ALTERNATIVE N FERTILIZER MANAGEMENT STRATEGIES EFFECTS ON SUBSURFACE DRAIN EFFLUENT AND N UPTAKE

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ABSTRACT. *Demonstrating positive environmental benefits of alternative N fertilizer management strategies, without adversely affecting crop growth or yield, was a major goal for the Midwest Management Systems Evaluation Areas (MSEA) program. Our project objectives within this program were to quantify the effects of split- and single-N fertilization strategies on NO_3-N concentration and loss in subsurface drain effluent and N accumulation and yield of corn (*Zea mays *L.) and soybean [*Glycine max *(L.) Merr.]. The study was conducted on glacial till derived soils in northeast Iowa from 1993 through 1995 using no-till and chisel plow tillage treatments. One-third of the 2,611 effluent samples had NO_3-N concentrations greater than 10 mg L^{-1}. Split applying fertilizer N based on pre-sidedress soil nitrate test (PSNT) results significantly increased corn yield for both tillage treatments in the extremely wet 1993 without increasing NO_3-N loss in drain effluent. Increased grain yield also resulted in significantly more N removal. When fertilizer N was applied based on the PSNT, no-till and chisel treatments had similar NO_3-N losses and concentrations. Average flow-weighted NO_3-N concentrations in drain effluent were not increased when larger amounts of fertilizer were applied based on PSNT. However, prior crop and tillage practices and differences in drain flow volume caused significant differences in NO_3-N losses and concentrations. These results suggest that spatial differences in flow volume are a major factor determining NO_3-N loss in drainage effluent. Significant differences suggest that combining no-tillage practices with split N fertilizer management strategies can have positive environmental benefits without reducing corn yield.*
Keywords. *Subsurface drainage, Pre-sidedress soil nitrate test, No-tillage, Water quality.*

A major goal for the Midwest Management Systems Evaluation Area (MSEA) project was to demonstrate the positive environmental benefits of alternative N fertilizer management strategies. This was important because many studies have shown NO_3-N concentrations exceeding 10 mg L^{-1} in subsurface drain effluent from cropland (Baker et al., 1975; Drury et al., 1993; Kanwar et al., 1997; Kladivko et al., 1991; Milburn et al., 1990). Many have also shown that the mass of NO_3-N lost in drain effluent tends to increase as corn fertilization rates increase (Angle et al., 1993; Baker and Johnson, 1981; Bergstrom and Brink, 1986). For example, Logan et al. (1980) reported that losses often exceeded 30 kg ha^{-1} yr^{-1} when N fertilizer was applied in excess of crop needs, while Bergstrom and Brink (1986) and Gast et al. (1978) measured annual NO_3-N losses of 91 kg ha^{-1} and 120 kg ha^{-1} from 200 kg N ha^{-1} and 448 kg N ha^{-1} application rates, respectively. With lower application rates (< 100 kg N ha^{-1}), Milburn and Richards (1994) measured NO_3-N losses of 10 to 30 kg ha^{-1} and annual flow-weighted NO_3-N concentrations of 2 to 5 mg L^{-1}.

Although NO_3-N loss in drain effluent tends to increase with N fertilization rate, mineralized N accounts for a large percentage of the N leached from soil or used by crops. Chichester and Smith (1978) found that applied N accounted for only 25% of NO_3-N leached from lysimeters. Furthermore, less than 50% of fertilizer N is typically recovered and removed by corn grain (Timmons and Cruse, 1990; Reddy and Reddy, 1993).

The mass of NO_3-N lost through subsurface drains depends primarily on the volume of water drained (Bolton et al., 1970; Devitt et al., 1976). Except for implementing controlled drainage, little can be done to alter drainage volume. A more cost effective method of reducing NO_3-N loss may be to split N fertilizer applications so that N availability and crop uptake are better synchronized.

