USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Field Assessment of Groundwater Quality Beneath Cracking Soil with Surface-Applied Hog Manure

Focus Categories: AG, GW, NPP

Keywords: Agriculture, Animal Waste, Contaminant Transport, Groundwater Quality, Hydrology, Infiltration, Mathematical Models, Soil Physics, Surface-Groundwater Relationships, Unsaturated Flow, Water Quality Modeling

Duration: March 1, 2000 to February 28, 2001

FY 2000 Federal Funds:

$ 11,258	$ 11,258	$ 0
Total	**Direct**	**Indirect**

FY 2000 Non-federal Funds:

$ 22,808	$ 12,317	$ 10,491
Total	**Direct**	**Indirect**

Principal Investigator:

Dr. Robert Horton
Department of Agronomy
Iowa State University

Congressional District: 3rd

Problem Statement and Research Objectives

Groundwater contamination as a result of hog manure application in the farm has long been recognized as a serious environmental threat particularly in Iowa, where numerous large hog confinement facilities exist. Hog manure has been used by farmers as a source of nutrients for crops through surface application (Hoag and Roka, 1995). Surface-applied manure is a potential source of nitrate in surface and groundwater (Simpson, 1991). Other contaminants such as phosphates and bacteria may also be present in the applied manure (Cook, 1998; Baker, 1999 and Lorimor, 1999) thereby all the more increasing the threat to groundwater quality degradation.

While a number of studies have been done on groundwater contamination by livestock manure (e.g. Korom, 1994; Rasmussen, 1998; Kitchen, 1997; Nissen, 1998; Cook, 1998; Hegde, 1998) and on methods to reduce manure impact on both surface and groundwater resources (e.g. Mikkelsen and Gilliam, 1995), studies on the manure transport in cracking soils have received very little attention. Cracking soils occupy a large part of the state of Iowa and a substantial part of the midwest region. Water containing manure can flow preferentially along openings of cracks. The formation of cracks and the widths of openings have been shown to be a function of soil water content (Noborio et al, 1998). Ewing et al. (1998) also reported that the depths of cracks of an Iowa cracking soil could reach 0.5 to 0.7 m below the ground surface and that the cracks are connected to wormholes so that the surface cracks act as collectors or funnels for wormholes which might carry contaminated surface water to groundwater. With field measurements, Lin et al (1998) found that areas with 1 to 5 mm-wide cracks had two to three times higher infiltration rates than sites with without cracks in cracking soils. After cracks appear to be closed with hydration, they still contribute to flow (Drumm and Wilson, 1997). Widths of cracks could reach as wide as > 30.0 mm in the field while they could be >0.1 m in extreme cases (Lin et al., 1998). Water can flow at rates as high as 0.5 m/s through 30 mm-wide surface cracks, several orders of magnitude larger than in clay. Thus, a risk of drinking water contamination due to surface-applied hog manure in regions with cracking soils might be higher than anticipated. In order to develop appropriate hog manure application strategies that will reduce groundwater quality degradation, detailed studies of preferential transport through dynamically changing cracks need to be conducted.

Furthermore, in terms of research methodology, no study on hog manure transport in cracking soils using time domain reflectometry (TDR) has ever been reported. This relatively new method for gathering water content and bulk electrical conductivity data has shown applicability in a number of solute transport experiments (e.g. Kachanoski et al., 1992; Elrick et al., 1992; Mallants et al., 1994 and 1996; Ward et al, 1994; Risler, et al., 1996; Rudolph et al., 1996; Persson, 1997; Vanclooster et al; 1993 and 1995; Lee et al., 1999) and even for cattle manure transport (Nissen et al., 1998). Yet, none of these research publications had ever dealt with manure transport in cracking soils. Thus, research efforts geared towards the use of TDR for monitoring manure transport in cracking soils is deemed an important research strategy towards fulfilling the overall goal of investigating and characterizing manure impacts on groundwater quality, particularly in cracking field soils in Iowa.

