Impact of historical and current farming systems on groundwater nitrate in Northern Missouri

N.R. Kitchen, P.E. Blanchard, D.F. Hughes, and R.N. Lerch

ABSTRACT: A major objective of the Management Systems Evaluation Areas (MSEA) Project has been to assess farming system impact on NO_3-N concentrations in shallow aquifers. In Missouri our interest was to assess farming systems on the claypan soil/glacial aquifer. Three fields were selected and instrumented with groundwater wells in the spring of 1991. Wells were sampled quarterly and analyzed for NO_3-N. Average NO_3-N concentration since 1991 was 7 mg l^{-1}, but 25% of the wells had NO_3-N in excess of 10 mg l^{-1}. In one field, NO_3 concentrations were much higher and are still decreasing after apparently receiving excess nitrogen (N) from manure and N fertilizer before 1980. Long-term N management has long-term impacts on groundwater quality in this aquifer. Current farming systems are probably affecting groundwater quality, but, because of the glacial till's apparent buffer for NO_3 storage, groundwater NO_3 concentration changes are slow.

By mass, the single greatest agrichemical input on cropland is nitrogen (N). The benefits of N fertilization in cropping systems are tremendous, with grain production typically two to five times greater with N fertilizer. However, because N can leach as NO_3, N fertilizer has been suspected as a primary source for increasing NO_3 concentrations in groundwater, and at some locations, to levels deemed unhealthy for human consumption. Concern also exists regarding nutrient loading from cropped fields into surface water bodies by means of runoff and groundwater base flow (McMahon et al. 1994; Spalding and Exner 1993). These concerns justify improved understanding of N source, transformation processes, and transport mechanisms under all land-use scenarios but particularly in agricultural settings where large amounts of N as an input are common. This research was initiated to specifically evaluate the impact of cropping systems as a source of NO_3 contamination in shallow groundwater.

Numerous well water surveys have been conducted over the last couple of decades documenting the extent of NO_3 contamination in groundwater, as well as the climate, soil, and management conditions that lead to contamination. Surveys indicate some intensive agricultural regions in the United States are more prone to NO_3 contamination than others (Madison and Brunett 1985; Hallberg 1989; Fedkiw 1991; Spalding and Exner 1993; Helsel 1995). While well water surveys may show general regional trends, isolating which human activities are contributing the most to increasing groundwater NO_3 using survey information is difficult. Wells used for surveys were generally not constructed for the purpose of groundwater assessment of contamination source, but as a water source. Rural wells are most often located near farmsteads where barns, feedlots, septic systems, fertilizer storage, etc., are potential point-sources of NO_3 leaching. In some areas of the midwestern United States, survey information has shown that the quality of well construction alone was the best explanation for the degree of NO_3 contamination (Spalding and Exner 1993; Burkhart and

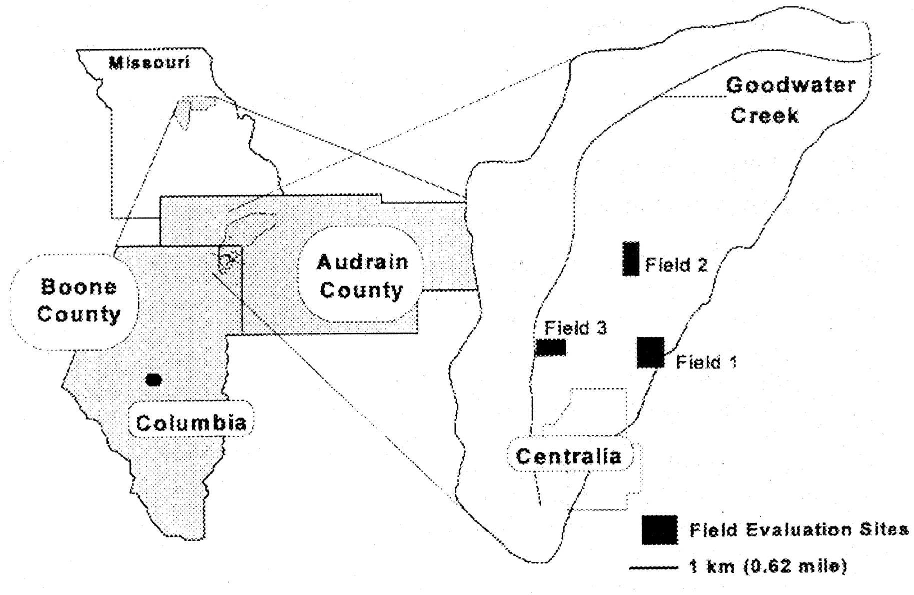

Figure 1. Location of MSEA groundwater assessment within the Goodwater Creek watershed in Missouri

