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Impacts of swine manure application and alternative N-management practices on productivity, sustainability and water quality

Rameshwar S. Kanwar
Iowa State University, rskanwar@iastate.edu

Douglas Karlen
United States Department of Agriculture

Cynthia A. Cambardella
United States Department of Agriculture

Thomas Moorman
United States Department of Agriculture, tom.moorman@ars.usda.gov

Thomas R. Steinheimer
United States Department of Agriculture

See next page for additional authors

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Abstract
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Lead Investigators
Rameshwar S. Kanwar, Douglas Karlen, Cynthia A. Cambardella, Thomas Moorman, Thomas R. Steinheimer, and Thomas S. Colvin

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Principal Investigator:
Rameshwar S. Kanwar
Agricultural and Biosystems Engineering
Iowa State University

Co-investigators:
Douglas L. Karlen
Soil Scientist

Cynthia A. Cambardella
Soil Scientist

Thomas B. Moorman
Microbiologist

Thomas R. Steinheimer
Microbiologist

Thomas S. Colvin
Agricultural Engineer
National Soil Tilth Laboratory
Ames, Iowa

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Background

Nitrate-nitrogen from farm operations, including row crop and animal agriculture, has been detected in the surface and groundwater sources in many agricultural regions of the country including Iowa. Current fertilizer and manure application methods and rates are believed to be significant contributors to the contamination of surface and groundwater.

As the incidence of agricultural chemicals in Iowa's surface and groundwater increases, nitrate-nitrogen (NO_3-N) is the chemical nutrient most commonly found in groundwater. Nitrogen from manure or fertilizers applied to the soil surface prior to and immediately following planting is particularly susceptible to loss through surface runoff or leaching to groundwater. Farmers need information that will allow them to select a combination of farming practices (tillage, crop rotations, manure application, and chemical management) that will minimize the movement of soil-applied chemicals into Iowa's water supplies.

Swine production in Iowa has changed radically with the recent adoption of larger, more intensive production confinement systems that may have a greater negative impact on water quality than previous smaller systems. Of particular concern are the surface runoff losses of nitrogen and phosphorous, and the leaching losses of nitrogen as NO_3-N. Ammonium-nitrogen can cause fish kills, NO_3-N has a safe drinking water level of 10 mg/l, and phosphate can promote the growth of algae and hasten the process of eutrophication in lakes and reservoirs. Another water quality issue is the potential for pathogenic bacteria to be transported from land treated with animal manure into water resources used for human consumption and recreation.

The investigators studied nine alternative nitrogen, tillage, and crop management strategies with these project objectives:

- determine the effects of five N-management practices (late-spring nitrate-nitrogen test, a reduced N application rate of 100 lb/ac, and swine manure application providing a total N rate of 100 lb/ac) on shallow groundwater quality under corn-soybean rotation with either no-till or chisel plowing as the primary tillage practice. Plots receiving swine manure were chisel plowed for corn in rotation with no-till soybeans.
- determine the effects of two alternate N-management practices (N application of 120 lb/ac with either swine manure or UAN fertilizer) on water quality under continuous corn with chisel plowing as the primary tillage practice.
- determine the effect of two alternate crop management systems, a) strip cropping:

narrow strips of corn, soybeans, and oats followed by a N-fixing berseem clover cover crop; and b) N-free cropping system: six-year rotation of alfalfa-alfalfa-alfalfa-corn-soybean-oats on shallow groundwater quality and sustainability of these two production systems.

Methods and materials

Experimental plots used in this study were located at Iowa State University's Northeast Research Center near Nashua. Forty 1-acre plots with fully documented tillage and cropping records for the past 17 years and a 16-year-old subsurface drainage system were used. Nine farming systems described in Table 1 were evaluated at the study site. Each treatment was replicated three times, except treatments 8 and 9 which were replicated only two times.

This study was also used to make comparisons between no-till and chisel plowing, between late spring N-test and single N applications of 100 and 120 lb/ac, between banding vs. broadcasting of herbicides, between 100 lb/ac of N from inorganic fertilizer and swine manure, between crop rotations of continuous corn and corn-soybeans, and their impacts on water quality.

