Project Completion Report

for

University of Wisconsin Water Resources Institute

Groundwater Research Project

R/UW-BMP-001S

entitled

"Field Monitoring of Drainage and Nitrate Leaching from Managed and Unmanaged Ecosystems"

by

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PROJECT SUMMARY

Title: Field monitoring of drainage and nitrate leaching from managed and unmanaged ecosystems

Project I.D.: R/UW-BMP-001S

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Background/Need: The appropriate balance between profitable agricultural production and environmental degradation is challenging to maintain because of the relative ease with which potentially environmentally harmful solutes, like nitrate-nitrogen (N), move with water through soil. Over fertilization of agricultural crops with N affects nitrate-N leaching and impacts groundwater quality. In Wisconsin alone, a significant number of counties, potentially affecting more than one million people, have areas of medium to high susceptibility for groundwater nitrate-N leaching from excess applications of N fertilizers. This is a problem that plagues the majority of the states in the upper Midwest.

Objectives: The main objective of this study was to continuously monitor drainage and nitrate-N leaching from managed and unmanaged ecosystems. Specific objectives accomplished during this study were the following: 1) continuous year-around monitoring of drainage and nitrate-N leaching from pre-existing, optimally N-fertilized, no-tillage and chisel plow corn plots; 2) installation of 4 new equilibrium-tension lysimeters in pre-existing no-tillage and chisel plow corn plots that monitored drainage and nitrate leaching at a reduced level of N fertilization; 3) cation and heavy metal leaching associated with nitrate leaching were monitored; and 4) a solute transport computer model was developed and validated with field measurements.

Methods: The objectives of this study were achieved through continuous year-around field monitoring of drainage and solute leaching from undisturbed soil columns using equilibrium tension lysimeters installed in fertilized (i.e., installed Fall 1995) and unfertilized (i.e., installed Fall 1999) chisel-plowed and no-tillage corn agroecosystems and a restored prairie (i.e., installed Fall 1995). Chemical analyses for nitrate-N and ammonium-N were determined colorimetrically using a continuous-flow ion analyzer. Soluble organic carbon was determined by high-temperature catalytic combustion. Soluble potassium, calcium, magnesium, zinc, manganese, copper, iron, sodium, and aluminum were performed by inductively coupled plasma - optimal emission spectrometry. All chemical analyses were conducted on instruments operated by the State Soil and Plant Analysis Lab. The solute transport computer model subroutine was developed in Fortran language and validated against drainage and nitrate-N leaching losses measured in the fertilized no-tillage and chisel-plowed corn agroecosystems as part of a doctoral dissertation.

Results and Discussion: Drainage generally occurred between January and June with, at times, high variability among replicate lysimeters. Between January 2000 and early January 2001, cumulative mean drainage was highest for the fertilized chisel-plowed corn agroecosystem, similar for the fertilized and unfertilized no-tillage corn agroecosystems, and lowest for the restored prairie and unfertilized chisel-plowed corn agroecosystems. Nitrate-N leaching losses were < 0.03, 3.5, 4.2, 23, and 58 kg ha^{-1} yr^{-1} in the prairie, unfertilized no-tillage, unfertilized chisel-plowed, fertilized no-tillage, and fertilized chisel-plowed corn agroecosystems, respectively. Significant cationic nutrient leaching (i.e., Ca, Mg, and Na) occurred along with nitrate-N leaching to preserve neutrality of the soil solution.

Conclusions/Implications/Recommendations: Corn crops fertilized with N at the optimum recommended rate to maximize profits from yields result in flow-weighted NO_3^--N concentrations at the bottom of corn root zones of 8.9 mgN L^{-1} and 11.7 mgN L^{-1} for chisel-plowed and no-till treatments. Significant drainage and leaching losses typically begin in January when, depending on the amount of residue cover on the soil surface, a portion of the upper soil profile is frozen. In addition, to maintain charge balance and neutrality of the soil leachate solution, an equivalent amount of positive charge must leach with each negatively charged NO_3^--N ion. Therefore, the long-term loss of soil fertility and cation exchange capacity may be a threat when nitrate-N leaching continues to occur due to N fertilization above and beyond what is required by a crop to produce a sufficient yield.

