National Phosphorus Runoff Project: Pennsylvania - Rainfall Simulator and Plot Scale Comparison

Andrew Sharpley and Peter Kleinman

USDA-ARS, Pasture Systems and Watershed Management Research Unit, University Park, PA 16802

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)using field-based rainfall simulators. The NPRP represents a consortium of federal and state agencies, as well as land grant universities, with collaboration in over 20 states. The objective of this phase of research was to compare overland flow patterns (e.g., time to initiation, volume, discharge rate, peak flow) and the concentrations of P (dissolved and total P), and sediment discharge using the Water Erosion Prediction Protocol (WEPP; Simanton and Renard, 1992) and NPRP rainfall simulators. Both simulators use the same rainfall generation system, nozzles, and intensity (70 mm h^{-1}), although the plot size of the NPRP (2 m^2) is much less than that of the WEPP (32.6 m^2). As the WEPP simulator more closely represents field-scale processes -- due to its large size and history of extensive testing, than does the NPRP simulator -- comparison of the two simulators provides insight into the hydrologic and P transport processes of the smaller, more portable NPRP simulator.

Research approach

Overland flow studies were conducted within USDA-ARS's mixed land-use watershed, FD-36, a 39.5 ha subwatershed of Mahantango Creek, a tributary to the Susquehanna River and ultimately the Chesapeake Bay (Fig. 1). Soils evaluated were Berks (Typic Dystrudepts) and Watson (Typic Fragiudults) channery silt loams.

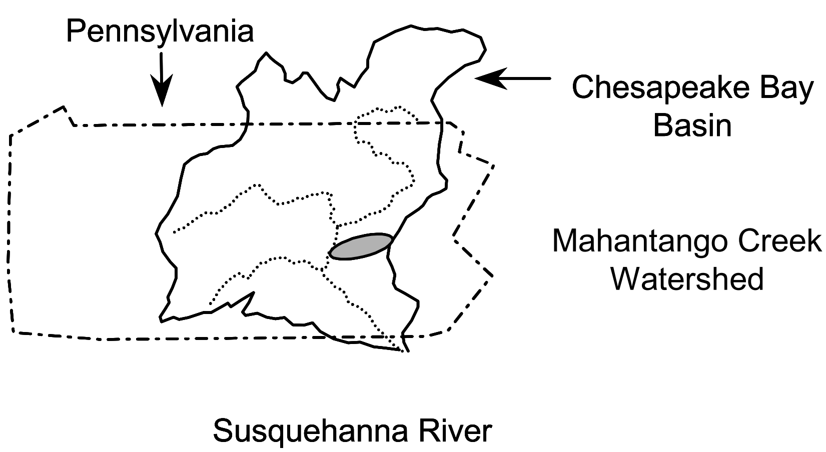

Figure 1. Location of the study area within the Mahantango Creek Watershed in relation to the Susquehana River and Chesapeake Bay Watershed.

To gain insight into landscape processes as well as to determine how NPRP data relate to previous rain simulation studies of national extent and validity of using small plots (2 m^2), NPRP and WEP rainfall simulations were conducted on adjacent plots (Fig. 2). Rainfalls were initiated at the same time on the same day. All plots were grassed (established orchardgrass).

Figure 2. Simultaneous WEPP and NPRP rainfall simulations on the Watson soil.

WEPP Rainfall Simulator Protocol

The WEPP simulator is trailer-mounted, with 10 rotating booms (each 7.6 m long) radiating from a central stem, which rotate at about 4 rpm (Simanton and Renard, 1992). The arms support 30 V-Jet 80100 nozzles positioned at various distances from the stem. The nozzles spray downward from an average height of 2.4 m, apply rainfall intensities of 70 mm h^{-1} and produce drop-size distributions similar to natural rainfall. Simulator energies are about 77% of those of natural rainfall and the simulator produces intermittent rainfall impulses at the plot surface as the booms pass over the plot. Rainfall spatial distribution over each plot has a coefficient of variation of less than 10%. Changes in rainfall intensities are produced by increasing or decreasing the number of open nozzles; 15 nozzles for 70 mm h^{-1}. Two plots, 3.05 m by 10.7 m (32.6 m^2), are covered by the simulator (Fig. 3).

