 3, and CRP = 2 mg/L. Drainage from the row crop systems in the first 3 yr following the two very dry years contained NO_3–N at levels of 2 to 4X the MCL of 10 mg NO_3–N/L even though annual fertilizer N rates were based upon a spring preplant soil NO_3 test on a 1.2-m sample. During the third consecutive year of significant drainage, NO_3–N concentrations from the row crop plots showed about a 50% reduction compared to previous years. This likely was due to purging of NO_3 from the soil profile during this wet period and perhaps to denitrification in 1993.

Temporal variation in NO_3–N concentration during the flow period generally was minimal (Fig. 4). In 1993, low NO_3–N concentrations under row crops in March were associated with very low flow rates (1–8 mm for the month). Also, NO_3–N concentration declined from 27 mg/L in April to 18 in July with CC. This decline

Table 8. Annual tile water flow as influenced by cropping system.

Cropping system	1988	1989	1990	1991	1992	1993	Total
	mm						
Cont. corn	0	0	20	178	131	441	770
Corn-Sb	0	0	19	274	123	489	905
Soybean-C	0	0	27	218	176	478	899
Alfalfa	0	0	0	40	55	321	416
CRP	0	0	0	44	86	510	640

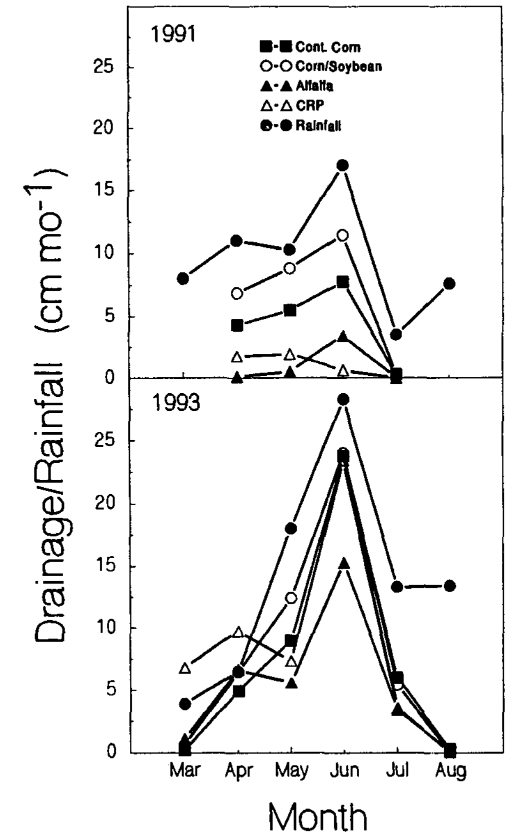

Fig. 3. Monthly tile flow as influenced by cropping system and rainfall in 1991 and 1993.

Table 9. Flow-weighted annual NO_3–N concentrations in the tile water as influenced by cropping system.

Cropping system	1990	1991	1992	1993
	NO_3–N, mg L^{-1}			
Cont. corn	30	39	40	20
Corn-Sb	22	29	26	14
Soybean-C	26	37	27	13
Alfalfa	†	4.1	3.8	1.3
CRP	†	3.9	1.3	0.3

† No tile flow.

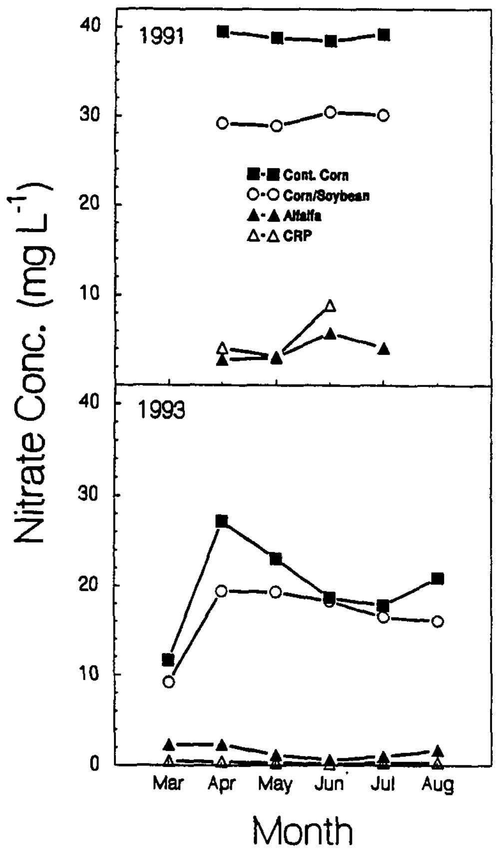

Fig. 4. Monthly flow-weighted nitrate-N concentration as affected by cropping system in a year of normal flow (1991) and excessive flow (1993).

likely was due to the excessive rainfall that purged RSN from the soil system. Fertilizer N applied on 28 June may have been the cause for the slight upturn in NO_3–N in August.

Nitrate–Nitrogen Loss in Tile Drainage

Nitrate–N loss (flux), the product of water flow multiplied by NO_3–N concentration, was substantially higher for the row-crop systems compared to the perennial crops (Fig. 5). Nitrate–N lost during the 4-yr period totaled 218 kg/ha for CC, 203 kg/ha for the C-Sb/Sb-C rotations, 7.2 kg/ha for alfalfa, and 4.5 kg/ha for CRP.

