National Phosphorus Runoff Project: Pennsylvania – Soil P and Overland Flow P Relationships

Andrew Sharpley[1], Peter Kleinman[1], Jennifer Weld[1], and Richard McDowell[2]

[1] *USDA-ARS, Pasture Systems and Watershed Management Research Unit, University Park, PA 16802*
[2] *AgResearch Ltd, Invermay Agricultural Research Centre, Private Bag 50034, Mosgiel, New Zealand*

Background

The effects of soil test phosphorus (P), field management and overland flow P losses from Pennsylvania soils are being studied as part of the National P Research Project (NPRP). The NPRP represents a consortium of federal and state agencies, as well as land grant universities, with collaboration in over 20 states. Pennsylvania's contribution to the NPRP has three immediate objectives: (1) quantify relationships between soil test P (STP), overland flow P and subsurface flow for Pennsylvania soils; (2) evaluate soil P extractants that can be used as indictors of soil P loss in overland and subsurface flow; and, (3) assess Pennsylvania's P Index, which identifies fields that are vulnerable to P loss. These objectives are expected to culminate in the development of cost-effective, integrated nutrient management strategies that target remedial activities on areas specifically at risk of P loss.

Research approach

Overland flow studies were conducted within USDA-ARS's mixed land-use watershed, FD-36 (Northumberland Co., south central PA), a 39.5 ha subwatershed of Mahantango Creek, a tributary to the Susquehanna River and ultimately the Chesapeake Bay (Fig. 1). The watershed is typical of upland agricultural watersheds within the nonglaciated, folded and faulted, Appalachian Valley and Ridge Physiographic Province. Soils evaluated were Berks (Typic Dystrudepts), Calvin (Typic Dystrudepts), Hartleton (Typic Hapludults), and Watson (Typic Fragiudults) channery silt loams.

Protocols outlined in the NPRP were followed in all phases of this research and included soil sampling, rainfall simulation, overland flow collection, and soil and water anlaysis. Briefly, two rainfalls (70 mm h^{-1} for 30 min) were applied to each paired plot at one-day intervals. This rainfall intensity and duration has a return frequency of approximately 10 years in the study area. Runoff water was analysed for dissolved reactive P (DRP) on a filtered sample (0.45 µm), and algal-available P (Fe-oxide strip P), total P, and suspended sediment on an unfiltered sample. After rainfall simulation, a minimum of 10 soil samples (0–5 cm) was collected within each plot, composited, air-dried, sieved (2 mm), and Mehlich-3, water, and $CaCl_2$ and extractable soil P determined.

The concentration of P in subsurface flow, as leachate from 30-cm deep soil cores (lysimeters) taken form FD-36, was also determined using NPRP protocols. Lysimeters were collected from all four soils used in the overland flow phase of this research (Berks, Calvin, Hartelton, and Watson). Lysimeters were subjected to simulated rainfall and