Swine manure was obtained from a manure pit under a growing/finishing building. Applying proper amounts of swine manure to reach target nitrogen levels was difficult. Analysis of applied manure showed application rates two to three times greater than target levels in 1993 and 1994, but closer to target levels in 1995 and 1996.

Results and discussion

The first year (1993) was extremely wet, causing all the tile to flow for much of the season. For 1994 through 1996, rainfall was either near normal or below normal and many of the tile lines did not flow during parts of the growing season. These differences in precipitation patterns had significant impacts on NO_3-N leaching to shallow groundwater and on corn yields. Near normal rainfall resulted in less NO_3-N leaching to shallow groundwater and higher N uptake by corn.

Effects of farming systems on subsurface drain flow volumes. When both yearly and average subsurface drainage flows were measured for 1993-1996, System 2 (no-till) had the greatest drainage volume during years when corn was planted while no significant difference was noted during years when soybean was planted. Generally total drain flows were higher in the soybean plots when compared to the corn plots, which may be due to the corn rooting system remaining from the previous year.

Impact of liquid swine manure on NO_3-N leaching. Although relatively large differences were observed with subsurface drainage volumes, the NO_3-N concentrations were less variable during the four years of the study. Achieving the desired N application rates with liquid swine manure continued to be one of the most challenging problems, not only for the farmers but also for the researchers. The difficulty in applying proper amounts of swine manure affected the NO_3-N leaching through the subsurface drainage as well. Generally, the highest NO_3-N concentrations in the drainage water occurred under continuous-corn and the cumulative effect of high manure application rates in 1994 and 1995 was apparent in the raised concentration levels. The high drainage volume observed in 1993 resulted in the greatest NO_3-N losses for both continuous corn and rotation practices in 1993, showing that precipitation is a major factor in nitrogen leaching losses to the shallow groundwater.

Effect of nitrogen management practices on NO_3-N leaching. Four-year averages for NO_3-N concentration show that concentrations were lowest during years when soybean was planted

Table 1. Management systems being evaluated at the Nashua water-quality site

System	Crop	Tillage	N-practice	Herbicides
1	Soybean	No-tillage, drilled beans	None	Broadcast, 2.5 lb/A Lasso; 50-100 g/A Pursuit
1	Corn	No-tillage row cleaners	25 lb/A preplant + UAN based on LSNT	Band 2.5 lb/A Dual + 2 lb/A Extrazine
2	Soybean	No-tillage, drilled beans	None	Post-emergence Pursuit only
2	Corn	No-tillage, row cleaners	100 lb N/A preplant	Broadcast Dual + Extrazine
3	Soybean	Chisel stover drilled beans	None	Broadcast Lasso + Pursuit
3	Corn	Field cultivate soy residue	25 lb/A preplant + UAN based on LSNT	Band Dual + Extrazine
4	Soybean	Chisel stover drilled beans	None	Post emergence Pursuit only
4	Corn	Field cultivate soy residue	100 lb N/A preplant	Broadcast Dual + Extrazine
5	Soybean	Chisel stover drilled beans	None	Broadcast Lasso + Pursuit
5	Corn	Chisel plow soy residue	Swine manure‡, ~100 lb N/A	Band Dual + Extrazine
6	Corn	Chisel plow, cont. corn	Swine manure, ~120 lb N/A	Broadcast Dual + Extrazine
7	Corn	Chisel plow, cont. corn	120 lb N/A preplant	Band Dual + Extrazine
8	Strip crop	Chisel plow	LSNT , 28% corn	Lasso 2.5 lb./A
9	Alfalfa/Corn /Soybeans	Chisel plow	None	Lasso 2.5 lb./A

and were highest under continuous corn. These data suggest that crop rotation may be used to lower NO_3-N concentrations in subsurface drainage water.

Nitrate-nitrogen losses through subsurface drainage water were related to drainage volumes observed for each plot. Generally, losses were greatest during 1993 due to higher precipitation, and less during 1994 and 1995 when precipitation was near normal. However, four-year average losses were higher under continuous corn when compared to rotation practices, except when compared to no-till in System 2.