Split fertilizer applications can reduce NO_3-N loss through subsurface drains (Kanwar et al., 1988), lower residual soil NO_3-N (Varshney et al., 1993) and increase nitrogen use efficiency by corn (Fox et al., 1986). Gerwing et al. (1979) demonstrated that four smaller fertilizer applications throughout the growing season on a sandy soil resulted in lower NO_3-N concentrations in soil solution and a shallow aquifer than a single spring application. Similarly, splitting N fertilizer applications with a point injector was shown to increase fertilizer N use

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efficiency by no-till corn compared to single knifed-in or surface-banded applications (Timmons and Baker, 1992).

This study was conducted to evaluate the effects of single and split nitrogen fertilizer applications on the concentration and amount of NO_3-N lost through subsurface drainage from no-till and chisel plow tillage practices within a corn-soybean rotation. The single and split fertilizer management strategies were evaluated by comparing flow-weighted NO_3-N concentrations, seasonal drain flow, NO_3-N loss, plant accumulation, and N removal with the harvested portion of each crop. For this study, NO_3-N loss refers only to the mass of NO_3-N lost through subsurface drains. Volatilization, immobilization, denitrification, and deep leaching were not quantified.

Materials and Methods

The study was conducted at Iowa State University's Northeast Research Farm near Nashua, Iowa. Soils at the site are Floyd loam (fine-loamy, mixed, mesic *Aquic Hapludolls*), Kenyon loam (fine-loamy, mixed, mesic *Typic Hapludolls*) and Readlyn loam (fine-loamy, mixed, mesic *Aquic Hapludolls*) (Karlen et al., 1991). These soils are moderately well to poorly drained and lie over loamy glacial till.

From 1978 to 1992, four tillage treatments (chisel plow, moldboard plow, ridge till, and no-till) and two crop sequences (continuous corn and corn-soybean rotation) were arranged in a split-block design. Effects of those practices on drain effluent were recently summarized by Kanwar et al. (1997) who concluded that continuous corn production was not sustainable and that alternative farming practices need to be evaluated to determine if they can be used to reduce drainage losses of agricultural chemicals. Therefore, farming practices were changed in 1993 to study differences between nitrogen management practices. However, because of the long-term management history, the experimental plots were not randomly assigned new treatments. The practices imposed were assigned based on previous treatments to reduce the transition time that might be required, especially with no-till (table 1). All three replications of prior treatments were converted to the same new treatment. This provided randomization and replication in three blocks, but since the treatments had different management histories, statistical comparisons for this study were based on simple t-tests (SAS, 1985). Parameters tested were: drain flow, NO_3-N loss, NO_3-N concentration, soil NO_3-N, crop yield, N uptake, and N removal. Four comparisons were made for each parameter to test significant differences ($p < 0.10$) between tillage systems for each nitrogen treatment and between nitrogen treatments for each tillage system. Probability values are included in the text for the reader's information.

Table 1. Current and previous management practices evaluated on till-derived soils in northeast Iowa

Tillage	1993 Crop	Nitrogen Treatment*	Previous Tillage	1992 Crop
No-tillage	Soybean	None	No-tillage	Corn
No-tillage	Corn	30 kg N ha^{-1} pre-plt + PSNT-based rate	No-tillage	Soybean
No-tillage	Soybean	None	Moldboard plow	Corn
No-tillage	Corn	110 kg N ha^{-1} pre-plt	No-tillage	Corn†
Chisel plow	Soybean	None	Ridge-tillage	Corn
Chisel plow	Corn	30 kg N ha^{-1} pre-plt + PSNT-based rate	Moldboard plow	Soybean
Chisel plow	Soybean	None	Chisel plow	Soybean
Chisel plow	Corn	110 kg N ha^{-1} pre-plt	Ridge-tillage	Corn†

* pre-plt refers to a pre-plant application of N fertilizer; PSNT-rate refers to the amount of N fertilizer recommended by the pre-sidedress soil nitrate test (Blackmer et al., 1989).