Based on the results of this study and on the information gathered in previous years prior to this study, we would recommend against Fall applications of inorganic N fertilizer or N-rich manure due to the potential for significant leaching to occur over the winter through frozen soil and in the spring of the year when the soil thaws. Because NO_3^--N concentrations are near the 10 mgN L^{-1} drinking-water standard for optimal fertilizer applications, our results suggest that excessively high ground water concentrations may be caused by excessive fertilization so that strong incentives for farmers to apply fertilizers at optimal rates (or less) should be imposed.

Related Publications:
Brye, K.R., J.M. Norman, L.G. Bundy, and S.T. Gower. 2001. Nitrogen and carbon leaching in agroecosystems and their role in denitrification potential. J. Environ. Qual. 30:58-70.

Key Words: drainage, leaching, nitrogen, nitrate, prairie, corn, no-tillage, and chisel-plowed

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INTRODUCTION

The appropriate balance between profitable agricultural production and environmental degradation is challenging to maintain because of the relative ease with which potentially environmentally harmful solutes, like nitrate-nitrogen (N), move with water through soil. Since crop yields respond positively to fertilizer, many farmers take on the attitude that "if a little is good, a lot is better". However, though this may be true in terms of maximizing production, it is certainly not accurate it terms of protecting valuable natural resources, such as clean groundwater, from environmental degradation.

Over fertilization of agricultural crops with N affects nitrate-N leaching and impacts groundwater quality. This is a problem that plagues the majority of the states in the upper Midwest. In Wisconsin alone, 50 of the 72 counties, potentially affecting 1.5 million people, have medium to high susceptibility for groundwater nitrate-N leaching from excess applications of N fertilizer. Schmidt and Sturgul (1989) reported that there were 11 counties where groundwater nitrate-N concentrations exceeded 10 mg L^{-1} in greater than 20% of the private wells tested, with the percentages ranging from 21 to 62%.

This story of rising nitrate levels in groundwater is repeated in virtually every area of the U.S. where agriculture is important. In fact, levels of nitrate-N are so high in the Upper Mississippi River Basin area that nitrate-N concentrations in the Mississippi River have doubled and the flux of nitrate-N has trippled since 1960 (Bratkovich, et al., 1994), contributing to hypoxic conditions in the gulf of Mexico with serious consequences (Rabalais et al., 1996). Because 57 % of the river's nitrate-N is attributed to fertilizer use, the Chief of the EPA Water Office has requested that a multi-agency White House committee review research and recommend management steps such as voluntary reductions of fertilizer use (Kaiser, 1996).

The purpose of this study was to evaluate N leaching from the root zone of managed and unmanaged ecosystems. The main objective of this study was to continuously monitor drainage and leaching of nitrate-N and other solutes from a restored prairie and fertilized and unfertilized, no-tillage and chisel-plowed corn agroecosystems using equilibrium-tension lysimeters. Specific objectives of this study were the following: 1) continue year-around monitoring of drainage and nitrate-N leaching from pre-existing, optimally N-fertilized, no-tillage and chisel plow corn plots; 2) install new equilibrium-tension lysimeters in pre-existing no-tillage and chisel plow corn plots to monitor drainage and nitrate-N leaching at a reduced level of N fertilization; 3) quantify cation and heavy metal leaching associated with nitrate-N leaching; and 4) develop a solute transport computer model to validate with field measurements.

PROCEDURES AND METHODS

The objectives of this study were achieved through continuous year-around field monitoring of drainage and solute leaching from undisturbed soil columns using equilibrium tension lysimeters (Brye et al., 1999) installed at 1.4 m below the soil surface in fertilized (i.e., installed Fall 1995) and unfertilized (i.e., installed Fall 1999) chisel-plowed and no-tillage corn agroecosystems and a restored prairie (i.e., installed Fall 1995). The restored-prairie site (planted in 1976) is located at Goose Pond Sanctuary (Arlington, WI) less than 2.5 km from the agricultural study site located on the University of Wisconsin-Madison's Arlington Agricultural Research Station (Arlington, WI) (Brye, 1997). The soil at both sites is a Plano silt loam (fine, silty, mixed, mesic, superactive, typic agriudoll)

The lysimeters were constructed out of stainless steel with a 0.2 μm porous stainless steel plate welded to the top of a leachate collection reservoir that has a capacity of ~23 L or ~ 100 mm of drainage (Brye et al., 1999). A regulated vacuum system was present at each study site to maintain constant suction on the lysimeters (Brye et al., 1999). Suction was adjusted accordingly depending on the matric potential fluctuations in the bulk soil surrounding the lysimeters (Brye et al., 1999). Matric potential fluctuations were continuously monitored in the surrounding bulk soil and immediately above the lysimeter's measurement area using heat dissipation sensors (Reece, 1996; Brye et al., 1999). Potential of the lysimeters was adjusted to be slightly more negative than what was recorded for the surrounding bulk soil so as to avoid ponding and by-pass flow around the lysimeter (Brye et al., 1999).