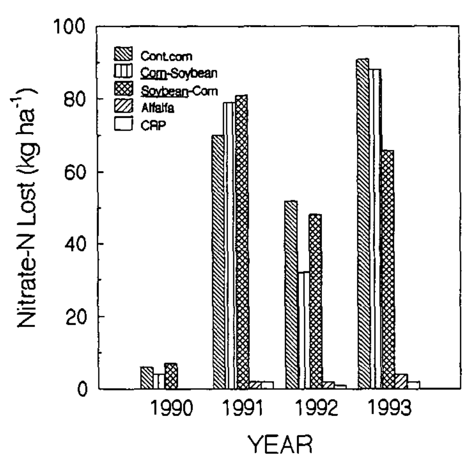

Fig. 5. Annual nitrate-N loss via tile drainage as influenced by cropping systems.

Compared to the CC system over the 4-yr period, NO_3 flux was reduced by 7% with the C-Sb/Sb-C rotation, 97% with alfalfa, and 98% with CRP.

DISCUSSION

This investigation, conducted during a 6-yr period when growing season precipitation ranged from 36% below normal to 66% above normal, provided a splendid opportunity to study the dynamics of four cropping systems on water use, N transformations and cycling, crop production, and the subsequent impacts on nitrate losses through subsurface drainage. The 2-yr dry period followed by a year of normal precipitation and then three wet years gave insight on the behavior of these crop and soil systems in various climate-driven scenarios and the resultant effect on NO_3 loss to water resources.

Dry conditions in the first 2 yr of the experiment did not impact establishment of the four crops. However, the soil water status and soil N mineralization were affected differently for each of the cropping systems. During the dry years, RSN accumulated throughout the profile in all cropping systems because of soil mineralization, yields were lower resulting in less crop uptake of fertilizer N, and NO_3 was not lost through leaching or denitrification. The perennial crops, however, reduced levels of RSN to a depth of 2.7 m compared to the row crops. The extended growing season of the perennial crops (usually mid-April to early October) provided a greater opportunity for season-long water use compared to little ET loss in the row crops before mid-June or after mid-September. Also, the rooting depth of alfalfa is greater than corn or soybean. This greater water demand not only reduced the soil water reserves to a depth as great as 3 m with alfalfa and 2.4 m with the CRP system, but also increased NO_3 uptake and assimilation by the perennial crops. On the other hand, RSN accumulations were higher in the row-crop systems, especially in the surface 0.3 m following fertilizer N application to corn. This accumulation of RSN in the soil profile above the tile lines, plus more stored soil water, provided a higher potential for more tile drainage and higher NO_3–N concentrations to occur in the drainage water from the row crops upon the return of normal to above-normal rainfall.

When growing season rainfall was 13 to 22% above normal, tile water drainage occurred in all cropping systems. Drainage volume from the alfalfa and CRP systems, however, was 50 to 80% lower than from the row crop systems. Much of the drainage occurred early in the season (March through mid-June) because of low ET demand during this period. Tile flow in the perennial crop systems did not occur after June. Moreover, soil water reserves in the top 1.5 m at the end of the season were slightly less than for the row crops. In the row crop systems, RSN levels in the profile were relatively high at the beginning of the wet period. As a result, drainage water contained from 26 to 40 mg NO_3–N/L. These high NO_3–N concentrations, coupled with the high drainage volumes, resulted in NO_3–N losses being about 45X higher in the row-crop systems compared to the perennial crops.

In the third consecutive wet year when rainfall exceeded normal by 66%, drainage occurred from all cropping systems, with least volume from alfalfa. The RSN levels in the soil profile were relatively low at the beginning of the season. As a result NO_3–N concentrations in the water were much lower, but were still above 10 mg/L in the row-crop systems. Nitrate loss via the drainage water was high primarily due to the high drainage volume.

A noticeable shift in species dominance within the CRP system appeared to be related to precipitation. Alfalfa dominated in the first 2 yr when conditions were dry, whereas grass dominated in the last three wet years. The deeply rooted alfalfa removed more soil water and N from deeper in the soil profile and accumulated more N in the aboveground biomass. As the grasses, primarily bromegrass, began to dominate, soil water and RSN remained at lower levels in the profile compared to the row crops. Apparently, much of the NO_3 formed through mineralization was immobilized by the fibrous rooting system of the grasses. Drainage volumes and NO_3–N concentrations in the water from the grass-dominated CRP plots were low. These results suggest that NO_3 losses to surface and groundwater resources were also very low before American settlers converted native grassland prairies to agricultural land.

Tilling the land for crop production leads to greater mineralization of soil organic matter. Coupled with N applications (both inorganic and organic), improved subsurface drainage through tile lines, and less efficient use of water by shallower rooted, shorter growing season crops, we can expect modern farming practices for corn and soybean production to contribute to higher losses of NO_3 to both surface and groundwater. In this study we used the best practices available to optimize crop production and profitability (fertilizer N based on a soil NO_3 test, high plant populations, good weed control, optimum tillage, etc.), yet NO_3–N concentrations in the drainage water from row crops exceeded 10 mg/L on this highly productive, high organic matter soil.

In summary, policy makers must keep in mind the influence of climate, soil, and cropping system when designing environmental policy. A crop production system on highly productive soils where biological influences can be significant will have difficulty attaining consistently a goal of <10 mg NO_3–N/L in subsurface drainage water, even though prudent N fertilization is followed. Adding perennial species to crop rotations will help reduce NO_3 losses in tile drainage and will reduce the water delivery ratio to surface water, thereby helping reduce flooding potential in these areas.

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