The main objectives of this research remain essentially the same as in the original proposal. The general objectives are:

1. To obtain field-measured data on water, manure and crack dynamics in cracking soils; and

2. To apply a numerical model to simulate water flow and manure transport through dynamically changing soil cracks.

Progress to Date

Preliminary laboratory soil column study

Prior to field experiments, a soil column study was performed using manure as tracer at the Soil Physics laboratory of Agronomy Department to test the applicability of TDR for manure transport experiments. A soil column with a diameter of 8.5 cm and a length of 20 cm was used for this purpose. A 15-cm long TDR probe was installed vertically in this column and was connected directly to a Tektronix 1502B cable tester. Hog manure was applied over the surface of the saturated soil column and the effluent flow was collected at regular time intervals. The electrical conductivity (EC) of the effluent samples was measured using a conductivity meter. The effluent EC breakthrough curve compared well with the TDR breakthrough curve indicating the feasibility of using TDR for manure transport studies.

Field experiments

Four field experiments have been conducted in the lysimeters at the Agronomy and Agricultural Engineering Research Center of Iowa State University, about 7 miles west of Ames. The lysimeter is a non-weighing type with a width of 0.97 m, length of 2.28 m and a depth of 1.35 m and has a built-in piezometer. The experimental set-up involves the use of a 1000-gal water tank with built-in flow regulator as water source for ponding the lysimeter and an impeller pump for collecting effluent samples from the tile drain at the bottom of the lysimeter. Sixteen (16) TDR probes ranging in length from 15 cm to 60 cm were installed vertically in the lysimeter and were connected to a multiplexer. A Tektronix 1502B TDR cable tester was connected to the multiplexer and a laptop computer to form the TDR data collection system. Liquid manure was obtained from the pit of Bisland farm in Madrid, Iowa.

The first two experiments were performed under saturated flow conditions on September 23 and October 21, 1999, respectively. The soil in the lysimeter was initially saturated from the bottom. Each of the 16 probes was set up by trial and error procedure to conform with the approximate initial moisture content of the soil using a TACQ program developed by Evett (1998). This program was also employed for collecting waveform data for moisture content and bulk electrical conductivity.The TDR measurement was commenced prior to the manure application. The hog manure was applied uniformly over the surface of the lysimeter at a rate approximately equal to actual farm application rates of about 5000 gal/acre for hog manure obtained from pits. Afterwhich, the surface was ponded at a constant head of about 6.5 cm. Effluent samples with a volume of about 150 mL were collected every 34 L, representing about 1/40 of the pore volume of the lysimeter. The experiments were performed until about 1 to 2 pore volumes were collected.

For the first experiment (September 23, 1999), the TDR probes ranged in length from 15 to 30 cm. For the second experiment (Oct 21, 1999), two of 15 cm probes were replaced by 60 cm probes, which were fabricated by the principal investigators at the Soil Physics laboratory of the Agronomy Department using 1/4 -in. diameter steel bars and a coaxial cable.

The raw TDR data extracted using the TACQ program (Evett , 1998) was then processed using a spreadsheet program developed by the principal investigators employing a simplified waveform analysis developed by Wraith et al (1993). In the first experiment, preliminary data analysis showed that the plot of the reciprocal of the resistive impedance load R, a representation of the bulk electrical conductivity, against time exhibited a high degree of noise. This is apparently due to the usage of electric power for both the TDR cable tester and the computer and also to the interference of other existing electromagnetic waves in the lysimeter area. In an attempt to circumvent this problem, the use of an optical isolator as an interface between the cable tester and the laptop computer was explored. However, this approach did not provide any solution to the problem. The noise in the TDR waveform was finally eliminated in the second experiment (Oct 21, 1999) by using an electric generator and car battery to power the laptop computer and the TDR cable tester, respectively. Preliminary data analysis showed that the plots of 1/R against time for most of the probes became nearly smooth.