Interpretive summary

Nitrates in groundwater are of public concern. This research investigated the role present and past cropping management has had on nitrate leaching into a shallow aquifer in northern Missouri. Twenty-five percent of the wells were found to be contaminated with nitrates greater than 10 mg NO3-N l-1. The results indicated that over-application of N as a nutrient for crops, whether from N fertilizer or animal manure applications, can result in elevated nitrates in groundwater to levels that persist from years to decades. This is because of the aquifer's ability to store nitrates.

Key words: farming systems, groundwater, nitrate, manure, nitrogen management, shallow aquifer.

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Table 1. Soil series and classification areas for three Missouri MSEA fields

Mapping Unit	Classification	Field 1	Field 2	Field 3
		% of area		
Adco silt loam, 0-1% slopes	fine, mont, mesic albaquic hapludalf	70	30	10
Mexico silty clay loam, 1-3% slopes, eroded	fine, mont, mesic udollic ochraqualf	20	0	0
Mexico silt loam, overwash, 0-2% slopes	fine, mont, mesic udollic ochraqualf	10	0	0
Mexico silt loam, 1-3% slopes	fine, mont, mesic udollic ochraqualf	0	30	65
Putnam silt loam, 0-1% slopes	fine, mont, mesic, mollic albaqualf	0	15	0
Vesser silt loam, 0-1% slopes	fine-silty, mixed, mesic, argiaquic	0	0	10
Leonard silty clay loam, 1-4% slopes, eroded	fine, mont, mesic, vertic ochraqualf	0	25	15
	Total field hectares	36	24	20

Table 2. Missouri MSEA farming systems crop rotations and N management

Farming System*	Year	Crop	N applied —kg/ha—	N management
1	1991	corn	190	preplant broadcast as UAN[†], incorporated
	1992	soybean	0	
	1993	corn	190	preplant broadcast as UAN, incorporated
	1994	soybean	0	
2	1991	grain sorghum	101	preplant broadcast as UAN, incorporated
	1992	soybean	0	
	1993	grain sorghum	101	preplant broadcast as UAN, incorporated
	1994	soybean	0	
3[‡]	1991	corn	118	side-dress knifed as NH3 at crop growth stage V5
	1992	soybean	0	
	1993	wheat	84	topdressed urea, split 1/3 fall and 2/3 spring
	1994	corn	151	preplant 22 kg/ha, remainder side-dress knifed as NH_3 at V5

*Farming System 1, 2 and 3 correspond with Field 1, 2, and 3, respectively

[†] UAN is urea-ammonium-nitrate solution fertilizer

[‡] in 1994, N rates were increased for corn and wheat crops as a result of adjusted yield goals

Kolpin 1993). Thus, interpreting the specific impact of a N input and cropping system management on groundwater NO_3 is confounded by many possibilities when considering well water survey results. While root-zone leaching studies show the movement of nitrates into the vadose zone and shallow aquifer, denitrification in these zones has been found in a number of studies to significantly modify nitrate concentrations (Keeney 1986).

A primary goal of the Management Systems Evaluation Areas (MSEA) Project has been to assess farming system impact on herbicide and NO_3-N concentrations in shallow aquifers (Onstad et al. 1991; Ward et al. 1994). In Missouri, our interest was to assess specific farming systems on the claypan soil/glacial-till aquifer. The approach for this work is unique in that assessment monitoring wells were drilled within cropped fields in order to isolate the contamination of cropping system management on groundwater quality. This paper reports on the NO_3-N concentrations over the first four years of assessment on Missouri's MSEA fields and explains the likely long-term impacts of cropping management on the glacial aquifer underlying claypan soil.