Chemical analyses for nitrate-N and ammonium-N were determined colorimetrically using a continuous-flow ion analyzer. Soluble organic carbon was determined by high-temperature catalytic combustion. Soluble potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), sodium (Na), and aluminum (Al) were performed by inductively coupled plasma - optimal emission spectrometry. All chemical analyses were conducted on instruments operated by the State Soil and Plant Analysis Lab. A solute transport computer model subroutine was developed in Fortran language and validated against drainage and nitrate-N leaching losses measured in the fertilized no-tillage and chisel-plowed corn agroecosystems as part of a doctoral dissertation (Brye, 1999).

RESULTS AND DISCUSSION

Drainage

Drainage measurements began in early December 1999 for the unfertilized no-tillage and chisel-plowed corn agroecosystems following several months of equilibration time after installation in early Fall 1999. Figure 1 depicts minimal drainage for the restored prairie and fertilized no-tillage and chisel-plowed corn agroecosystems between July and December 1999, but that drainage initiated in all five ecosystems in January 2000. Between January 2000 and early January 2001, cumulative mean drainage past the 1.4 m soil depth plane was highest for the fertilized chisel-plowed corn agroecosystem, similar for the fertilized and unfertilized no-tillage corn agroecosystems, and lowest for the restored prairie and unfertilized chisel-plowed corn agroecosystem (Table 1). The drainage patterns recorded for all five ecosystems during 2000, where the majority of the drainage occurred in the first six months of the year between January and June, were similar to the annual patterns previously observed for the prairie and fertilized corn agroecosystems (Brye et al., 2000).