Effect of late spring NO_3-N test (LSNT) on water quality under no-till system: In spite of higher total N applications, LSNT plots exhibited NO_3-N drainage water concentrations quite similar to plots with single N application rates of 100 lb/ac.

Effect of LSNT on water quality under chisel plow system: Results indicated that with both LSNT and single N applications of 100 lb/ac, it is quite possible to bring the NO_3-N concentrations in the drainage water quite close to or even below 10 mg/l (drinking water standard).

Effect of strip crops and forage cropping system on water quality: Clear indications are that forage and strip cropping systems could reduce the NO_3-N concentrations in the drainage water well below the drinking water standard of 10 mg/l.

Overall, several N management systems (LSNT, strip cropping, alfalfa crop, single N application at 100 lb/ac) could be used successfully to reduce leaching of NO_3-N into shallow groundwater.

Effect of pesticide management systems on water quality. Data indicate that herbicide losses are more affected by rainfall amounts than by the N management system used.

Effect of banding vs. broadcast on herbicide leaching: Banding appears to be highly significant in reducing the overall yearly atrazine and metolachlor losses with the subsurface drainage water. Herbicide leaching losses were much lower from manure plots than from non-manure plots. Swine manure may decrease atrazine leaching to groundwater for two reasons. One, the increased microbial activity in the manure plots may increase the microbial degradation of atrazine, making it less available for leaching to groundwater. Two, the greater degree of adsorption of atrazine to organic matter supplied by swine manure would also act to deter the atrazine from leaching to groundwater. The amount of rainfall and resulting runoff also play a major part in herbicide losses with runoff water.

Effect of swine manure on fecal coliform in the drainage water. The average fecal coliform count in the drainage water was less than 10, which indicates that manure plots have not significantly increased the fecal coliform count in the groundwater (although one count of 14 shows elevated levels).

Effect of N management systems on crop yields, N mineralization, and N-uptake. Compared to natural systems, agricultural systems are extremely leaky, especially with regard to N. Up to 75 percent of the fertilizer N recovered by corn plants may derive from the N-pool created by mineralization of soil organic matter. Therefore, soil organic matter must be considered an important resource in agroecosystems, capable of providing substantial amounts of N for crop growth. This may be especially true for agricultural systems where manure is applied as a source of N.

The corn plant's need for N is greatest from mid-June to mid-August in Iowa. Since corn is obtaining up to three-quarters of its N from the mineralization of soil organic matter, the change in mineralization potential in midsummer should be correlated with observed crop N uptake. Higher corn yields were observed under the LSNT treatments for both no-till and chisel plow systems in comparison to the single N applications at 100 lb/ac. The next highest corn yields were obtained under continuous-corn production for both liquid UAN and manure applications. Soybean yields were similar and were not affected by N applications in corn years.

Corn response: Both rotated and continuous corn yields have been lower than the previous long-term averages for several reasons. In 1993, excessive rainfall and unexpectedly low levels of N from the swine manure had very negative impacts on yields. The 1994 yields for Systems 3 and 4 were closer to the long-term chisel plow mean, but no-till yields for Systems 1 and 2 lagged behind the long-term average for the research farm. This implies that 100 lb/ac preplant N is not sufficient for no-till corn production on these soils, but it may also reflect a high loss of residual N from the 1993 floods. The 1995 yields were quite low for all systems because of a severe hailstorm during pollination and early grain-fill. Additional data are needed to fully understand the crop production impacts of the altered management practices.

When averaged for both chisel and no-till practices, the LSNT approach has consistently resulted in higher corn grain yields than a preplant application of 100 lb/ac N. However, the LSNT predicted an average fertilizer requirement of 115 lb/ac with some variation among years and between tillage treatments.

Soybean response: Three-year average soybean yields for all five management systems ranged from 42 to 45 bu/ac. These were similar to the 15-year averages of 42 and 41 bu/ac for chisel plow and no-till soybean. The average yield for Systems 1 to 4 was 44 bu/ac for both chisel and no-till treatments, suggesting that changing from row beans to drill beans may not result in major soybean yield differences on these types of soils.