Materials and methods

The Missouri MSEA project is being conducted within the 7,300-ha (18,000 acres) Goodwater Creek Watershed in north-central Missouri (Figure 1). This watershed is typical of the 2.8 million ha (7.0 million acres) Central Claypan Region of Missouri and Illinois. Within the study watershed, 1.5-3.0 m (5-10 ft) of loess (wind-blown soil) overlies 3-12 m (10-40 ft) of glacial till. The modern soil, which developed from the loess, contains a claypan that limits water percolation and promotes surface water runoff. Groundwater recharge occurs primarily by flow through cracks in the claypan and other preferential pathways (Blevins et al. 1996). The loess and till comprise the glacial aquifer, the groundwater of interest for this study.

In late 1990, three farm fields were chosen within the Goodwater Creek Watershed in north-central Missouri (Figure 1). The criteria that were used for field selection included similar characteristics in soils, landscape relief, and antecedent cropping and fertilizer history for the decade prior to project initiation. Soil series and classification obtained from 1:1200 order-one soil survey are given in Table 1.

In the early spring of 1991 each field was instrumented with five to seven groundwater well nests, with three to four wells in each nest. At least three nests per field were located within the field boundary; some nests were positioned along the field edge. The wells within each nest were within close proximity of each other, with the total nest area encompassing about 25 m^2 (270 ft^2). The wells within each nest were drilled and screened at different depths to determine groundwater flow and water quality differences by depth. Screened intervals were 1.2 m (4 ft) and ranged from the top of the glacial till [2.9 m (9.4 ft)] to the bottom of the glacial till [15.7 m (51.6 ft)]. The depth for individual wells varied between well nests since chosen depths corresponded with fractures and sand lenses observed in drill cores collected at each nest site. Installation of the majority of the wells was completed prior to farming system implementation in the spring of 1991. In June 1992, an additional shallower well was drilled at most well nest locations to represent as close as possible the average water table depth. For these shallow wells, screened intervals were 0.61 m (2 ft) with an average depth of 3.2 m (10.4 ft).

Crop rotations and associated N management of the three MSEA farming systems are presented in Table 2. The goal and a more detailed description of each farming system have been given previously (Ward et al. 1994).

Starting in June 1991, well samples were collected quarterly; March, June, September, and December. The wells are constructed of 5.08 cm (2 in) diameter PVC pipe and equipped with a dedicated WaTerra[1, 2] hand pump. The hand pump is composed of 1.59 cm (0.625 in) OD high density polyethylene tubing with a Delrin[3] plastic foot valve. Three volumes of water were purged from each well prior to sample collection. Samples were kept on ice from the field to the laboratory.

Water samples for NO_3 analyses were filtered (0.45 micron) within 48 hours of sampling. From 1991 to 1993, samples of sulfuric-acid were preserved by lowering the pH to approximately 2.0 and refrigerated prior to analysis (EPA 1983). Analysis for NO_3-N was done within 28 days. Beginning in 1993, samples were filtered, refrigerated, and analyzed within five days of collection. If samples could not be analyzed within five days, they were frozen and analysis was done within 30 days of collection. From 1991-93, NO_3-N was measured colorimetrically by reduction to nitrite in a sulfanilaminide complex using a continuous flow autoanalyzer (Bran and Lubbe, Elmsford NY). The detection limit for this method was 0.05 mg N l^{-1} (ppm). From 1993-95, nitrate was measured colorimetrically by reduction to nitrite using a Cd column and continuous flow autoanalyzer (Lachet Instruments, Milwaukee, WI). The detection limit for the Cd reduction method was 0.05 mg N l^{-1}. Initial water samples were analyzed for NO_2-N and NH_4-N and relative to NO_3-N were found to be at very low concentrations.

Results and discussion

Between May 1991 and June 1995, over 800 groundwater samples taken from the three Missouri MSEA fields were collected and analyzed for NO_3-N. Nitrate-N concentrations by field, nest, and well are shown over the four-year assessment period in Figure 2. Wells at each nest are identified by depth using the middle of the screened interval.

