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Project Summary

Nitrates in Groundwater Resulting from Manure Applications to Irrigated Cropland

Wynn R. Walker and Bruce E. Kroeker

Yearling beef manure was applied in three rates and three frequencies to 57 experimental plots located within a 9.3 ha field near Grand Junction, Colorado. The basic management practices investigated were irrigation and manure loading frequency, irrigation efficiency, and manure loading rates. Climatological conditions, soil moisture, evapotranspiration, groundwater outflows, and the furrow irrigation system performance were measured in the field plots. The soil was sampled and tested for nitrate-nitrogen (NO_3-N), total Kjeldahl-nitrogen (TKN), ammonium-nitrogen (NH_4-N), total organic carbon (TOC) and the common salinity constituents. Vacuum extractors below the soil root zone in 10 plots were used to measure and sample the water percolating downward. Crop N-uptake was evaluated by periodic analysis of plant samples. A soil-plant-water-N simulation model reported in the literature was used to evaluate the field data and predict the conditions in the field plots.

Model simulations were run for a wide range of typical Grand Junction conditions to evaluate the effect of irrigation and manure utilization practices on NO_3-N contamination of groundwater. The results indicate the time required to reach a steady-state condition and the quantitative effects of irrigation efficiencies, irrigation frequency, manure loading rates, manure loading frequency, and initial soil organic matter content.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In the United States, annual excremental animal manures are estimated to exceed human wastes by an order of magnitude. For the feeding operations that are increasingly using confinement systems, the large manure volume creates a sizeable disposal problem. Land application of animal manure has been a fertilization practice for thousands of years and today remains the cheapest and most common manure disposal method. Most land surfaces used for applying manures are agricultural croplands, many of which require irrigation to supplement natural precipitation.

Animal manure contains a variety of salt and organic materials that easily dissolve or suspend in water and thereby degrade water quality. The spreading of manure over agricultural lands gives rise to two broad water quality detriments. First, precipitation and irrigation overland flows erode surface materials including the organic and mineralogical components of the manure and transport them to nearby receiving waters where the nutrients can lead to eutrophication and the salts to toxic impacts on native biota. The second problem centers on the infiltration of water through the soil toward groundwater basins. Soluble N, C, and salt constituents are transported downward by the water and are partially transformed by the soil and its microbial population. In both aspects of this environmental problem, the control of the water movement through improved irrigation and tillage practices can substantially reduce the detriments.

The least understood problem is the management of irrigation and land disposal systems in conjunction with an objective of groundwater quality control. The literature does not describe many studies in which manure application, irrigation, and groundwater systems are investigated collectively. This study evaluated the effects of various irrigation practices and manure loading rates on the movement of pollutants toward groundwater basins. Thus, the study was designed to provide a range of conditions broad enough to verify a simulation model of the physiochemical-biological processes involved. The model can be used to evaluate alternative management practices as long as the range of conditions for which it had proven reliable is not exceeded.

The scope of this study was necessarily limited by time, space and funding. Of the variety of animal manures being applied to irrigated lands, only yearling beef cattle manures were studied, the characteristics of which are summarized in Table 1. To lessen groundwater impacts, the surface runoff component was minimized by incorporating the manure into the upper 20 cm of the soil and controlling the field tailwater runoff rates. The field was planted to corn and was watered with conventional furrow irrigation practices.

Table 1. *Summary of Manure Characteristics*

Constituent	*Average Composition (% Dry Weight)*
Dry Matter	66.68
Volatile Solids	63.74
Biochemical Oxygen Demand$_5$	2.57
TKN	2.24
NH_4-N	0.30
Total Inorganic-N	0.30
Total Carbon	28.20
TOC	26.70
Total Phosphorus	0.19
Othophosphate	0.03
Chemical Oxygen Demand	3.51
Calcium	2.96
Sodium	0.67
Potassium	2.13
Chloride	1.65

Conclusions

A computer simulation model reported in the technical literature was tested with three years of field data from an irrigated site near Grand Junction, Colorado, where variable applications of yearling beef manure had been made. With adjustments to the rate coefficients for the mineralization of the manure, the model predicted field measurements within 10% to 25% for more than 80% of the total data base. Since individual components of the model have been verified elsewhere under other soil, crop and climatic conditions, it is concluded that it represents a usable and effective simulation tool.

The mathematical and conceptual sophistication of the model is within the expertise of practicing engineers and soil scientists. Input data are easily collected as part of routine monitoring and evaluation studies.

Results of the model testing indicate that the most important irrigation of the season in moving NO_3-N toward a groundwater system is the first water application. In most surface irrigated conditions, about 50 to 75 percent of the annual deep percolation comes from the preplant or emergence irrigation. Subsequent irrigations occur when the soil surface exhibits a lower infiltration rate and the crop root zone is active to a greater depth. For the Grand Junction soil, improving the first irrigation from a typical 24-cm application to a 12-cm application reduced the annual N flux below the 200-cm depth by more than 50 percent.