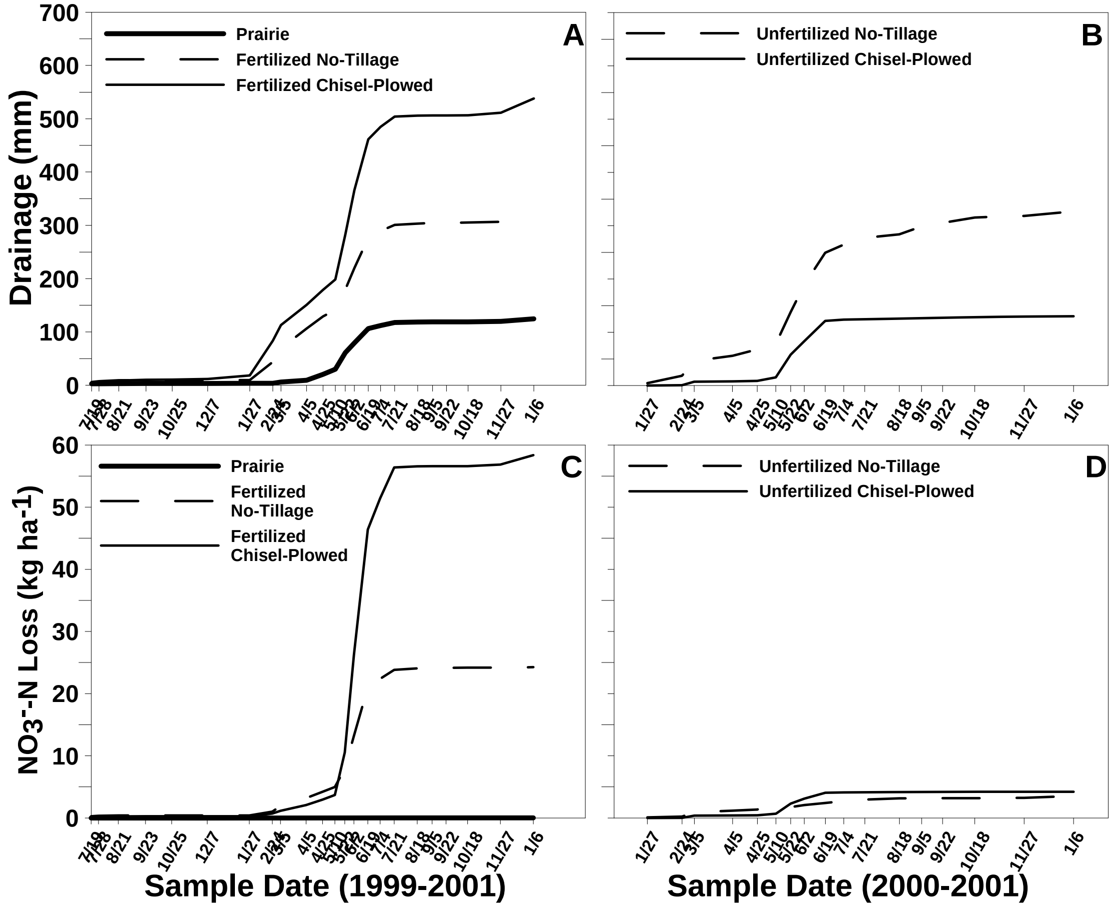

Figure 1. Cumulative drainage below 1.4 m for (A) the prairie and fertilized no-tillage and chisel-plowed corn agroecosystems between July 1, 1999 and January 6, 2001, and (B) for the unfertilized no-tillage and chisel-plowed corn agroecosystems between December 1, 1999 and January 6, 2001. Cumulative nitrate-nitrogen (NO_3^--N) leaching losses are shown for (C) the prairie and fertilized no-tillage and chisel-plowed corn agroecosystems between July 1, 1999 and January 6, 2001, and (D) for the unfertilized no-tillage and chisel-plowed corn agroecosystems between December 1, 1999 and January 6, 2001 (D).

The variability between replicate lysimeters within the same ecosystem treatment was similar to that previously observed for the prairie and fertilized corn agroecosystems, where the lowest variability was recorded in prairie and the highest variability recorded in the fertilized chisel-plowed corn agroecosystem (Brye et al., 2000). However, the variability associated with replicate lysimeter drainage measurements was surprisingly high for unfertilized no-tillage corn agroecosystem (Table 1). Basically, one lysimeter collected the majority of the leachate in these systems while the other lysimeter, about 15 m away, collected almost half as much leachate solution. This demonstrates the potential for inherently high spatial variability with soil hydraulic properties, which will also translate into high spatial variability with field measurements of solutes leaching losses.

Table 1. Cumulative drainage, flow-weighted mean nitrate-nitrogen (NO_3^--N) and soluble organic carbon (SOC) concentrations and cumulative NO_3^--N, total inorganic N (i.e., nitrate- + ammonium-N), and SOC leaching losses for the prairie, fertilized (f) and unfertilized (nf), no-tillage (NT) and chisel-plowed (CP) corn agroecosystems. Note the different time periods of measurements. Standard errors are reported in parentheses.

System	**Time Period**	**Drainage**	**NO_3^--N**	**NO_3^--N**	**Total Inorganic N**	**SOC**	**SOC**
		mm	mg L^{-1}	kg ha^{-1}	kg ha^{-1}	mg L^{-1}	kg ha^{-1}
Prairie	7-1-99 to 1-6-01	124 (16)	0.1 (<0.1)	<0.1 (<0.1)	<0.1 (<0.1)	12 (0.3)	11 (0.4)
NTf		310 (21)	5.2 (0.5)	24 (3)	24 (3)	40 (0.7)	58 (7)
CPf		538 (185)	7.4 (0.1)	58 (9)	59 (9)	38 (11)	103 (23)
NTnf	12-1-99 to 1-6-01	327 (257)	1.5 (0.2)	3 (2)	4 (2)	36 (2)	76 (61)
CPnf		130 (57)	2.3 (0.1)	4 (2)	4 (2)	32 (13)	21 (4)

Table 2 summarizes mean cumulative drainage by quarter (i.e., season) for the five ecosystems. This data further supports previous observations by Brye et al. (2000) that drainage through the Plano silt loam soil, influenced by the typical precipitation patterns in south central Wisconsin, occurs during the first and second quarters (i.e., January through June) of the year.

Inorganic N Leaching

Inorganic N leaching losses from the agroecosystems were dominated by nitrate-N (NO_3^--N) (Table 1). Nitrate-N leaching comprised, on average, 99.6 and 97.5 % of the total inorganic N leaching losses recorded for the fertilized and unfertilized corn agroecosystems, respectively, while NO_3^--N leaching comprised, on average, 36.7 % of the total inorganic N leaching losses recorded for the restored prairie.