Nitrate-N concentrations were quite variable, ranging from non-detectable to over 20 ppm. Averaged overall wells and years, NO_3-N concentration was 7 mg l^{-1}, with about 25% of the wells having NO_3-N in excess of 10 mg l^{-1}, the U.S. Environmental Protection Agency (EPA) drinking water standard. Within some nests, NO_3-N concentrations among wells were nearly identical (e.g., Field 2: nest B and C), but for ten of the fifteen well nests, at least two wells within a nest differed by at least 5 mg l^{-1} at some point during the four-year period. This result suggests that NO_3 storage and transport in the glacial aquifer is stratified. There were no consistent relationships found between NO_3 concentrations and well depth. For example, nest A of Field 3 NO_3-N concentrations of the deepest and shallowest wells were similar but about four times less than the mid-range depth wells (Figure 2). Other work has established that NO_3-N concentrations decrease with well depth (Hallberg 1989). Further investigation found no significant correlation between NO_3 and well hydraulic conductivity (K), landscape position, or season of the year (data not included). Nitrate concentrations from the fields were similar to other glacial-till wells distributed throughout the Goodwater Creek watershed (data not included).

Impact of historical N management on groundwater No_3-N. Baseline well samples collected prior to the establishment of the MSEA farming systems and subsequent samples have shown NO_3

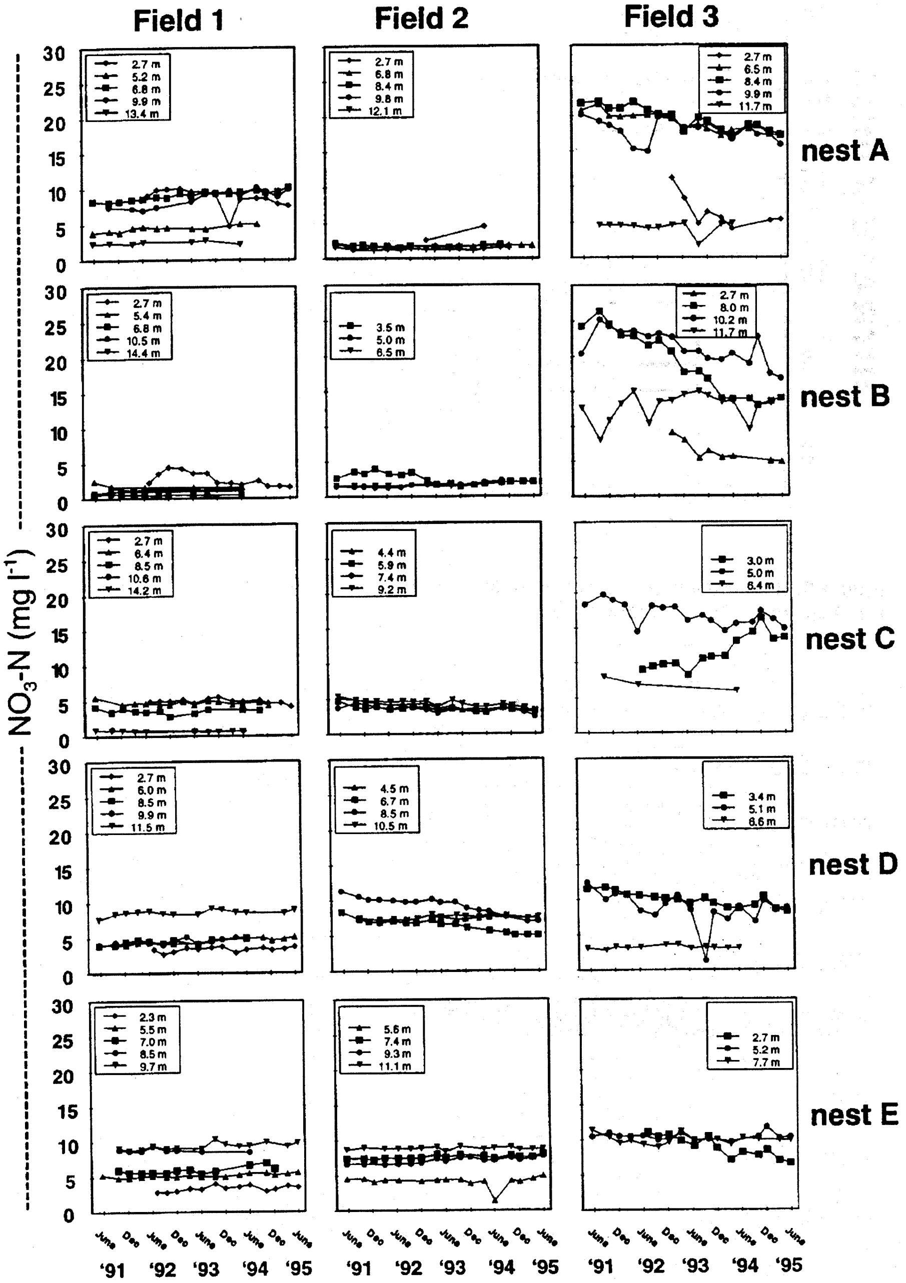


Figure 2. Nitrate concentration in glacial-till groundwater quarterly for four years by field (columns) and nests within fields (rows)