The third and fourth experiments were performed on October 28 and November 18, 1999 under transient unsaturated flow condition. A lysimeter with soil exhibiting an appreciable number of cracks was chosen for this experiment. Sixteen (16) TDR probes ranging in length from 15 to 60 cm were installed in the lysimeter, some vertically and the others at an angle, some within the cracks and others away from the cracks. The geometrical configuration of the cracks was photographed and also traced using plastic sheets to capture the relative location of the probes and cracks. The basic experimental setup employed in the previous experiments was used in these two experiments. The appropriate noise-eliminating power supplies were similarly employed. Hog manure was applied uniformly over the dry soil surface of the lysimeter at a rate of 5000 gal/acre. After infiltration, the surface was ponded with water at a constant head of 6.5 cm. Effluent samples were then collected until 1 to 2 pore volumes were discharged.

Laboratory analysis of effluent samples

The electrical conductivity of each sample from the 4 experiments was measured using a conductivity meter at the Soil Physics laboratory of the Agronomy Department. Electrical conductivity breakthrough curves (BTC's) were then generated for each of the 4 experiments. The resulting curves generally followed the typical behavior of breakthrough curves although a double hump was exhibited in the lysimeter experiments on soils with cracks.

A number of samples from the first experiment were recently tested for orthophosphate (PO_4-P) to gain an initial understanding of the nature of the effluent samples collected. The effluent samples are currently stored at a temperature of 4 deg. C for further laboratory analysis of the various major chemical constituents such as chloride and nitrate.

Soil core sampling

In view of the anticipated need to continue gathering additional information on manure transport in cracking soils even for shorter scales, several soil core samples were collected from the cracking soil area at the Agronomy and Agricultural Engineering Research Center within the vicinity of the lysimeter site. The core samples have a diameter of 10 cm and have lengths of 30 to 60 cm. They are currently stored at a temperature of 4 deg C and will be used for manure transport column experiments during winter time, when field experimentation is not feasible to perform.

Proposed changes and/or additions

In order to generate a broader database on manure transport in cracking soils that could serve as adequate basis for numerical modeling and for generating conclusive findings, the following changes and/or additions will be made to the original proposal:

1. In addition to lysimeter studies, actual field experiments using relatively pristine plots or sites with installed piezometers or tile drains will be used. Hog manure will be applied in the same manner as in real farms and will be allowed to infiltrate naturally the way it does during actual farm application or by rainfall rather than forced to infiltrate by ponding as in the case of lysimeter experiments. Moreover, groundwater quality will be monitored over a span of several months to allow for adequate mineralization effects to take place. A sufficient number of TDR probes will be installed within the cracks and away from the cracks and both moisture and electrical conductivity fluctuations will be monitored using a TDR cable tester. The termination of the experiment will be determined through occasional checks on both the water quality of the groundwater samples or tile drain samples and on TDR readings. Replications of this type of experiment will be done throughout the growing season.

2. To generate a more comprehensive evaluation of groundwater quality beneath manure amended areas, groundwater samples will be analyzed not only for NO_3-N and Cl as implied in the original proposal but also for orthophosphates and possibly bacteria. The bulk electrical conductivity of the groundwater and tile drain samples will similarly be determined and compared with TDR readings.

3. To enable numerical modeling using a field or watershed scale, hydrologic data such as rainfall, evapotranspiration and other hydrologic data that may be used to calculate evapotranspiration and runoff along with crop and soil management data will be collected. The spatial distribution of all parameters including cracks, TDR probe distribution, tile drain and piezometer layout will be determined to allow for 2- or 3-dimensional numerical modeling of manure transport. The use of numerical contaminant transport models such as HYDRUS 2D (Simunek et al., 1996), GLEAMS-CF (Morari and Knisel, 1997) and other potentially-applicable numerical models will be explored for simulating manure transport based on the data gathered.

4. Laboratory soil column studies using soil cores with cracks will be performed. During winter time, when field experiments are not feasible to perform, soil column studies will be performed to generate more information on the behavior of manure movement through

cracking soils. This will provide additional data and information on manure transport even at smaller scale and could serve as basis for estimating transport characteristics at this scale.

Future Plans

Research work leading to the acquisition of more information on the transport of hog manure in cracking soils and on the characterization of the dynamics of manure transport through numerical modeling will continue to be carried out in the coming year.