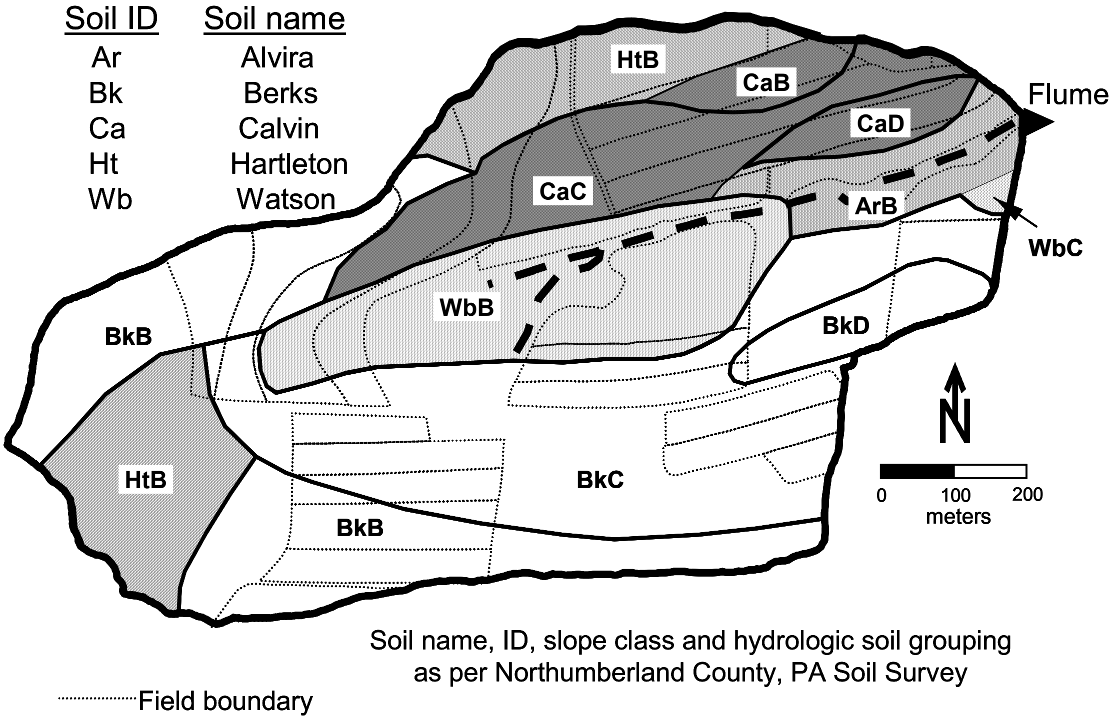


Figure 1. The FD-36 watershed, soil type distribution and field boundaries.

collected leachate analysed for DRP leachate.

Research findings

Objective 1: Soil test P – overland flow relationship

The concentration of DRP in overland flow from plots located in fields that had not been fertilized or manured in the last six months was related to Mehlich-3 soil P concentration (Fig. 2). In all soils, as Mehlich-3 soil P concentration increased, so did the potential for DRP enrichment of overland flow. The curvilinear relationship of Figure 2 can also be described by two linear relationships intersecting at a Mehlich-3 soil P concentration of 220 mg kg^{-1} for the Berks soil and 175 mg kg^{-1} for the Calvin, Hartleton and Watson soils (McDowell and Sharpley 2001). Although both models accurately describe the dependence of overland flow DRP on soil P concentration, the split-line model identifies a threshold, above which the increase in P concentration of overland flow is greater per unit increase in Mehlich-3 P than below the threshold (Fig. 2). Mehlich-3 P values for both split-line thresholds support the environmental soil P threshold proposed for Pennsylvania of 200 mg kg^{-1}.

The concentration of DRP in subsurface flow is also related to surface soil P. As the Mehlich-3 P concentration of surface lysimeter soil (15 to 775 mg kg^{-1}) increased, so too did the concentration of DRP in subsurface flow from the lysimeters (0.07 to 2.02 mg L^{-1}; Fig. 3). The dependence of subsurface DRP transport on surface soil P is evidence of the importance of P in preferential flow pathways such as earthworm burrows and old root channels, as shown in Figure 4. Lime slurry (1 part $CaSO_4$ and 10 parts water) was