Nitrate-N leaching losses followed the same patterns as were recorded for drainage from the fertilized and unfertilized corn agroecosystems (Figure 1). However, the first and second quarter increases in leaching losses from the unfertilized corn agroecosystems were not as prominent as those from the fertilized corn agroecosystems during the same time period (Figure 1 and Table 2).

Table 2. Cumulative mean drainage and nitrate-N (NO_3^--N) by quarter for the restored prairie and fertilized (f) and unfertilized (nf), no-tillage (NT) and chisel-plowed (CP) corn agroecosystems. Standard errors are reported in parentheses.

Quarter-Year/ Measurement	Ecosystems				
	Prairie	**NTnf**	**CPnf**	**NTf**	**CPf**
Quarter 3 - 1999 (July - September)					
Drainage (mm)	3.4 (0.3)	-	-	9.5 (4)	10 (8)
NO_3^--N Load (kg ha^{-1})	0	-	-	0.4 (0.1)	0.3 (0.1)
Quarter 4 - 1999 (October - December)					
Drainage (mm)	0	-	-	0	1.2 (1)
NO_3^--N Load (kg ha^{-1})	0	-	-	0	0
Quarter 1 - 2000 (January - March)					
Drainage (mm)	2.8 (2)	46 (44)	7.2 (2)	60 (18)	101 (64)
NO_3^--N Load (kg ha^{-1})	0	1 (1)	0.4 (0.2)	1.5 (0.5)	0.9 (0.5)
Quarter 2 - 2000 (April - June)					
Drainage (mm)	100 (13)	203 (160)	114 (62)	207 (9)	348 (115)
NO_3^--N Load (kg ha^{-1})	0.02 (0.01)	1.5 (0.7)	3.7 (2)	19 (3)	45 (12)
Quarter 3 - 2000 (July - September)					
Drainage (mm)	12.9 (2)	56 (34)	5.3 (4)	28 (5)	45 (4)
NO_3^--N Load (kg ha^{-1})	0	0.8 (0.1)	0.1 (0.1)	3.2 (1)	11 (1)
Quarter 4 - 2000 (October - December)					
Drainage (mm)	5.5 (4)	22 (19)	3.4 (3)	5.0 (3)	32 (11)
NO_3^--N Load (kg ha^{-1})	0	0.3 (0.3)	0	0.1 (0.1)	1.8 (2)

Though an appreciable amount of drainage occurred through the soil profile of the restored prairie, concentrations of inorganic N in the soil leachate solution were so small (i.e., flow-weighted mean concentrations ~ 0.06 and 0.04 mg L^{-1} for NO_3^-- and NH_4^+-N, respectively) that mass losses of inorganic N were negligible (Table 1). Similarly, flow-weighted mean concentrations of NO_3^-- and NH_4^+-N were relatively small,1.5 and 0.03 mg L^{-1} for the unfertilized no-tillage corn and 2.3 and 0.1 mg L^{-1} for the unfertilized chisel-plowed corn, respectively (Table 1). However, significant nitrate-N leaching losses occurred from the fertilized corn agroecosystems due to two factors: 1) significant water movement and 2) higher concentrations of inorganic N, particularly NO_3^-- N, in the soil leachate solution compared to the concentrations found in leachate solutions under the unfertilized systems. Flow-weighted mean concentrations of NO_3^-- N were 5.2 and 7.5 mg L^{-1} in leachate solutions under the fertilized no-tillage and chisel-plowed corn agroecosystems, respectively (Table 1). These higher concentrations caused cumulative mean NO_3^-- N leaching losses to be 24.2 and 58.6 kg ha^{-1} from the fertilized no-tillage and chisel-plowed corn agroecosystems, respectively (Table 1).

Other Solute Leaching

Flow-weighted mean soluble organic carbon (SOC) concentrations in the leachate solutions were similar among the corn agroecosystems, ranging from 32 to 40 mg SOC L^{-1} for the unfertilized chisel-plowed and fertilized no-tillage corn agroecosystems, but were smaller for the restored prairie, 12 mg SOC L^{-1} (Table 1). Due to significant differences in the amount of drainage that was recorded through the soil profiles of the ecosystems, SOC leaching losses varied considerably among ecosystems. Cumulative mean SOC leaching between July 1999 and early January 2001 was 11, 58, and 103 kg SOC ha^{-1} in the prairie, fertilized no-tillage, and fertilized chisel-plowed agroecosystems, respectively, while cumulative mean SOC leaching between December 1999 and early January 2001 was 21 and 76 kg SOC ha^{-1} in the unfertilized chisel-plowed and no-tillage corn agroecosystems, respectively (Table 1). Even with these amounts of SOC leaching from the root zones of the corn crops along with the nitrate-N, the SOC supply would still limit the amount of denitrification that denitrifying organisms could achieve under the fertilized corn agroecosystems, but the SOC supply would be many times more than what would be necessary for denitrifiers to denitrify all of the nitrate-N leaching from the prairie given the appropriate conditions for denitrification to occur (Brye et al., 2001).