As indicated in the proposed changes and additions, laboratory soil column studies will be performed during the winter season, while field work is not feasible. This will involve the use of the collected undisturbed soil core samples with cracks. Manure transport experiments under saturated and unsaturated soil conditions will be performed employing both TDR measurement and direct effluent measurements. Results of these experiments will be analyzed and experimental breakthrough curves (BTCs) will be generated. The BTCs will then be simulated using appropriate numerical models in order to mathematically characterize the behavior of manure transport in cracking soils.

Additional lysimeter experiments will be performed under saturated and unsaturated soil conditions and under steady and transient flow conditions at the Agronomy and Agricultural Engineering Research Center to generate more replications and to obtain more data on manure transport. This will be done most preferably in the summer when the cracking of soils is more prominent and when daytime is long enough to enable the performance of relatively longer duration experiment at above freezing air temperatures.

As proposed, field experiments using actual plots or fields with cracking soils and with installed piezometers or tile drains will be performed. An appropriate experimental site at the Agronomy and Agricultural Engineering Research Center will be selected. Several multiplexed TDR probes will be installed over the research site. Hog manure will be applied over the surface in a fashion similar to actual farm application in terms of rate and method of application. The groundwater quality will then be monitored at regular time intervals by collecting groundwater and tile drain samples over several months that will allow potential nitrification and other biodegradation processes. The groundwater samples will be analyzed for the major chemical constituents that may pose a threat to groundwater quality such as nitrates and orthophosphates along with electrical conductivity and chloride contents. The TDR data will similarly be analyzed and compared with effluent data. Other hydrologic data such as rainfall and evapotranspiration will also be collected. The spatial distribution of the probes and the cracks will be obtained during the course of the experiments for use in the subsequent two dimensional contaminant transport modeling. The use of 2-D HYDRUS (Simunek et al., 1996), GLEAMS-CF models (Morari and Knisel, 1997) and other potentially-applicable numerical models will be explored for modeling the BTC's obtained in these experiments. Several replications of this type of experiment is deemed necessary to obtain a more reliable basis for generating conclusive results. These experiments will be performed in late spring and during summer up to late fall of the coming year. Data analysis, modeling and publication of results will be carried out during the remaining period of this project's extended duration.

On top of all this, the collected effluent data from the 4 field experiments already done to date will be analyzed for the major chemical constituents such as chloride, orthophosphate and possibly nitrates. Breakthrough curves for each of these constituents will be generated . The TDR data collected from the field experiments will similarly be analyzed and compared with the directly measured electrical conductivity data. The resulting breakthrough curves will then be modeled using appropriate numerical codes such as HYDRUS among other codes that may be applicable.

References

Baker, J.L. 1999. Personal communication. Department of Agricultural and Biosystems Engineering, Iowa State University. Ames, IA.

Cook, M.J. 1998. Bacteria in agricultural drainage as affected by manure management. M.S. Thesis. Iowa State University. Ames, IA.

Drumm, E.C., and G.V. Wilson. 1997.Infiltration tests on fractured compacted clay. J. Geotech. *Geoenviron. Eng*. 123;469-473.

Elrick, D.E., R.G. Kachanoski, E.A. Pringle and A.L. Ward. 1992. Parameter estimates of solute transport models based on time domain reflectometry measurements. *Soil Sci. Soc. Am. J*. 56:1663-1666.

Evett, S.R. 1998. The TACQ computer program for automatic measurement of water content and bulk electrical conductivity using time domain reflectometry. *ASAE meeting presentation.* Paper No. 983182. USDA-ARS. Bushland, TX.

Ewing, R.P., P.M. Walter, and R. Horton. 1998. An integrated approach to investigating soil cracks in the field. *Soil Sci. Soc. Am. J*. (In review)

Hegde, P. 1998. Impact of swine manure application on groundwater quality: a lysimeter study. M.S. Thesis. Iowa State University. Ames, IA.

Hoag, D.L. and F.M. Roka. 1995. Environmental Policy and swine manure management: Waste not or want not? *Am. J. Alt. Agr.* 10:163-166.

Kachanoski, R.G., E.A. Pringle, and A.L. Ward. 1992. Field measurement of solute travel times using time domain reflectometry. *Soil Sci. Soc. Am. J*. 56:47-52.