† These plots were in continuous corn since 1978, the other corn plots were rotated annually with soybean.

Table 2. Average nitrogen fertilizer rates applied for 1993 through 1995

Management System	Amount of N Fertilizer Applied ($kg\ ha^{-1}$) 1993	1994	1995
No-tillage with PSNT-based N*	144	169	193
No-tillage with pre-plant N	110	110	110
Chisel plow with PSNT-based N*	93	160	160
Chisel plow with pre-plant N	110	110	110

* Fertilizer rates listed for PSNT treatment include the 30 kg N ha^{-1} applied with the planter.

The new treatments consisted of a corn-soybean rotation with no-till and chisel plow tillage practices. Corn stover was chisel plowed in the fall. These plots were field cultivated after spring fertilizer applications and before planting corn or soybean. No-till plots were not tilled before planting, but all corn plots were cultivated once during the summer for weed control. Both chisel plow and no-till soybean treatments were planted with a no-till drill, so those plots were not cultivated during the summer.

Single spring and spring-summer split fertilizer applications were made on the corn phase of each tillage system. Liquid urea-ammonium nitrate (UAN) for the single application treatment was applied at 110 kg N ha^{-1} before planting with a spoke injector, which injects liquid fertilizer at approximately 20-cm intervals, 25 cm from corn rows (Baker et al., 1989). Urea was applied with the corn planter at 30 kg N ha^{-1} for split application treatment. The amount of sidedress nitrogen applied on the split application treatment was determined by using the pre-sidedress soil nitrate test (PSNT) as developed for Iowa by Blackmer et al. (1989). Three, 30-cm soil samples were taken from each plot when corn was between 15 and 30 cm tall. UAN was applied with a spoke injector to increase soil NO_3-N in the top 30 cm to 25 mg kg^{-1}. The amount of nitrogen added ranged from 50 to 170 kg N ha^{-1} (table 2).

Drainage Effluent Collection and Analysis

In 1979, subsurface drains were installed at 29-m spacings, approximately 1.2 m deep. Each 58 × 67-m plot has a drain along the center and along the north-south borders. A 9-m grass strip isolated the plots on the east and west sides. Center drains were routed to sumps for monitoring while border drains isolated plots on the north and south sides. Each sump contained a sump pump with flow meter (Bjorneberg et al., 1996a). Flow meters were read manually three times per week during 1993 and until mid-June 1994. Meters were read twice per week beginning mid-June 1994 and during 1995 (typically Monday and Friday). Data collection took place from approximately mid-March to the beginning of December.

Water samples for NO_3-N analysis were collected from the sumps when flow meters were read during 1993 and the beginning of 1994. Sampling frequency was decreased in mid-June 1994 to reduce analytical expenses. For the remainder of 1994 and all of 1995, a small percentage of water discharged by the sump pump (approximately 0.02%) was collected for NO_3-N analysis through an orifice tube on the sump discharge line (Bjorneberg et al., 1996a). Sample bottles were removed every Friday during the monitoring year. From corn planting in mid-May until 31 July, samples were analyzed spectrophotometrically each week using a Lachat Model AE ion analyzer (Lachat Instruments, Milwaukee, Wis.). Weekly samples were composited to monthly samples before corn was planted (i.e., March, and April) and after July 31 (i.e., August, September, October, and November).

Nitrate-N loss (kg ha^{-1}) through subsurface drains was calculated for each interval between water sample collection. Annual total drain flow and NO_3-N loss were used to calculate the annual flow-weighted NO_3-N concentration for each experimental plot. Average NO_3-N concentrations for a treatment were the mean of the flow-weighted concentrations for the three plots within a treatment.