Two rainfall simulation runs were made on each plot pair on consecutive days. Rainfall application rate is measured with a recording rain gauge and rainfall distribution on each plot was measured with six non-recording rain gauges. Plot overland flow is measured by specially designed precalibrated flumes (4 L sec^{-1} maximum capacity) equipped with water-level recorders that measured instantaneous flow depth. Continuous hydrographs are produced using the flume's depth/discharge rating table. During a run, times of ponding (half of the plot surface had standing water), runoff initiation, sediment samples, and end of runoff were recorded on field notes for later comparison to recorder charts. Although overland flow samples were collected at 5 min intervals starting 2.5 min after flow initiation, data presented in this preliminary report, reflects a composite samples (flow weighted) of bulked flow, as for the NPRP simulations.

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 approximate 10 years in the study area.

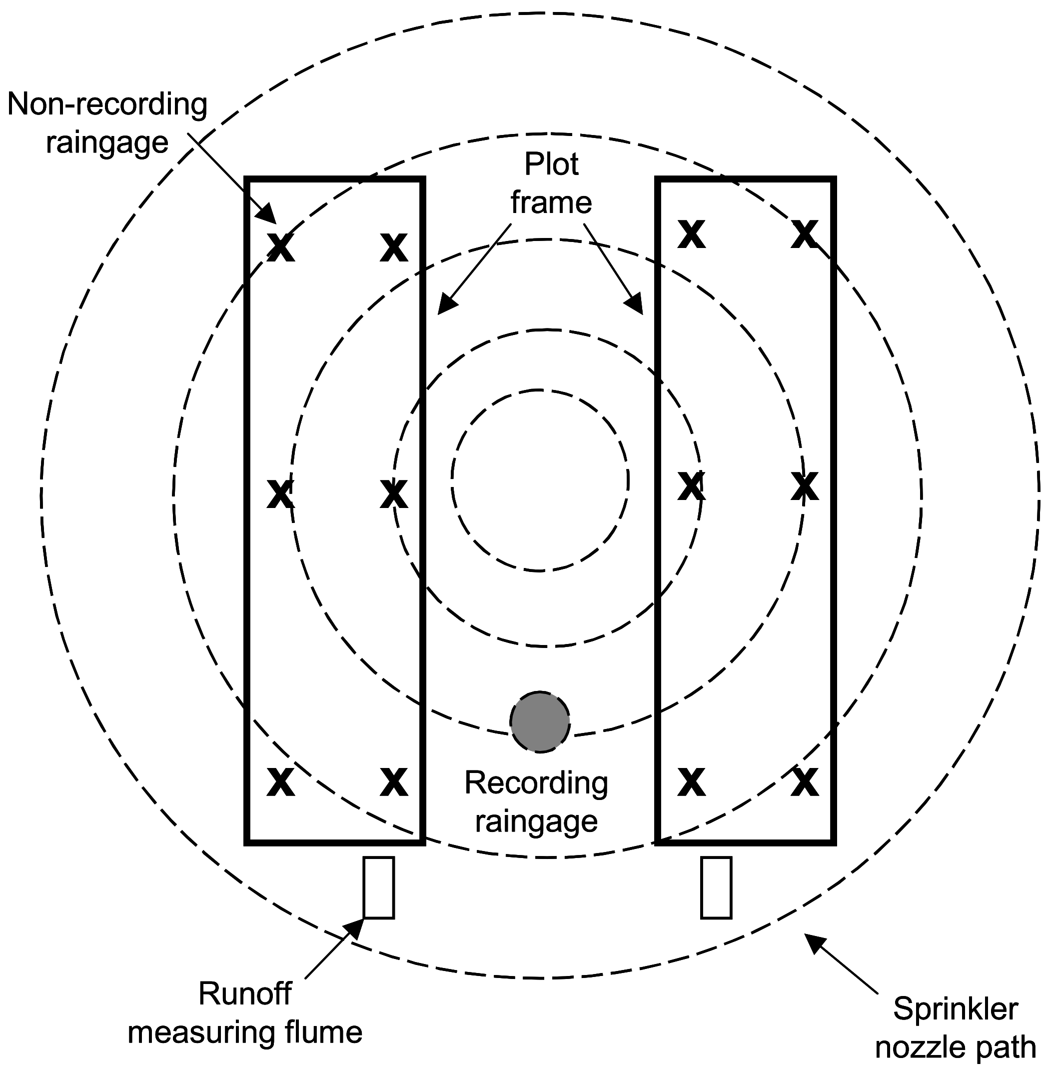

Figure 3. Plot layout for WEPP rainfall simulations.