Flow-weighted mean concentrations of essential plant macro- (i.e., K, Ca, and Mg) and micro-nutrients (i.e., Na, Zn, Mn, Cu, Fe, and Al) contained in the soil leachate solutions collected by the equilibrium-tension lysimeters from early December 1999 through mid-March 2001 are summarized in Table 4. Macro-nutrient concentrations were similar among corn agroecosystems and slightly lower for the restored prairie. The micro-nutrient concentration was similar to that of the macro-nutrients, except that the flow-weighted mean concentrations of Fe and Al were actually several times larger in the prairie than in the corn agroecosystems.

Cumulative mean leaching losses of macro- and micro-nutrients for early December 1999 through mid-March 2001 are summarized in Table 4. Micro-nutrient leaching losses, excluding Na, ranged from < 0.01 kg ha^{-1} for Mn and Cu in the fertilized no-tillage corn agroecosystem and prairie to > 0.3 kg ha^{-1} for Al in the prairie. Micro-nutrient leaching losses were generally similar among corn agroecosystems with the leaching losses from the prairie typically smaller, except for higher leaching losses in the prairie than in the corn agroecosystems for Fe and Al. On the other hand, leaching losses for Ca, Mg, and Na were an order of magnitude larger than leaching losses for most micro-nutrients, where leaching losses were generally similar among corn

Table 3. Cumulative drainage and mean flow-weighted concentrations of macro- and micro-nutrients measured in leachate solutions collected with equilibrium-tension lysimeters between December 1, 1999 and March 18, 2001 for the prairie, fertilized (f) and unfertilized (nf), no-tillage (NT) and chisel-plowed (CP) corn agroecosystems. Standard errors are reported in parentheses.

Measurement	Prairie	NTnf	CPnf	NTf	CPf
Drainage (mm)	150 (19)	347 (277)	209 (64)	316 (22)	581 (198)
K (mg L^{-1})	0.2 (0.02)	0.5 (0.03)	0.6 (0.1)	0.5 (0.1)	0.5 (0.1)
Ca (mg L^{-1})	8.2 (1.8)	54 (3.0)	48 (6.2)	47 (0.7)	56 (5.4)
Mg (mg L^{-1})	3.4 (0.7)	31 (3.9)	32 (6.0)	32 (8.9)	29 (4.2)
Na (mg L^{-1})	7.9 (0.8)	11 (2.2)	16 (1.6)	15 (2.6)	13 (0.9)
Zn (mg L^{-1})	0.08 (<0.01)	0.05 (0.01)	0.07 (<0.01)	0.05 (0.01)	0.08 (<0.01)
Mn (mg L^{-1})	0.02 (0.01)	0.03 (0.02)	0.1 (0.1)	0.01 (<0.01)	0.01 (<0.01)
Cu (mg L^{-1})	0.01 (<0.01)	0.03 (0.02)	0.06 (0.03)	0.01 (<0.01)	0.01 (<0.01)
Fe (mg L^{-1})	0.06 (0.03)	0.01 (<0.01)	0.01 (<0.01)	0.01 (<0.01)	0.01 (<0.01)
Al (mg L^{-1})	0.11 (0.05)	0.03 (<0.01)	0.03 (<0.01)	0.03 (<0.01)	0.03 (<0.01)

agroecosystems with the leaching losses from the prairie typically smaller. Calcium leaching losses were by far the greatest compared to other macro-nutrients; ranging from 12 kg Ca^{+2} ha^{-1} for the prairie to 244 kg Ca^{+2} ha^{-1} for the fertilized chisel-plowed corn agroecosystem.

Summary of Previous Data Collection

Table 5 contains an annual summary of precipitation, cumulative drainage, mean flow-weighted NO_3^- -N concentrations, and the cumulative NO_3^- -N load for the restored prairie and fertilized no-tillage and chisel-plowed corn agroecosystems from 1996 through 2000.