[1] WaTerra Pumps, Ltd., Ontario Canada

[2] Mention of trade names or specific products is made only to provide information to the reader and does not constitute an endorsement by the University of Missouri or the USDA Agricultural Research Service

[3] Trademark of DuPont

concentrations in Field 3 were about twice those of Fields 1 and 2 (Figure 3). Also, core samples collected during the well drilling were analyzed for NO_3-N. Core samples from Field 3 had significantly more NO_3 than did the samples from Fields 1 and 2 (data not included). Since the fields had similar management for a decade before the MSEA project started, no significant differences in groundwater quality had been anticipated.

A historical investigation from interviews with previous landowners and farm operators regarding the past management on these three fields revealed notable management differences extending as far back as the 1930s (Figure 4). Crops and N fertilizer use were comparable during the 1980s, which met the criteria for selecting these three fields. However, prior to 1980 management was distinctively different for Field 3. Because of its close proximity to several animal feedlots, within 300 m (980 ft), manure was readily available and was often applied to Field 3 for many years during 1930-1980. No measurements or records were kept as to the amount of manure that was applied each year, but farmers described manure application as "heavy" for some years. Manure application was usually during the winter and early spring. During the period of 1930 to the late 1950s, the manure source for Field 3 came from two separate feed lots and included both sheep and cattle manure. In the 1960s, hog and cattle manure were both applied. In the 1970s, only cattle manure was used. In addition to the feedlot manure, animals were allowed to graze crop residues after grain harvest in the fall and winter of some years.

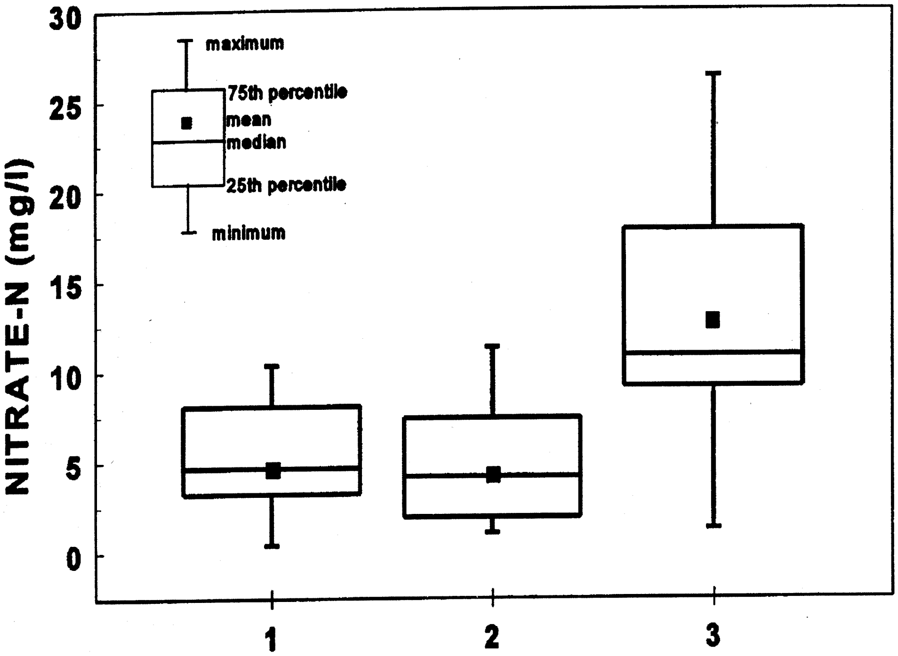


Figure 3. Box and whisker diagram of NO_3-N concentration for the four-year assessment on three Missouri MSEA fields