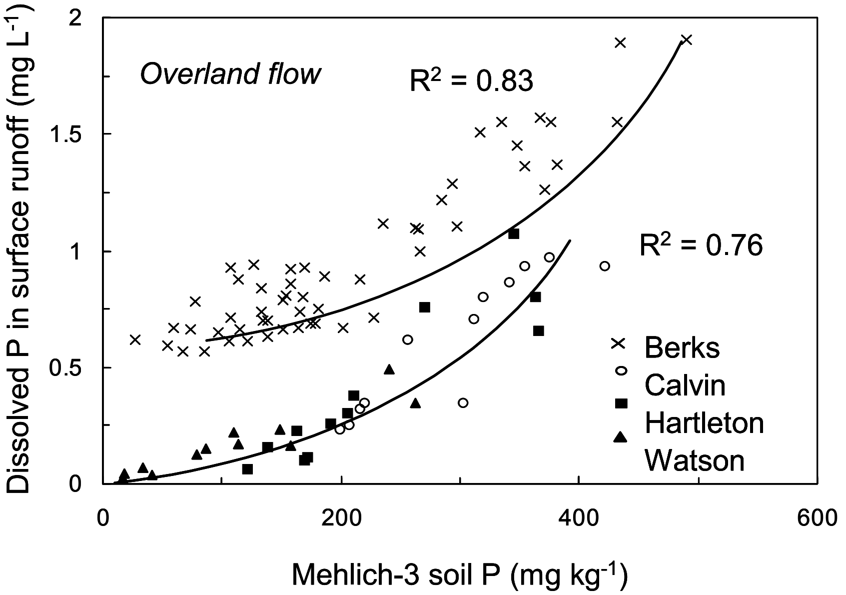


Figure 2. Relationship between the concentration of dissolved P in overland flow and Mehlich-3 extractable soil P concentration of surface soil (0 - 5 cm) from the FD-36 watershed (McDowell and Sharpley, 2001 and Sharpley et al., 2001).