Soil Sampling and Analysis

Three, 120-cm soil cores were collected with a hand sampler from each experimental plot before fertilizer application (early May) in the spring and after harvest in the fall (later October). A 2.5-cm diameter plastic liner was used inside the soil sampler to protect the soil from contamination. Soil compaction in each core was measured at 30-cm increments by comparing the depth to soil surface with the depth to soil in the sampler. Soil cores were promptly frozen after collection. Prior to analysis, the three cores from a plot were cut, compensating for soil compaction, into sections representing 0 to 10, 10 to 20, 20 to 30, 30 to 60, 60 to 90, and 90 to 120-cm depth increments. Nitrate-N was extracted from soil with potassium chloride and analyzed spectrophotometrically using a Lachat Model AE ion analyzer (Lachat Instruments, Milwaukee, Wis.). Results from each depth increment were combined to give the mass of nitrate-N in the 120-cm soil profile.

Plant Sampling and Analysis

Each year, six corn plants were chosen randomly from each 0.4-ha plot at physiologic maturity or growth stage R6 (Ritchie et al., 1996) to determine total N accumulation. In 1994 and 1995, six to ten plants were also collected in June, July, and August to determine how the various treatments were affecting N status throughout the growing season. For soybean, 3 to 4 m of row were collected at growth stage R10 (Hanway and Thompson, 1971) each year. All plant samples were dried at 65°C, weighed, chopped, ground to pass a 0.5-mm stainless steel screen, and analyzed for total N using a Carlo-Erba Model NCS 1500 (Haake Buchler Instruments, Patterson, N.J.) dry combustion analyzer. Total aerial biomass and N accumulation by corn were computed based upon measured plant populations, which averaged 6.5 plants m^{-2} each year. Accumulation by soybean was computed per unit area based on a row spacing of 0.25 m. Grain yields for each plot were measured using a modified commercial combine. All stover was left in the field. To calculate N removal, grain samples were ground and analyzed for N concentration using the Carlo-Erba analyzer.

Results and Discussion

Rainfall during the 1993 growing season was above normal throughout the Midwest, and as a result the drains flowed almost continuously. Precipitation at the site exceeded 1000 mm which was approximately 250 mm above the long-term average. Rainfall was closer to normal during 1994 (670 mm) and 1995 (800 mm), causing drains to flow sporadically during both monitoring seasons. The crops were damaged by hail in July 1995, with an unofficial yield loss estimate of 30%.

Drainage Volume and Nitrate Concentrations

Excessive rainfall in 1993 resulted in two to five times more drainage than during 1994 or 1995 (table 3). Nitrate-N loss through subsurface drains was also greatest in 1993. However, NO_3-N concentration in drain effluent tended to be greatest in 1995. The percentage of drain effluent samples exceeding 10 mg L^{-1}, the U.S. Environmental Protection Agency drinking water standard, was greater during 1995 (47%) than 1993 (31%) or 1994 (28%). Over the three-year study, 33% of the 2,611 effluent samples exceeded 10 mg L^{-1}.

The annual average flow-weighted NO_3-N concentration for the chisel-plow, pre-plant soybean treatment was almost double the average concentration for other soybean treatments in 1993 (table 3). The average concentration for chisel-plow, pre-plant soybean was significantly greater than no-till, pre-plant ($p = 0.01$) and chisel-plow, PSNT ($p = 0.01$). The high annual concentration was not a result of fertilizer application method because soybean plots were not fertilized. It was also not likely a result of tillage because NO_3-N concentrations from no-till, PSNT and chisel-plow, PSNT were not significantly different (table 3). The high average concentration for chisel-plow, pre-plant soybean was probably a carry-over effect from growing soybean in both 1992 and 1993 (table 1).

