Report for 2002NY2B: Predicting Dissolved Phosphorus Losses in Overland Flow in Northeastern U.S.

- Articles in Refereed Scientific Journals:
  - Gao, B.; M. T. Walter; T. S. Steenhuis; J.-Y. Parlange; K. Nakano; W. L. Hogarth; C. W. Rose. 2003. Investigating Ponding Depth and Soil Detachability for a Mechanistic Erosion Model using a Simple Experiment, Journal of Hydrology. <in press>

Report Follows:

Problem & Research Objectives:

On May 24, 1999, the U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) adopted a policy that requires the use of a P index or comparable vulnerability assessment techniques when developing nutrient management plans (NMP) for concentrated animal feeding operations (CAFOs) or for other farms near P sensitive reservoirs, lakes and streams (Lander, 1999). A major limitation in the implementation of the P index for NMPs is the poor scientific understanding of the transport of dissolved phosphorus (P) into runoff water from agricultural and forests lands. Most of the previous research on the fate of P in the agricultural landscape was directed towards supplying P to crops for optimal growth. Moreover, it was assumed that P loss in runoff was only in the particulate form because of the strong P adsorption properties of most soils. However, many recent studies have confirmed the findings of Hergert et al. (1981) that it is not only particulate P (PP) that is lost but that also dissolved P (DP) is a significant part of the total P losses in the agricultural runoff water. Consequently, improved understanding of the amount of DP loss in runoff will greatly enhance P loss prediction techniques, such as the P index method. Better understanding of DP losses will also help in the selection of effective best management practices (BMP).

The overall goal of this project was to improve P loss prediction techniques for variable source, saturated areas located in agricultural landscapes. The particular goal was to systematically derive a predictive relationship for the concentration of DP in the runoff water based source factors such as soil type, the amount and type of P in the soil, climatic factors including rainfall amount and energy, and landscape factors including initial moisture content, ponding depth and rate of upward and downward flux. The project will ultimately lead to more physically robust P index tools for the unique soils and conditions in the Northeast, an improved understanding of P fate and transport processes, and improved decision making regarding P control and management practices applicable to these conditions.

Methodology:

The experimental methods and set-up were derived from a study in which the upland erosion component of the Rose and Hairsine model was validated (Heilig et al., 2001; Gao et al., 2003). The experimental apparatus was, in principle, very simple and is designed to isolate the soil, climate, and landscape factors that contribute to the P loss in runoff water. Rainfall was simulated using a computer-controlled rainmaker that oscillated simultaneously along two orthogonal tracks. Each experiment consisted of carefully establishing a flat soil surface with a predetermined amount of ponded water followed by application of rain.

In the early studies by Heilig et al. (2001) and Gao et al. (2003), we found that the Rose and Hairsine model predicted the sediment concentration in runoff water very well. The model assumed that the fine particles loosened by the rain splash were removed preferentially in the runoff water resulting in a shield of coarse particles near the surface with a depth of approximately 0.5 cm.

The hypothesis for this study was that the loss of the fine particles due to raindrop splash is similar to the loss of the DP from this surface layer due to raindrop impact.

Only a selected set of the climate, soils, and landscape factor interaction were investigated during this short, one-year study. In the first two experimental sets, the mechanisms that contribute to the P loss in the runoff water were be quantified and the results were used to adapt the Rose and Hairsine upland erosion model for DP loss.

Principal Findings & Significance:

Unexpectedly, we found that solute transport between the soil matrix and runoff is fundamentally different from the transport of small particles (e.g., clay). Clay particles are entrained into runoff by raindrop impacts and the rate of entrainment slows and eventually ceases as a shield layer of heavy particles develops across the soil surface. The initial solute entrainment rate was much more rapid than for clay and as the rainfall continued the entrainment rate slowed to a constant, non-zero level. We hypothesized that the early, rapid entrainment period was also controlled by raindrop impacts and ultimately the entrainment rate was controlled by diffusion from deep soil layers. We successfully tested this new hypothesis for how solutes move between soil and runoff water by developing a quantitative model and testing against experimental data. This new description of solute transport challenges the widely used, traditional "diffusion" (Wallach et al. 1988) and "mixing layer" (Steenhuis and Walter 1981) models. We found that an acceptable solution for our hypothesized process takes a mathematical form similar to the Rose soil-erosion model and that we can use erosion parameter determined by the Rose model to help understand the role of raindrop impact on solute transport between soil and runoff.

We demonstrated the importance of raindrop processes by developing a simple model for predicting soil solute loss to overland flow that combined rain impact physics with the diffusion theory developed by Wallach et al (1988). We showed that the raindrop detachment effect, which was ignored in previous studies and commonly used models, plays an important role during the solute transport process. Furthermore, our new model also fits previously published data by Ahuja et al. (1981), that has been used in many widely cited investigations. We have improved our understanding of the physical processes involved by developing a numerical model, which also agreed with our experimental data and previously published data. The numerical model allowed us to develop a simpler, more accurate form of our original model.

We carried out several experiments studies to comparing non-sorbed chemical transport to DP (a chemical that sorbs to soil) transport. The experimental data suggested that the adsorption-desorption processes of soil on DP transport can be largely simplified in the modeling process by assuming a constant adsorption and desorption partition coefficient. This method is similar to that which was successfully applied to predicting of preferential flow solute concentrations by Steenhuis et al. (1994). We demonstrated that our new model predicts both sorbing (i.e., DP) and non-sorbing chemical transport between soil and overland flow for various rainfall intensities and soil types.

References:

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