added to the surface of one of the lysimeters and rainfall applied. The lime moved into the soil, highlighting old root channels and earthworm burrows.

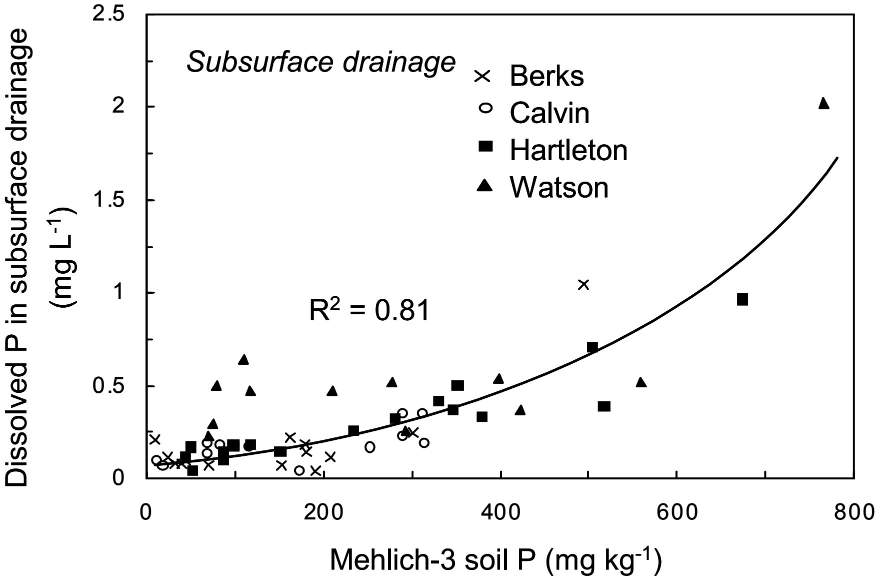
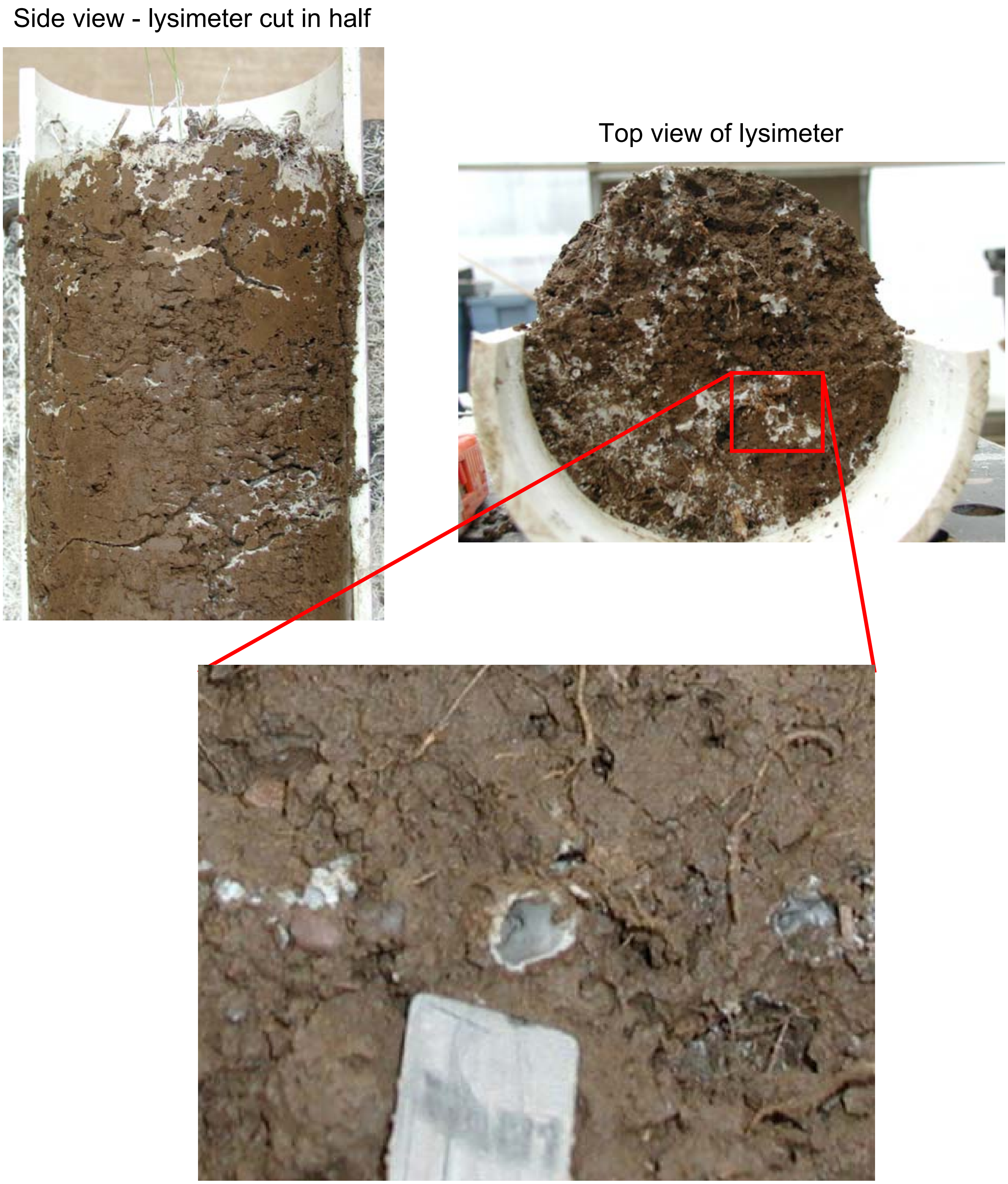