No-till, pre-plant corn had greater annual drain flow than no-till, PSNT ($p = 0.02$) and chisel-plow, pre-plant ($p = 0.04$) in 1993. This treatment also had greater annual NO_3-N loss than no-till, PSNT ($p = 0.03$) and chisel-plow, pre-plant ($p = 0.06$) in 1993 (table 3). Part of the reason for

Table 3. Tillage practice and fertilizer management effects on annual flow volume, NO_3-N loss, and flow-weighted NO_3-N concentration from subsurface drains on till-derived soils in northeast Iowa

Management System	Corn Flow (mm)	Corn N-loss (kg ha^{-1})	Corn Nitrate Conc. (mg L^{-1})	Soybean Flow (mm)	Soybean N-loss (kg ha^{-1})	Soybean Nitrate Conc. (mg L^{-1})
			1993			
No-tillage, PSNT-based N	265a	25.3a	9.4	391	23.0	5.9a
No-tillage, pre-plant N	492bX	45.7bX	9.3	573X	37.1	6.5bX
Chisel plow, PSNT-based N	258	32.4	11.4	501	30.4	6.3A
Chisel plow, pre-plant N	352Y	32.8Y	9.3	282Y	32.3	11.5BY
			1994			
No-tillage, PSNT-based N	62	6.0	9.5	61	3.9	6.2
No-tillage, pre-plant N	165X	14.6X	9.2	109	7.6	6.7X
Chisel plow, PSNT-based N	123	9.0A	9.8	68	6.6	8.8
Chisel plow, pre-plant N	29Y	3.3BY	11.2	56	5.4	9.6Y
			1995			
No-tillage, PSNT-based N	94a	10.3a	10.9a	109	9.2	8.5
No-tillage, pre-plant N	201bX	25.2bX	12.6bX	250	23.2	9.1
Chisel plow, PSNT-based N	82	11.7	13.4	203	18.3	10.4
Chisel plow, pre-plant N	67Y	10.5Y	15.5Y	95	10.2	10.9

Significant differences ($P < 0.10$) between fertilizer treatments are denoted by "a, b" for no-tillage and "A, B" for chisel plow and between tillage treatments are denoted by "x, y" for PSNT and "X, Y" for pre-plant.

Table 4. Tillage practice and fertilizer management effects on three-year total flow volume, NO_3-N loss, and flow-weighted NO_3-N concentration from subsurface drains on till-derived soils in northeast Iowa

Management System	Corn–Soybean–Corn Rotation Flow (mm)	N-loss ($kg\ ha^{-1}$)	Nitrate Conc. ($mg\ L^{-1}$)	Soybean–Corn–Soybean Rotation Flow (mm)	N-loss ($kg\ ha^{-1}$)	Nitrate Conc. ($mg\ L^{-1}$)
No-tillage, PSNT-based N	421a	39.6a	9.3	563	38.1	6.8
No-tillage, pre-plant N	803bX	78.5bX	9.8	987X	74.9	7.6X
Chisel plow, PSNT-based N	408	50.6	11.3	828	57.8	7.4A
Chisel plow, pre-plant N	476Y	48.6Y	10.2	406Y	45.8	11.3BY

Significant differences ($P < 0.10$) between fertilizer treatments are denoted by "a, b" for no-tillage and "A, B" for chisel plow and between tillage treatments are denoted by "x, y" for PSNT and "X, Y" for pre-plant.

greater drain flow and NO_3-N loss may be that the no-till, pre-plant plots had been no-till continuous corn from 1978 to 1992 (table 1). No-till continuous corn had greater drain flow (Bjorneberg et al., 1996b) and lower yield (Karlen et al., 1991) than plowed continuous corn treatments at this site.

Annual average NO_3-N concentrations in drain effluent from corn plots were not significantly greater for PSNT treatments (table 3) even though 30 to 70% more nitrogen was applied (table 2). In fact, the no-till, pre-plant treatment had greater average concentration than the no-till, PSNT ($p = 0.05$) treatment in 1995 and greater NO_3-N loss than the no-till, PSNT treatment in 1993 ($p = 0.03$) and 1995 ($p = 0.06$). However, applying more nitrogen based on PSNT resulted in greater NO_3-N loss for chisel plow corn in 1994 ($p = 0.10$).