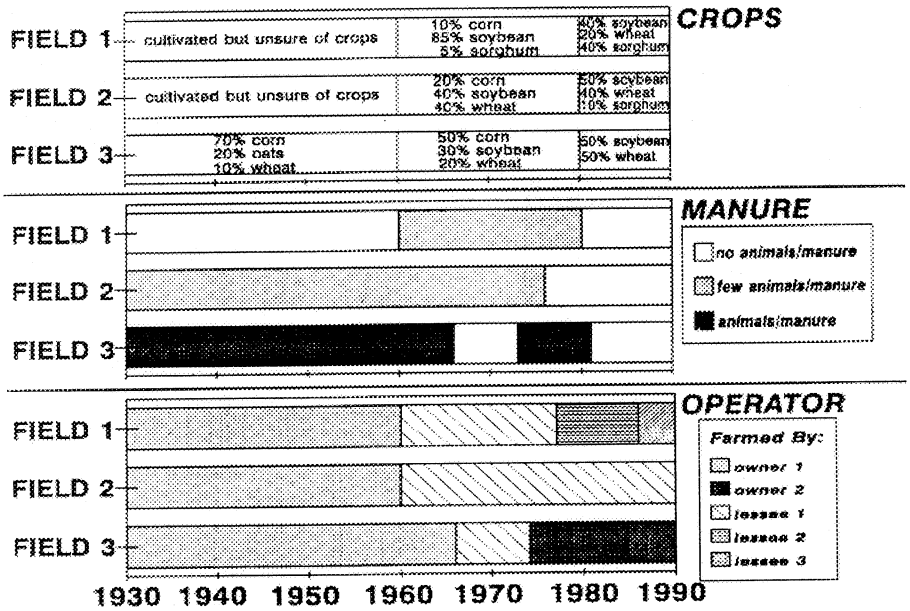


Figure 4. Contrasting historical management for the three Missouri MSEA fields as obtained from interviews shows that Field 3 had much greater animal feeding and manure applications than the other two fields

From 1960 through 1980, corn was grown more often on Field 3 than on the other two fields (Figure 4). Commercial N fertilizer was applied to corn at about 112 kg ha^{-1} (100 lb ac^{-1}). This fertilizer N input was in addition to any N from manure application. Thus, for about 6-8 years during these two decades, both N fertilizer and manure were applied for a corn crop. Three points help support the conclusion that manure applications were applied to Field 3 for disposal purposes and not as a nutrient source. First, the N fertilizer amount used for corn was similar to the amount applied to fields that had no manure applications. Thus, no N credit was given for manure. Second, application of manure on Field 3 was described by those who farmed the fields as always being the greatest near the point of entry onto the field and less as you moved further distance from the entry point. Third, manure was also applied during soybean-crop years.

The farmers surveyed stated when a farm consisted of both grain crop and animal production, proximity of the animal feedlot to a field was the most important factor determining whether or not a field received manure. Second was whether or not the field was owned versus leased by the farmer. Improved crop growth from manuring cropland was perceived by these farmers to be a benefit realized over several years after a manure application. Since leased land was usually done on a year-to-year basis, operator-owned fields preferentially received manure application. No feed-lot operations existed next to Fields 1 and 2 from 1930 to 1990. Furthermore, these fields were farmed by lease arrangement since 1960 (Figure 4). In contrast, Field 3 was both located next to feed lots and mostly owner-farmed.

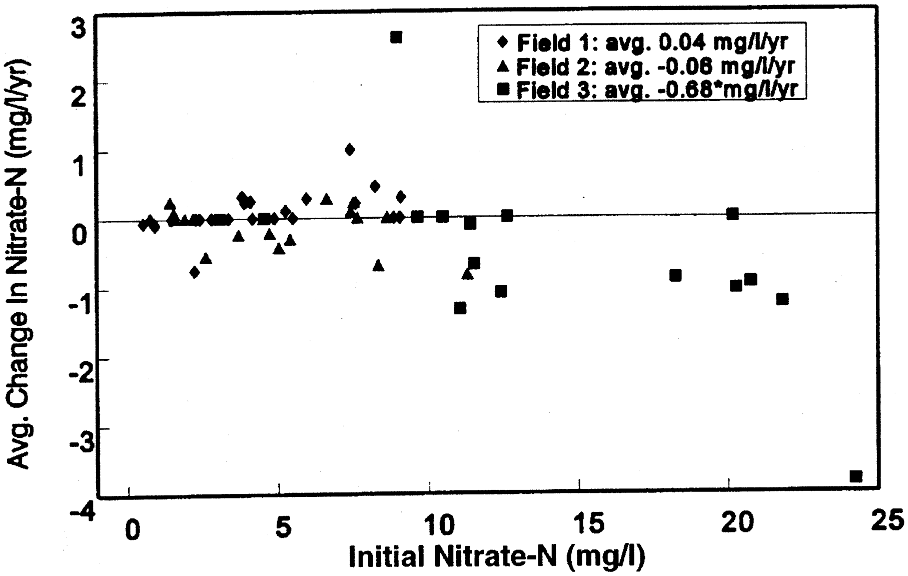
The historical information gathered implies that Field 3 had received a greater total N input from 1930-1981 than did