Manure applications on irrigated lands increase N losses from the system by both denitrification and leaching in direct proportion to the loading rates. Increasing the net weight application rate from about 12 metric tons/ha (MT/ha) to 404 MT/ha increased denitrification losses by 900 kg-N/ha/yr, and leaching losses to the groundwater basin by 360 kg-N/ha/yr.

Probably the most interesting conclusion regarding the loading management is the effect of application frequency on the N losses due to denitrification and leaching. Applying manure each year, every other year, and every third year over an extended period results in very small changes (about 10 percent) in the amount of N leached from the 200 cm profile. The losses due to denitrification on the other hand are reduced significantly by less frequent loadings. Consequently, as a disposal practice, manure applications should be made more frequently in order to maximize the treatment efficiency of the soil-crop system.

The salts in the manure applied to irrigated lands create conditions detrimental to efforts aimed at controlling N contamination of groundwater resources. Heavy loadings and efficient irrigation practices will result in very large accumulations of salts in the soil profile between 40 cm and 120 cm and therefore will seriously affect crop yields. The same heavy loadings coupled with traditional irrigation practices still result in salination of the soil profile below 60 cm but do not tend to accumulate salts beyond a level dictated by the annual leaching fraction.

Recommendations

The effects of animal manure additions to the upper soil profile on the decomposition of soil and organic materials under field conditions need further attention in the model. The modification in the mathematical forms of the model should probably be made in the mineralization rate coefficients. The rate coefficients for other N and C transformations worked well for local conditions and have also been verified elsewhere.

Controlling the applied depth of irrigation water during the first irrigation should be the most emphasized irrigation practice for managing the contribution of N to underlying groundwater basins. More frequently, irrigation should also be considered for controlling N leaching.

Annual manure loadings should be encouraged over less frequent applications, where disposal rather than fertilization is the primary objective of the program. Careful evaluation of the salts contained in the manures should be made if crop production is to be maintained, particularly if high irrigation efficiencies can be achieved consistently.

Modeling Irrigation and Manure Loading Practices

Several modifications were made to the original computer code in order to study the consequences of various irrigation and manure disposal practices on the N system. Following the revisions, a large array of initial conditions, irrigation practices, and manure loading strategies were evaluated. In order to illustrate the results, the effects of irrigation practices as represented by irrigation efficiency and the effects of manure loading practices as represented by loading rates will be summarized.