Kitchen, N.R. 1997. Impact of historical and current farming systems on groundwater nitrate in Northern Missouri. *Journal of Soil and Water Conservation*. 52:272-277

Korom, S.F. 1994. Nitrate contamination from dairy lagoons constructed in coarse alluvial deposits. *Journal of Environmental Quality*. 23:973-976.

Lorimor, J. 1999. Personal communication. Department of Agricultural and Biosystems Engineering, Iowa State University. Ames, IA.

Lee, J., R.Horton and D.B. Janes. 1999. Shallow TDR probe describes solute transport through soil cores. *Soil Sci. Soc. Am. J.* (In review).

Lin, H.S., K.J. McInnes, L.P. Wilding, and C.T. Hallmark. 1998. Macroporosity and initial moisture effects on infiltration rates in Vertisols and vertic integrades. *Soil Sci.* 163:2-8.

Mallants, D., M. Vanclooster, M., and J. Feyen. 1994. Estimating solute transport in undisturbed soil columns using time domain reflectometry. *J. Contam. Hydrol.* 17:91-109.

Mallants, D., M. Vanclooster, N. Toride, J. Vanderborght, M.Th. van Genuchten, and J. Feyen. 1996. Comparison of three methods of calibrating TDR for monitoring solute movement in unsaturated soil. *Soil Sci. Soc. Am. J*. 60:747-754.

Mikkelsen, R.L., and J.W. Gilliam. 1995. Animal waste management and edge of field losses. pp. 56-68. In K. Steele (ed.) *Animal waste and the land-water interface*. Lewis Publ., Boca Raton, FL.

Morari, F., and W.G. Knisel. 1997. Modifications of the CREAMS model for crack flow. *TRANSACTIONS of the ASAE*. 40: 1337-1348.

Nissen, H.H. , P. Moldrup, K. Henriksen. 1998. Time domain reflectometry measurements of nitrate transport in manure amended soil. *Soil Sci. Soc. Am. J*. 62:99-109.

Noborio, K., C.S. Tan, and R.G. Kachanoski. 1998. Temporal changes in fractal dimensions of soil cracks with dessication. *The International Conference on Precision Agriculture*, July 19-22, 1998, St. Paul, MN.

Persson, M. 1997. Soil solution electrical conductivity measurements under transient conditions using time domain reflectometry. *Soil Sci. Soc. Am. J*. 61:997-1003.

Rasmussen, P. 1996. Monitoring shallow groundwater quality in agricultural watersheds in Denmark. *Environmental Geology*. 27:309-319.

Risler, P.D., J.M. Wraith, and H.M. Gaber. 1996. Solute transport under transient flow conditions estimated using time domain reflectometry. *Soil Sci. Soc. Am. J*. 60:1297-1305.

Rudolph, D.L., R.G. Kachanoski, M.A. Celia, D.R. Leblanc, and J.H. Stevens. 1996. Infiltration and solute transport experiments in unsaturated sand and gravel, Cape Cod, Massachusetts: Experimental design and overview of results. *Water Resour. Res.* 32:519-532.

Simpson, T.W. 1991. Agronomic use of poultry industry waste. *Poultry Sci.* 70:1126-1131.

Simunek, J., M. Sejna and M. The. van Genuchten. 1996. HYDRUS-2D. Simulating water flow and solute transport in two-dimensional variably saturated media. U.S. Soil Salinity Laboratory. USDA-ARS. Riverside, California.

Vanclooser, M., D. Mallants, J.Diels, and J. Feyen. 1993. Determining local-scale solute transport parameters using time domain reflectometry (TDR). *J. Hydrol.* 148:93-107.

Vanclooser, M., D. Mallants,J. Vanderborght, J. Diels, J.V. Orshoven, and J. Feyen. 1995. Monitoring solute transport in a multi-layered sandy lysimeter using time domain reflectometry. *Soil Sci. Soc. Am. J*. 59:337-344.

Wraith, J.M., S.D. Comfort, B.L. Woodbury and W.P. Inskeep. 1993. A simplified waveform analysis approach for monitoring solute transport using time domain reflectometry. *Soil Sci. Soc. Am. J.* 57:637-642.