N-Leaching Model

A simple convective model for predicting N leaching was created and validated with measurements from this study (Figure 2) with reasonable results.

CONCLUSIONS AND RECOMMENDATIONS

Corn crops fertilized with N at the optimum recommended rate to maximize yields do not necessarily protect the environment from the potential for groundwater contamination due to nitrate-N leaching even in a fine textured silt loam soil. Significant drainage and leaching losses typically begin in January when, depending on the amount of residue cover on the soil surface, a portion of the upper soil profile is frozen. Though mean concentrations of nitrate-N may not

Table 4. Cumulative mean macro- and micro-nutrient leaching losses measured with equilibrium-tension lysimeters between December 1, 1999 and March 18, 2001 for the prairie, fertilized (f) and unfertilized (nf), no-tillage (NT) and chisel-plowed (CP) corn agroecosystems. Standard errors are reported in parentheses. Note the kg ha^{-1} units for K, Ca, Mg, and Na versus the g ha^{-1} units for the remainder of the micro-nutrients.

Measurement	Prairie	NTnf	CPnf	NTf	CPf
K (kg ha^{-1})	0.2 (0.02)	1.5 (1.2)	0.6 (0.1)	1.2 (<0.01)	2.6 (1.6)
Ca (kg ha^{-1})	12 (1.9)	157 (127)	104 (37)	111 (2.1)	244 (88)
Mg (kg ha^{-1})	5.4 (0.7)	91 (75)	61 (23)	61 (7.9)	120 (23)
Na (kg ha^{-1})	11 (0.5)	28 (20)	25 (3.7)	41 (1.3)	65 (26)
Zn (g ha^{-1})	63 (7.4)	132 (112)	100 (15)	117 (38)	245 (132)
Mn (g ha^{-1})	7.9 (2.9)	18 (1.6)	21 (1.9)	7.9 (0.9)	30 (20)
Cu (g ha^{-1})	4.5 (0.4)	22 (4.3)	21 (5.4)	12 (2.2)	25 (7.4)
Fe (g ha^{-1})	169 (117)	24 (19)	19 (1.5)	22 (9.3)	52 (20)
Al (g ha^{-1})	332 (220)	78 (68)	46 (9.7)	107 (40)	167 (71)

have been in excess of the 10 mg L^{-1} threshold as a drinking water standard for a long period of time, short intervals of intense rainfall can result in a flush of water through the soil profile that contains a relatively large mass of nitrate-N. In addition, to maintain charge balance and neutrality of the soil leachate solution, an equivalent amount of positive charge must leach with each negatively charged NO_3^--N ion. Therefore, the long-term loss of soil fertility and cation exchange capacity is a real threat when nitrate-N leaching continues to occur due to N fertilization above and beyond what is required by a crop to produce a sufficient yield.

Based on the results of this study and on the information gathered in previous years prior to this study, we would recommend against Fall applications of inorganic N fertilizer or N-rich manure due to the potential for significant leaching to occur over the winter through frozen soil and in the spring of the year when the soil thaws. Over five years both fertilized systems leach about 1/4 of the applied fertilizer and the resulting flow-weighted NO_3^--N concentration at a 1.4 m depth is 11.7 mgN L^{-1} for NT and 8.9 mgN L^{-1} for CP; remarkable close to the drinking water standard. Because NO_3^--N concentrations are near the 10 mgN L^{-1} drinking-water standard, our results suggest that excessively high ground water concentrations may be caused by excessive fertilization so that strong incentives for farmers to apply fertilizers at optimal rates (or less) should be imposed.

Table 5. Annual summary of precipitation, cumulative drainage, mean flow-weighted NO_3^- -N concentrations, and the cumulative NO_3^- -N load for the restored prairie and fertilized no-tillage (NTf) and chisel-plowed (CPf) corn agroecosystems from 1996 through 2000. Standard errors are reported in parentheses.