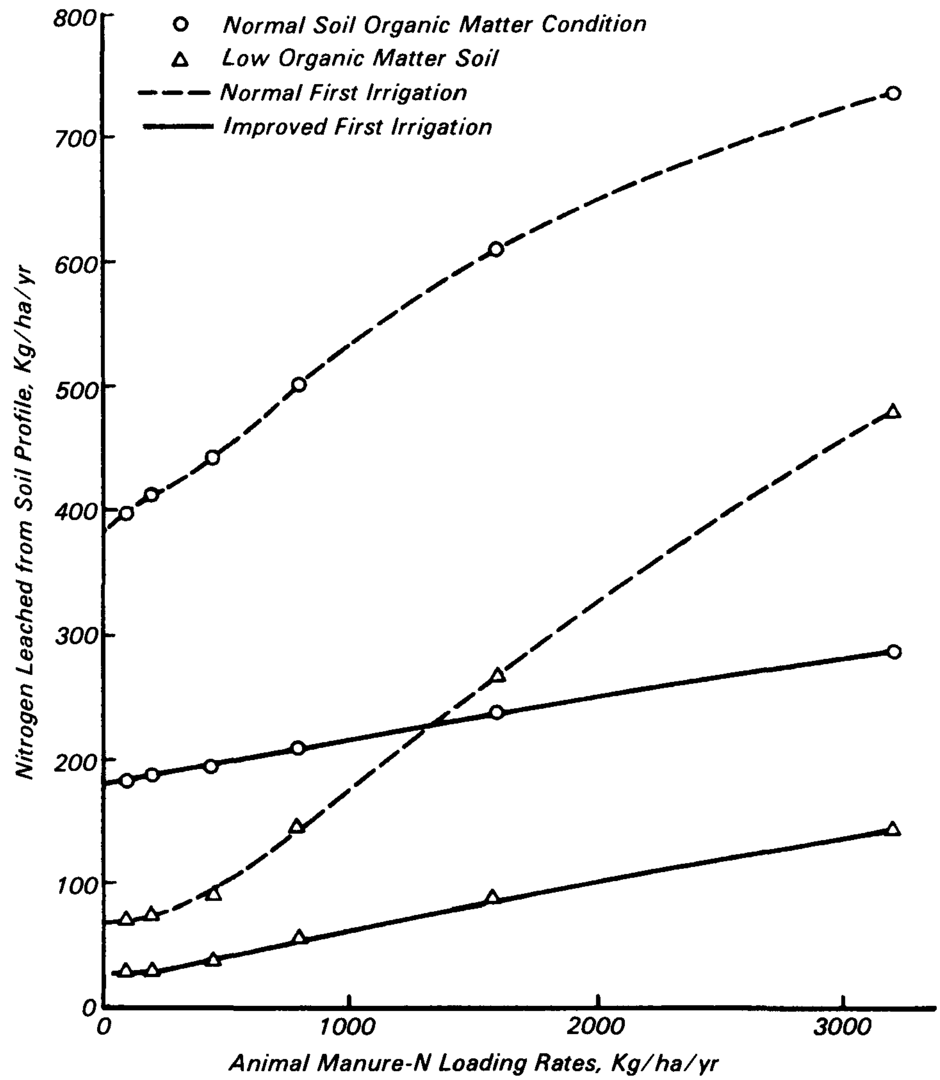

Figure 1. *Comparison of nitrogen leaching rates as functions of manure-N loading rates for normal and improved first irrigation efficiency.*

Effects of Irrigation Efficiency

Using the normal site conditions, leaching and denitrification losses resulting from the range of annual manure loadings were simulated over the period of years required to reach "equilibrium" at a 2-m depth in the soil. These tests were made for irrigation application efficiency typical of furrow irrigation systems as well as an "improved" condition in which the applied depth during the first irrigation was reduced by one-half. The results are illustrated in Figure 1 and include results for the case in which the natural organic matter content in the soil profile was defined at 20 percent of the normal condition.

For the normal condition, leaching rates shown in Figure 1 increase approximately linearly from about 400 kg-N/ha/yr to over 700 kg-N/ha/yr. By improving only the first irrigation, these rates are decreased by about 50 percent.

There are indications in the literature that maintaining soil moisture at various levels could have significant effects on denitrification. The effect, therefore, would reduce the leaching losses of NO_3-N and NH_4-N. In the field investigations, irrigations were initiated when the available soil moisture had been depleted by 60, 30, and 15 percent, respectively. To test the effects of average soil moisture levels, the normal site condition receiving spring manure loadings over extended periods were simulated at these three values. The results indicated that changing the frequency reduced NO_3-N leaching substantially, but the effect is primarily one of irrigation efficiency rather than frequency. However, the frequency of applying irrigation water was important if viewed from its actual effect on irrigation efficiency. The wetter soil condition, found under more frequent irrigated systems, exhibits lower infiltration characteristics and therefore provides a more manageable irrigation system.

Effects of Manure Loading Practices

A definite effect on N leaching and denitrification was evident from the level of soil organic matter present at the time the manure disposal was started. A similar loading simulation on a soil of low initial organic content produced less potential N contamination of the groundwater than a soil naturally high in organic matter.

In addition to loading rates, another manure management alternative is to apply the manure in varying annual cycles. Following the experimental design, the consequences of applying the wastes annually, every second year, and every third year were studied. To present these results in a somewhat different light, the ratio of N leaching losses to denitrification losses for the three alternatives are plotted in Figure 2 for the unimproved irrigation system at Grand Junction. When manure was applied each year, the leaching-denitrification ratio was greater than one until the annual loading rate was about 800 kg-N/ha/yr. Then, the denitrification losses were larger than the leaching losses. When the manure was applied every second year, the transition occurs at approximately 2,100 kg-N/ha/yr. For loadings of every third year, the leaching losses are always substantially higher

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than the denitrification losses. It is important to note that when the total nitrogen leaching was evaluated, the differences between the three treatment levels were less than 10 percent.

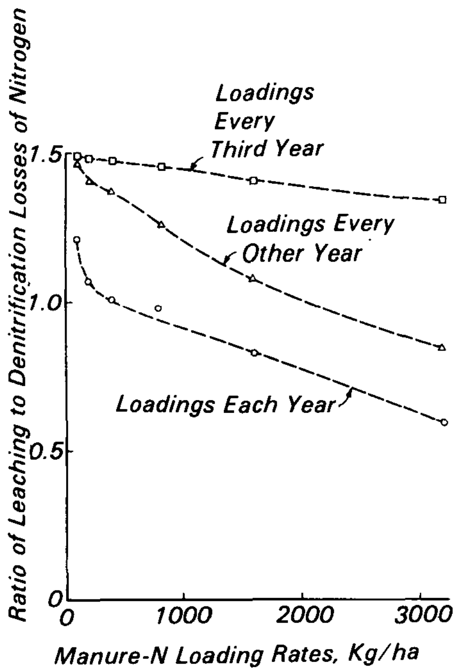

Figure 2. *The effect of variable intervals between manure applications on the ratio between denitrification and leaching of nitrogen.*

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The complete report, entitled "Nitrates in Groundwater Resulting from Manure Applications to Irrigated Cropland," (Order No. PB 82-255 415; Cost: $10.50, subject to change) will be available only from:

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