No-till, pre-plant corn had significantly greater drain flow ($p = 0.04$, 0.09, and 0.05) and NO_3-N loss ($p = 0.06$, 0.08, and 0.06) than chisel plow, pre-plant corn all three years (table 3). This difference could be attributed to tillage except there was not a difference in flow or loss between no-till and chisel plow corn under the PSNT treatment.

Three-year totals for the study show that the corn-soybean-corn no-till, pre-plant treatment had higher total drain flow ($p = 0.05$) and NO_3-N loss ($p = 0.04$) than the no-till, PSNT treatment (table 4). Site variability and the previous no-till continuous corn treatment may have played a large part in the higher drain flow since splitting fertilizer application should not decrease drain flow. The three-year NO_3-N losses and concentrations from PSNT treatments were similar or less than those from single application treatments even though more nitrogen was applied to the PSNT treatments.

Soil N Changes

When significant differences occurred between tillage treatments, no-till always had less NO_3-N in the upper 1.2 m of soil than chisel plow (table 5). Applying more nitrogen based on the PSNT did not increase the amount of NO_3-N in the soil on no-till treatment (table 5). Chisel plow corn fertilized according to PSNT had greater soil NO_3-N than the single application treatment on two occasions: before planting in 1993 ($p = 0.06$), which was before any fertilizer was applied, and after harvest in 1994 ($p = 0.02$). A carry-over effect of continuous corn may partially explain the difference in soil NO_3-N before planting in 1993. However, a similar difference should have occurred between no-till treatments, since the no-till pre-plant treatment was no-till continuous corn before 1993 (table 1). The difference in soil N occurring between chisel plow treatments after harvest in 1994 is worth noting because the pre-plant treatment had significantly less NO_3-N loss in drain flow and less soil NO_3-N after harvest.

Table 5. Tillage and fertilizer management effects on soil nitrate-N in the upper 1.2 m of till-derived soils in northeast Iowa

Management System	Corn Before Planting ($kg\ ha^{-1}$)	Corn After Harvest ($kg\ ha^{-1}$)	Corn Change ($kg\ ha^{-1}$)	Soybean Before Planting ($kg\ ha^{-1}$)	Soybean After Harvest ($kg\ ha^{-1}$)	Soybean Change ($kg\ ha^{-1}$)
1993						
No-tillage, PSNT-based N	65	44	−21	58	47	−10
No-tillage, pre-plant N	55	28	−27	58	40	−18
Chisel plow, PSNT-based N	56A	38	−19	75	38	−37
Chisel plow, pre-plant N	31B	40	9	80	50	−30
1994						
No-tillage, PSNT-based N	55	29x	−26	37	22	−15
No-tillage, pre-plant N	44	26	−18	29X	25X	−4
Chisel plow, PSNT-based N	54	51Ay	−3	38	33	−6
Chisel plow, pre-plant N	58	31B	−27	44Y	44Y	−1
1995						
No-tillage, PSNT-based N	38	43	5	13x	32x	19
No-tillage, pre-plant N	48X	21X	−28	16X	25	9X
Chisel plow, PSNT-based N	56	50	−6A	35y	45Ay	10A
Chisel plow, pre-plant N	82Y	37Y	−45B	40Y	29B	−11BY

Significant differences ($P < 0.10$) between fertilizer treatments are denoted by "a, b" for no-tillage and "A, B" for chisel plow and between tillage treatments are denoted by "x, y" for PSNT and "X, Y" for pre-plant.

Crop Growth and N Accumulation

Whole plant samples collected in June, July and August of 1994 and 1995 showed significant differences in dry matter accumulation and N uptake during the growing season due to tillage or N fertilizer management (data not presented). Corn samples collected at physiologic maturity showed significant differences in total N uptake for comparisons involving the chisel-plow, pre-plant N treatment in 1995 ($p = 0.01$ and 0.02), but there were no significant differences in 1993. Soybean showed no significant differences in total N accumulation due to tillage or N management treatment (table 6).