Year/System	**Precipitation, mm**	**Drainage, mm**	**NO_3^--N, mg L^{-1}**	**N Load, kg ha^{-1}**
1996-Prairie	693	112 (5)	0.1 (< 0.1)	0.3 (< 0.1)
NTf	744	262 (51)	16.3 (2.4)	63.7 (15)
CPf	744	351 (32)	12.0 (1.6)	63.1 (15)
1997-Prairie	762	83 (6)	0.1 (< 0.1)	0.1 (< 0.01)
NTf	616	271 (45)	11.5 (3.5)	32.1 (5.5)
CPf	616	411 (83)	8.4 (0.5)	35.0 (8.7)
1998-Prairie	935	208 (7)	0.1 (< 0.1)	0.2 (< 0.01)
NTf	981	424 (3)	17.2 (8.4)	103 (52)
CPf	981	593 (86)	9.3 (1.1)	76.3 (19)
1999-Prairie	760	99 (5)	0.1 (< 0.1)	0.01 (< 0.01)
NTf	760	239 (6)	2.5 (0.9)	6.0 (2.6)
CPf	760	329 (43)	2.1 (0.9)	8.6 (3.7)
2000-Prairie	1000	121 (11)	0.1 (< 0.1)	0.02 (< 0.01)
NTf	1000	300 (18)	6.8 (0.8)	23.8 (2.3)
CPf	1000	526 (97)	10.0 (0.2)	58.7 (7.8)

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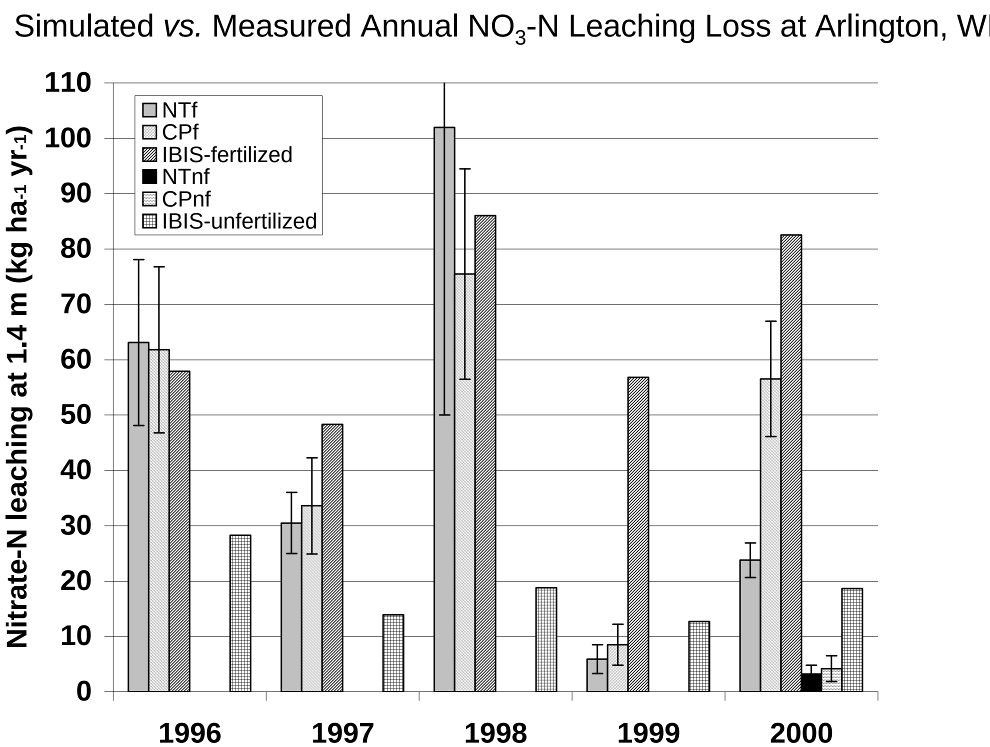

Figure 2. Validation of simple nitrate leaching model on no-till fertilized (NTf)(begun 1995), chisel-plowed fertilized (CPf), no-till non-fertilized (NTf)(begun 1999), and chisel-plowed non-fertilized (CPnf) treatments.

APPENDIX A

Publications

Brye, K.R., J.M. Norman, L.G. Bundy, and S.T. Gower. 2000. Nitrogen leaching losses from conventional- and no-tillage corn. Wisconsin Fertilizer, Aglime & Pest Management Conference Proceedings. p. 387-396.

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Brye, K.R., P.W. Barak, and J.M. Norman. 2001. Soluble nutrient leaching from a restored tallgrass prairie and corn agroecosystems. Soil Sci. Soc. Am. J. *In Preparation*

Presentations

Brye, K.R., J.M. Norman, L.G. Bundy, and S.T. Gower. 2000. Carbon leaching and its role in the carbon budgets of natural and managed ecosystems. Agronomy Abstracts. p. 199. American Society of Agronomy Annual Meetings, Minneapolis, MN, November 5-9.