Figure 3. Relationship between the concentration of dissolved P in subsurface drainage from 30 cm deep lysimeters and the Mehlich-3 extractable soil P concentration of surface soil (0 - 5 cm) from the FD-36 watershed (McDowell and Sharpley, 2001).



Side view - lysimeter cut in half

Top view of lysimeter

Figure 4. Lime slurry was surface applied to the lysimeters and rainfall added to highlight old root channels and earthworm burrows.

Objective 2: Evaluate alternative soil P extractants to estimate overland and subsurface flow P

A variety of soil extracts have been evaluated as possible indicators of P loss potential by relating P extracted from soil to P in overland or subsurface flow. According to Ryden and Syers (1975), a soil P extract should reflect both the cation status and the ionic strength of the flow, to be an effective indicator of DRP in surface or subsurface flow. Based upon the overland flow and subsurface flow studies described in Objective 1, McDowell and Sharpley (2001) determined that soil extractions with water and 0.01*M* $CaCl_2$ provided the best prediction of DRP concentrations in overland and subsurface flow, respectively (Fig. 5).

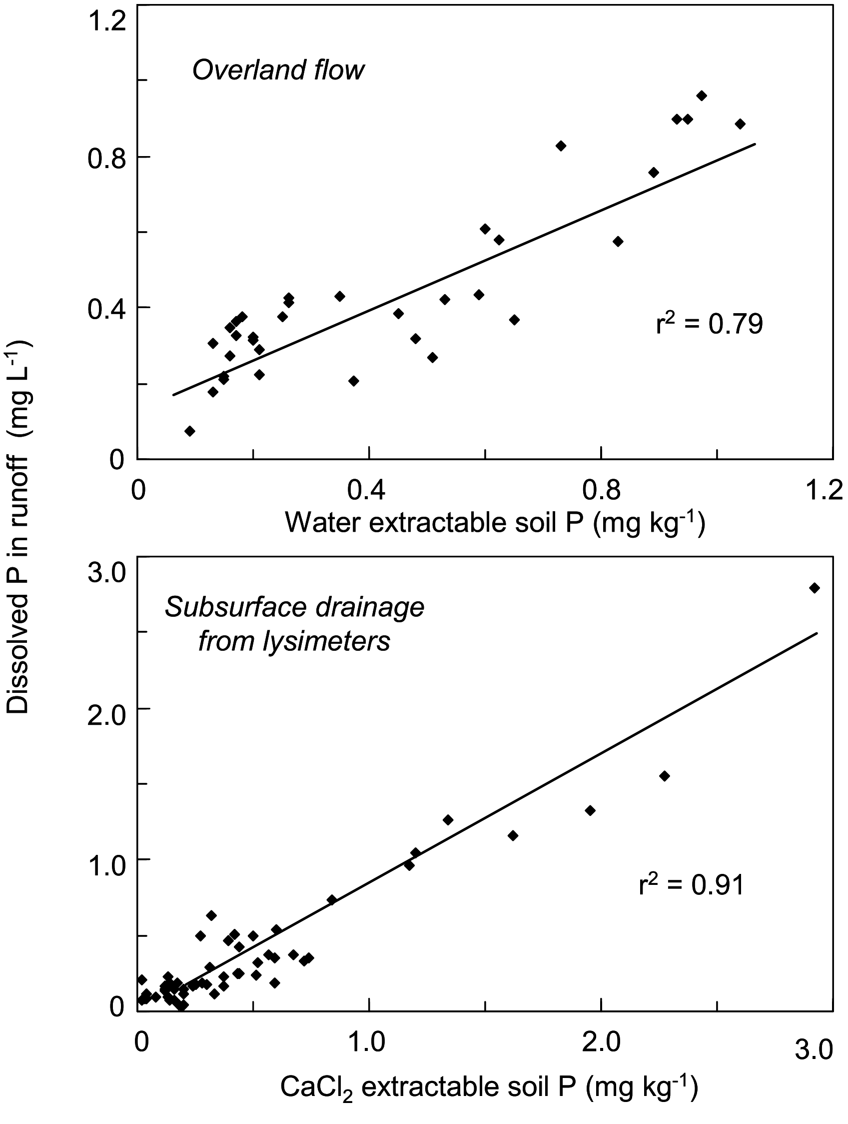


Figure 5. Relationship between the concentration of dissolved P in overland flow and subsurface drainage from 30 cm deep lysimeters and the water and $CaCl_2$ extractable soil P concentration, respectively of surface soil (0 - 5 cm) from an central PA watershed (see Sharpley et al., 1999).

This research shows that simple laboratory desorption methods can be used to estimate the near-term potential for P loss. In addition, medium- and long-term estimates of DRP in overland and subsurface flow can be estimated by combining desorption techniques with "infinite sinks" such as Fe-oxide strips or anion exchange resins.

Objective 3: Assess Pennsylvania's P Index

When rainfall/runoff studies were conducted on field that had received fertilizer or manure within three weeks of rainfall simulation, the concentration of DRP and total P in overland flow was not related to Mehlich-3 soil P (R^2 of 0.42; $p > 0.05$; Fig. 6). Application of manure and fertilizer concentrates soluble P at the soil surface where it is vulnerable to removal by runoff. As expected, DRP concentrations in runoff increased with increasing rates of applied P. The average DRP concentration in overland flow was 1.06 mg L^{-1} from sites receiving 56 kg P ha^{-1} (as triple superphosphate), 1.76 mg L^{-1} P from sites receiving 112 kg P ha^{-1} (as swine slurry), and 2.42 mg L^{-1} from sites receiving 150 kg P ha^{-1} (as poultry manure). Average total P concentrations from these sites were 1.67, 2.56, and 3.36 mg L^{-1}, respectively (Fig. 6).

Using Pennsylvania's P Index described in Sharpley et al. (2001) each site was evaluated on the basis of its vulnerability to P loss. Pennsylvania P Index ratings for each site were closely related to the loss of total P in overland flow from all sites (Fig. 6). Thus, consideration of site potential for overland flow and erosion, P application rate and method, and Mehlich-3 soil P concentration effectively described overland flow P concentration and loss from recently fertilized and manured fields, as well as from untreated fields. Clearly, the P index described P loss potential from a wider range of land management conditions than did Mehlich-3 soil P alone (Fig. 6). Similar relationships to those shown in Figure 6 are expected to exist in other watersheds, with ranges in P concentration and loss reflecting local conditions.