Nitrogen mineralization potential: The capacity of a soil to supply plant-available N can be described by quantifying the N mineralization potential of that soil. There was a slight increase in mineralization potential in fall 1994 that carried over to 1995, indicating that the soil was beginning to recover from the flushing that occurred during the summer of 1993. These data suggest that a portion of the potentially mineralizeable N pool in soil may be vulnerable to leaching if the conditions are appropriate as they were in 1993. Since a growing corn crop derives up to 80 percent of its N from the mineralization of soil organic N, loss of mineralization capacity could result in below-average yields until soil organic N pools return to earlier levels.

Conclusions

The late spring nitrate test (LSNT) resulted in the lowest four-year average NO_3-N concentrations in subsurface drainage water when compared to the other six N-management systems studied at this site, including the single N application rates of 100 bu/ac, manure applications, and higher N application rates at 120 bu/ac.

The alternate cropping systems like strip cropping and alfalfa resulted in the lowest NO_3-N concentrations in subsurface drainage water in comparison to all management practices evaluated at this research site.

Continuous corn plots receiving swine manure applications resulted in significantly higher NO_3-N concentrations in subsurface drain water in comparison with manure-applied corn plots rotated with soybeans. This indicates that the use of swine manure under corn-soybean rotation showed the potential to reduce negative water quality impacts with proper manure management.

The highest corn yields were obtained with the LSNT under both the no-till and chisel plow system. The next highest corn yields were obtained from manured plots rotated with soybeans.

Reduced herbicide inputs through banding (one-third of the herbicide used compared to the broadcast practice) resulted in significantly reduced herbicide leaching losses to subsurface drainage water in comparison with herbicide broadcast practice.

Impact of results

Nitrogen management is the key factor for controlling groundwater contamination by nitrogen fertilizers and manure applications. The potential negative water quality impacts stemming from excessive use of N fertilization and animal manures are well-known to farmers and the chemical and livestock industry. The results of this study suggest that increased emphasis should be placed on the use of soil tests (like the late spring nitrate test) to determine appropriate N application rates and give proper credit to N sources such as animal manure, soil residual nitrogen, and crop residue. Manure and fertilizer applications should be based on manure nutrient and soil N test information to reduce NO_3-N leaching and increase plant N uptake for greater yields. Animal manure should be analyzed before application, in order to avoid applying excessive amounts of nutrients.

The results of this study show clearly that the use of different systems such as strip crops and alfalfa can significantly reduce NO_3-N leaching to groundwater while increasing N self-sufficiency in sustainable cropping systems. These cropping systems decrease N fertilizer costs for farmers and provide long-term N_2 fixation for N self-sufficiency. Increased use of forage legumes will also help in maintaining long-term sustainable farming systems.

For more information, contact R.S. Kanwar, Agriculture and Biosystems Engineering, Iowa State University, Ames, Iowa 50011; (515) 294-4913; e-mail rskanwar@iastate.edu

Education and outreach

1994: Presentations on the project were made in Ames to international tour groups, Extension staff, and agricultural and biosystems engineering faculty. Field days were held in Ames and Nashua. The project was described at the International Seminar on Environment and Water held at Katmandu, Nepal.

1995: The project was discussed at the International Conference on Sustainability and Environment held at Hisar, India; at the Systems for Sustainable Agriculture Conference in Los Banos, Philippines; and at the World Bank Conference on Environment and Water Quality Standards in Tashkent, Uzbekistan. In Ames, the study was featured at an ISU Extension Workshop and the agronomy department field day. Papers on the research were presented at the National Water Quality Conference in Kansas City and at the International Conference on Environment and Sustainability at Orlando, Florida.

1996: Field days in Ames and Nashua provided opportunities to explain the project's findings. The research was also disseminated at the International Conference on Environmental and Biological Engineering in Beijing, China, and the International Agricultural Engineering Conference in Poona, India.

1997: Events were held at the Nashua experimental site: two field days and two crop professional and Extension tours. International exposure for the project included the International Conference of Hydrologic Sciences in Rabat, Morocco, and a Short Course on Water Quality in Tashkent, Uzbekistan.

Nine research publications have been prepared based on the data collected and research findings from this project.