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IMPROVING PREFERENTIAL FLOW MODULES BY EXPERIMENTATION

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ABSTRACT

Preferential flow is the process whereby water and solutes move by preferred pathways. During preferential flow, local wetting fronts propagate to considerable depths in the soil profile, essentially bypassing the matrix pore space. Under such conditions classical methods, such as the convective-dispersive equation, for quantifying flow of water and solutes in uniform soils are not valid. This project set out to develop methods to predict fast and early breakthrough of solutes. To facilitate understanding of these processes, several field drainage studies were conducted in the United States and Israel. In both countries, solutes moved rapidly down and could be found below 1 m depth soon after application. Based on these experiments, we developed and validated a number of modules to predict the solute concentration of the preferentially moving water in the vadose zone. We also successfully simulated the initial high solute concentration in agricultural tile lines shortly after the chemical was applied. The understanding gained on fast transport of agri-chemicals is instrumental in developing management practices to reduce the nonpoint sources and to increase the leaching efficiency of salt affected soils.

DETAILED DESCRIPTION OF THE RESEARCH ACTIVITIES AND RESULTS (EVALUATION OF THE RESEARCH ACHIEVEMENT WITH RESPECT TO THE ORIGINAL RESEARCH PROPOSAL AND ITS OBJECTIVES)

The work is summarized in the paragraphs below with reference to the publications resulting from this project. The funding contributed, in part, to over 25 publications and 13 presentations. The research is summarized according to the original objectives. We will not repeat what is in the publications.

OBJECTIVE 1: *Set up field experiments and measure the concentration of various tracers applied to soil so that we can test and validate preferential flow models.*

Relevant Data and Methodology. Field experiments were carried out on plots in the USA at Willsboro, NY and the Robinson Farm in the Catskills and in Israel at the Kibbutz Sarid. Laboratory experiments were also carried out. The experiments are described in: 1) Willsboro plots: Geohring (1999), Geohring et al. (1998a,b), Kung et al. (1998), Rothstein et al. (1996); Shalit et al. (1995), Shalit and Steenhuis (1996), Steenhuis et al. (1997a,b), and Wells et al. (1998); 2) Robinson Farm: Scott et al. (1998); and 3) Kibbutz Sarid: Shalit et al. (1998, 1999). A laboratory experiment to study the difference in movement of adsorbed tracers (metals) in disturbed and undisturbed columns was carried out by Camobreco et al. (1996).

Results and Discussion. These experiments found that a small but significant portion of the solutes (including, phosphorus, carbofuran, atrazine, 2,4-D, E-Coli, chloride, and several other tracers) moved rapidly to the groundwater once the distribution zone near the surface is saturated. Once saturated, 1 mm of water can move the tracers more than 1 m deep. The specific results can be found in the attached papers.

OBJECTIVE 2: *Measure basic parameters for soils and solutes with standard methods to examine how well they can be used to predict movement under field conditions.*

Methodology, Results and Discussion. We studied the data collected in the experiments described above and found that none of the traditionally measured parameters (i.e., soil hydraulic conductivity and soil water characteristic curve) could predict solute movement under preferential flow conditions. In the article of Baveye et al. (1998) fractal analysis was tried to describe the preferential flow paths. Although we were able to find the fractal dimensions with great accuracy, we could not use the dimension for discriminating between the various preferential flow paths. The manuscripts in the modeling section (below) indicate that the most important variables in predicting the concentration in preferentially moving water are the total water content of the distribution zone and the adsorption partition coefficient. In order to predict the concentration in the tile line the assumption is made that only a small portion of the field contributes solutes to the tile line.

OBJECTIVE 3: *Use the above measurements to adapt, test, and validate the various models.*

Results and Discussion. We developed a great number of models. These models can be divided up as follows: 1) Improvement in the infiltration theory: Parlange et al. (1997, 1998a); 2) Better ways to model solute concentration in preferential flow: Boll et al. (1997), Shalit et al. (1995), Shalit and Steenhuis (1996), Steenhuis et al. (1995, 1997a,b, 1998, 1999a,b), Wallach and Parlange (1998), Wallach and Steenhuis (1998), and Wells et al. (1998); and 3) Modeling the crack network: Chertkov (1999) and Chertkov and Ravina (1998, 1999 a,b,c,d,e).

DESCRIPTION OF COOPERATION

We met at several international meetings to discuss the research; Dr. Wallach spent his 1 year sabbatical leave at Cornell; and both Mr. Shalit and Dr. Ravina visited Cornell for extended periods of time. There are several papers that are authored by the Investigators in both countries.

CONCLUSIONS

Groundwater pollution occurs rapidly and can be detected shortly after application and with the first rainfall. However, unfortunately, very few validated models exist that can predict the fast transport of pesticides. With support of this BARD research project, we have derived expressions in the vadose zone for arrival time and concentration of preferentially moving water. They are based on a conceptual model in which a layer near the surface becomes saturated and distributes the water and solutes to the preferential flow paths. Solute concentrations in agricultural tile lines can be predicted based on the following assumptions:

1. The distribution zone and the groundwater reservoir are linear reservoirs.
2. The travel time between two reservoirs is short.
3. The percolation through the macropores begins when the distribution layer is near saturation and ceases when the rainfall stops (or very shortly thereafter). Matrix flow may continue, but does not carry any solutes from the surface.
4. Not all the land area between the tile lines contribute water and solutes to the tile lines.

With these assumptions, the high solute concentrations can be predicted that occur with the first rainfall after the chemical is applied. The conclusions of this project and others have been summarized in overview articles by Geohring (1999), Parlange (1996, 1997, 1998b), Steenhuis et al. (1995), and Wallach et al. (1998).

The understanding gained on fast transport of agri-chemicals will be instrumental in developing management practices to reduce the nonpoint sources and to increase the leaching efficiency of salt affected soils. For example, application of agri-chemicals on wet soils will transport a much greater quantity of agri-chemicals or phosphorus to a stream via tile lines than a soil below field capacity. The research also indicates that a ban of manure spreading during the winter (with subsequent manure application in the spring when the soil is wet) will cause a greater phosphorus loss than daily winter spreading.

PUBLICATIONS (* = attached in Appendix)

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Chertkov, V.Y. and I. Ravina. 1999d. Modeling Distribution of Horizontal-Crack Volume in Swelling Soils. Soil Science Society of America Journal. (Submitted)

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