Fields 1 and 2. A few additional soil measures support the historical records of manuring differences between the three fields. From soil samples taken in April 1991 average soil organic carbon in the surface horizon for Fields 1, 2, and 3 was 10.6, 9.8, and 12.3 g kg^{-1}, respectively. Field average plant-available phosphorus in soil determined using the acid-fluoride extraction (Olsen and Sommers 1982) was twice as high in Field 3 as the other two fields. Further, soil sampling on a 30-m (98 ft) grid and mapping for Field 3 showed highest plant-available P near the field entrance and generally decreasing with increasing distance from the entrance. During the interviews, the previous land operators acknowledged that manure application almost always started on the entrance-side of the field. These, along with our well results, imply that N management can have long-term impact (over decades) on groundwater quality with significant storage of NO$_3$ within the glacial-till aquifer.

These results and other hydrological measurements taken from these same wells give support for our working hypothesis of water flow in the glacial till underlying claypan soils. The glacial till has mobile water in fractures which are prevalent throughout the glacial till but probably occupy less than 1% of the volume, and "immobile" water in the porous but low permeability matrix (Blanchard and Kitchen 1993). If high concentrations of NO$_3$ are present in the fractures for a long period of time, then a large amount of NO$_3$ can be stored in the aquifer due to diffusion from the mobile to the immobile water. Changing N management at the surface might reduce the NO$_3$ concentration in the water recharging the aquifer, but the NO$_3$ stored in the matrix can diffuse back into the mobile water, and keep NO$_3$ concentrations in the mobile water high. One decade of similar management (1980s), the time used for screening fields during the MSEA site selection process, was inadequate for obtaining three fields alike in glacial-till groundwater NO$_3$-N concentration. In contrast, shallow groundwater has been shown to respond to N management in a relatively short period of time (4-19 months) in other hydrogeologic settings (Hall 1992).

Impact of MSEA farming systems. The influence of the MSEA farming systems on groundwater NO$_3$ concentrations is difficult to evaluate after only four years. As described, the glacial-till matrix seems to buffer rapid changes in NO$_3$-N concentration. For this assessment period, four cropping years represent two rotations on Fields 1 and 2 and one and a third rotations on Field 3. Given these data only span four cropping years where N management was carefully monitored, our interpretation of current practices could at best be described as preliminary.

Changes in NO$_3$-N concentration over the assessment period were statistically tested with simple linear regression for significant (F-test P = 0.05) positive or negative change over time (F-test Ho: slope of the linear function over the four-year period = 0). The regression analysis was done for each field well with three or more quarterly samplings. In Figure 5 each point represents the average annual change (regression slope) for a well in relation to the initial groundwater NO$_3$-N concentration obtained in June 1991. Wells that had no significant change over the four year period are represented by a point lying on the x axis where $y = 0$.



* Significant T-test (Pr < 0.05) for Ho: Field average=0.

Figure 5. Average annual change in groundwater NO$_3$-N concentration over four years on Missouri MSEA fields

One-half of the wells show no significant change over the four-year assessment period (Figure 5). Twenty-two percent of the wells had an average annual change $\geq \pm 0.5$ mg l^{-1}year^{-1}. Only 3% of the wells (two wells) increased at a rate ≥ 0.5 mg l^{-1} year^{-1}. In contrast, 19% of the wells (twelve wells) significantly decreased in NO$_3$-N concentration ≥ 0.5 mg l^{-1} year^{-1}. Ten percent of the wells (six wells), all from Field 3 and with initial concentrations 10 mg l^{-1}, had annual decreases ≥ 1.0 mg $\geq$ l^{-1}year^{-1}.