Grain Yield and N Removal

Soybean yield in 1994 was significantly less for both no-till ($p = 0.03$) and chisel plow ($p = 0.02$) treatments in plots where corn fertilization in 1993 was based on the PSNT, but all other comparisons were not significantly different. This yield reduction does not seem to correlate with the amount

Table 6. Tillage and fertilizer management effects on crop yield, aerial N accumulation, and estimated N removal by grain harvested from till-derived soils in northeast Iowa

Management System	Corn Yield ($Mg\ ha^{-1}$)	Corn N Uptake ($kg\ ha^{-1}$)	Corn N Removal ($kg\ ha^{-1}$)	Soybean Yield ($Mg\ ha^{-1}$)	Soybean N Uptake ($kg\ ha^{-1}$)	Soybean N Removal ($kg\ ha^{-1}$)
1993						
No-tillage, PSNT-based N	6.50a	132	80a	2.56	356	–
No-tillage, pre-plant N	4.11b	69	42b	2.66	387	–
Chisel plow, PSNT-based N	6.74A	130	73	2.66	366	–
Chisel plow, pre-plant N	4.91B	75	51	2.64	422	–
1994						
No-tillage, PSNT-based N	7.27ax	217	98ax	3.12a	280	–
No-tillage, pre-plant N	6.33bX	149X	69bX	3.47b	338	–
Chisel plow, PSNT-based N	8.16y	266	116y	3.17A	316	–
Chisel plow, pre-plant N	7.95Y	226Y	106Y	3.59B	352	–
1995						
No-tillage, PSNT-based N	4.86	224	74	2.85	299	151
No-tillage, pre-plant N	4.51	234X	65	2.90	310	151
Chisel plow, PSNT-based N	5.21	233A	80	2.87	273	150
Chisel plow, pre-plant N	5.18	330BY	79	2.91	323	158

Significant differences ($P < 0.10$) between fertilizer treatments are denoted by "a, b" for no-tillage and "A, B" for chisel plow and between tillage treatments are denoted by "x, y" for PSNT and "X, Y" for pre-plant.

of N applied or the amount lost with subsurface drainage. N removal with soybean seed was measured only in 1995 and no significant differences were observed.

Split N application treatments had significantly greater corn yields than the single pre-plant application for both no-till ($p = 0.02$) and chisel plow ($p = 0.02$) treatments during the extremely wet 1993 growing season (table 6). This suggests 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. Split applied fertilizer also had significantly greater corn yield than the single application for no-till in 1994 ($p = 0.02$). For both N management treatments, chisel plowing resulted in greater corn yields than no-till in 1994 ($p = 0.02$ and 0.01). Hail damage reduced corn yields in 1995, presumably causing the differences among treatments to be non-significant. Removal of N with the corn grain was obviously closely related to yield, since grain N concentrations (data not presented) were fairly constant. For the no-till treatment, removal was significantly greater for the split application in both 1993 ($p = 0.01$) and 1994 ($p = 0.02$). The chisel plow treatment had significantly greater N removal than no-till ($p = 0.01$) when N fertilizer was applied prior to planting in 1994.

Conclusions

Nitrate-N concentrations in 33% of the drain effluent samples collected during this study exceeded 10 mg L^{-1}. Seasonal average NO_3-N concentrations in effluent were not greater when fertilizer was split applied, even though 30 to 70% more fertilizer N was applied when compared to single application treatments. Split applying UAN fertilizer with a spoke injector increased corn yield for the chisel plow treatment during the extremely wet 1993 growing season. Split applying UAN on no-till resulted in as great or greater corn yields and similar or lower NO_3-N concentrations and losses in drain effluent as compared to single, pre-plant applications. There were only a few significant differences in aerial dry matter or N accumulation by corn and soybean crops due to the tillage and N fertilizer treatments. Based on these results, we conclude that combining no-tillage practices with a split N fertilizer management strategy based on the PSNT can have positive environmental benefits without reducing corn yield when rotated with soybean on these till-derived soils.

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