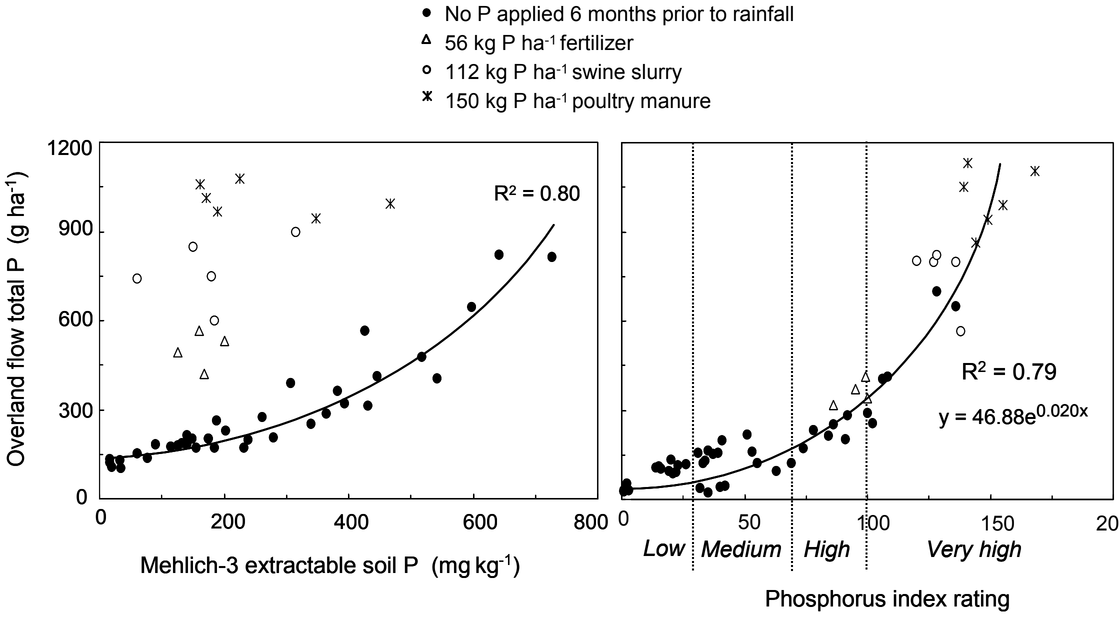


Figure 6. Relationship between total P loss in overland flow and Mehlich-3 extractable soil P concentration and P index rating for plots in fields where no P had been applied within the last six months and where fertilizer or manure had been applied within three weeks of rainfall in FD-36 watershed. Regression equations and corresponding coefficients apply only to plots not having received P in the lat six months (Sharpley et al., 2001).

Ongoing research

Research under the NPRP continues in Pennsylvania, with an emphasis on providing data necessary to quantify the effects of animal diet on P transport in overland flow, the benefits of alternative nutrient management practices, better identify areas in the landscape that are prone to runoff and calibrate the Pennsylvania P Index.

Acknowledgements

The following individuals have contributed to greatly to NPRP research in Pennsylvania: Jamie Davis (USDA-ARS, University Park, PA), Dennis Genito (USDA-ARS, University Park, PA), Bart Moyer (USDA-ARS, University Park, PA), Joe Quatrini (USDA-ARS, University Park, PA), Todd Strohecker (USDA-ARS, Klingerstown, PA), Terry Troutman (USDA-ARS, Klingerstown, PA), and Joan Weaver (USDA-ARS, University Park, PA).

References

McDowell, R.W., and A. N. Sharpley. 2001. Approximating phosphorus release to surface runoff and subsurface drainage. J. Environ. Qual. 30:508-601.

Ryden, J.C. and J.K. Syers. 1975. Rationalization of ionic strength and cation effects on phosphate sorption by soils. J. Soil Sci. 26:395-406.

Sharpley, A.N., P.J. Kleinman, R.W. McDowell, and J.L. Weld. 2001. Assessing site vulnerability to phosphorus loss in an agricultural watershed. J. Environ. Qual. 30:2026-2036.