A comparison of the change in NO$_3$-N by field is summarized in the legend for Figure 5. While for Fields 1 and 2, individual wells showed both significant increases and others decreases, average change for these fields was small and statistically does not support any conclusion of a real change over this period. However, Field 3 is different from the other fields and has significantly decreased in NO$_3$-N at the rate of 0.68 mg l^{-1} year^{-1}. This decrease for Field 3 is undoubtedly real and probably reflects both pre-MSEA practices (1981-1990) as well as the influence of MSEA Farming System 3 (1991-1995). Given that groundwater hydrology is similar for these three fields, this analysis supports the hypothesis that the present N management for Field 3 is more unlike the N management for the period which resulted in NO$_3$ build-up in the aquifer than between the same time periods for the other two fields. If NO$_3$-N concentrations were to continue to decline at about the same rate and Fields 1 and 2 remained unchanged, groundwater NO$_3$-N among these fields would be about the same by the year 2002. Additional investigations are testing the assumption that groundwater flow is similar between fields and how flow affects NO$_3$-N storage in the aquifer.

Conclusion

Non-point source NO$_3$ contamination of groundwater in the glacial aquifer has occurred from past management. Judging by results to date, current N management practices represented by these three farming systems do not appear to be greatly increasing NO$_3$ in groundwater. It is important to note that the concentration of

NO_3 in a glacial aquifer represents the cumulative effect of many years of N management at the land surface. Only by collecting samples over time from the same wells, while at the same time documenting the land management practices, can a determination be made of the impact of those practices on groundwater quality. Data collected to date at the Missouri MSEA are not sufficient to determine specific fertilizer N application rates or N management strategies that will cause degradation of groundwater quality.

REFERENCES CITED

Blanchard, P.E., and N.R. Kitchen. 1993. Nitrate transport in fractured till: The importance of diffusion and matrix biogeochemistry. EOS 74:281.

Blevins, D.W., D.H. Wilkerson, B.P. Kelly, and S.R. Silva. 1996. Movement of nitrate fertilizer to glacial till and runoff from a claypan soil. Journal of Environmental Quality. 25:584-593.

Burkhart, M.R., and D.W. Kolpin. 1993. Hydrologic and land-use factors associated with herbicides and nitrate in near-surface aquifers. Journal of Environmental Quality 22:646-656.

Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency. EPA-690/4-79-020. Cincinnati, OH.

Fedkiw, J. 1991. Nitrate occurrence in U.S. water (and related questions): A reference summary of published sources from an agricultural perspective. USDA Working Group on Water Quality. Washington DC

Hall, D.W. 1992. Effects of nutrient management on nitrate levels in groundwater near Ephrata, Pennsylvania. Groundwater 30:720-730.

Hallberg, G.R. 1989. Nitrate in groundwater in the United States. p.25-74. In Nitrogen management and groundwater protection R.F. Follett (ed.). Elseivier, Amsterdam.

Helsel, D.R. 1995. Nitrate in the nation's waters: A summary of recent studies. Update Water Resources, Universities Council on Water Resources. 101: 12-17.

Keeney, D. 1986. Sources of nitrate to groundwater. CRC Critical Reviews in Environmental Control 16:257-304.

Madison, R.J., and J.O. Brunett. 1985. Overview of the occurrence of nitrate in groundwater of the United States, in National water summary 1984–hydrologic events, selected water-quality trends, and ground-water resources. United States Geological Survey Water-Supply paper 2275; p. 93-105.

McMahon, P.B., D.W. Litke, J.E. Paschal, and K.F. Dennehy. 1994. Groundwater as a source of nutrients and atrazine to streams in the South Platte river basin. Water Resources Bulletin 30:521-530.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-430. In Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, A.L. Page (ed.). Madison, WI.

Onstad, C.A., M.R. Burkart, and G.D. Bubenzer. 1991. Agricultural research to improve water quality. Journal of Soil and Water Conservation 46: 184-188.

Spalding, R.F., and M.E. Exner. 1993. Occurrence of nitrate in groundwater–a review. Journal of Environmental Quality 22:392-402.

Ward, A.D., J.L. Hatfield, J.A. Lamb, E.E. Alberts, T.J. Logan, and J.L. Anderson. 1994. The management systems evaluation areas program: Tillage and water quality research. Soil and Tillage Research: 30:49-74.