NPRP Rainfall Simulator Protocol

Simulations were conducted at the same intensity (70 mm h^{-1}), duration (30 min), and sequencing (1-day interval) as that used in the WEPP simulations. Prior to rainfall, soil moisture is determined by a theta probe.

Analyses

Runoff water was analysed for dissolved reactive P (DRP) on a filtered sample (0.45 µm), and total P and suspended sediment on an unfiltered sample. After rainfall simulation, a minimum of ten soil samples (0–5 cm) was collected within each plot, composited, air-dried, sieved (2 mm), and Mehlich-3 extractable soil P determined.

Research findings

Comparison of NPRP and WEPP rainfall simulators

Overland Flow Response

Response time between the initiation of rainfall and overland flow for both soils was similar for NPRP and WEPP simulators on days 1 and 2 (Table 1). However, the total overland flow volume and peak flow rates were greater from NPRP than WEPP simulators for both soils (Table 1). For both simulators there tended to be more overland flow occurring more rapidly after the start of rainfall on day 2 than day 1, although this was not significant in most cases for the events considered in this preliminary study. This was the case even though volumetric soil moisture content (surface 5 cm of soil) before rainfall on the Watson soil increased from 0.40 on day 1 to 0.50 on day 2 and on the Berks soil increased from 0.28 on day 1 to 0.39 on day 2.

Differences in overland flow response between soils were consistent with either simulator. For example, it took appreciably longer for overland flow to occur and in lower volumes for the coarser textured Berks than Watson soil these differences in overland flow reflect the greater permeability of the Berks (15 to 150 mm h^{-1}) than Watson (1.5 to 15 mm h^{-1}) soils.

P Transport

Dissolved reactive P concentration of overland flow was mostly greater with the NPRP than WEPP simulator on days 1 and 2 for both Watson and Berks soils (Table 1). Concentrations were lower in day 2 than 1, likely due to a temporary dilution of the pool of P that can be released to overland flow in the interacting depth of surface soil. Greater DRP concentrations in overland flow for NPRP than WEPP simulators were evident even though overland flow volume was greater with the NPRP simulator (Table 1). Thus, the difference in DRP concentration between simulators was not a result of simple dilution of P by overland flow. The difference may be due to the lower sediment discharge from NPRP than WEPP flows, resulting in a lower readsorption of P by particulates during flow. This would be consistent with the lower flow-path length of the NPRP (2 m) than WEPP (10.7 m) plots, reducing the possibility for readsorption to occur.

The lower sediment discharge from the NPRP than WEPP generated rainfalls is reflected in lower particulate and total P concentrations in overland flow, for the former simulator (Table 1). Again, it is likely that the longer flow-path length of WEPP than NPRP increased overland flow velocity, erositivity, and subsequent entrainment of

Table 1. Overland flow, P concentration, and sediment discharge from the NPRP ($2\ m^2$ plots) and WEPP ($32.6\ m^2$ plots) rainfall simulators, both using a 70 mm hr^{-1} intensity.

Parameter †	NPRP		WEPP	
	Day 1	Day 2	Day 1	Day 2
Berks - Mehlich-3 P of 386 mg kg^{-1}				
Response time, min	20 *a*	12 *b*	21 *a*	14 *a*
Flow, L m^{-2}	18.8 *a*	22.9 *b*	6.9 *c*	8.2 *d*
Peak flow rate, L m^{-2} min^{-1}	0.91 *a*	1.01 *a*	0.29 *b*	0.39 *b*
Dissolved P, mg L^{-1}	0.766 *a*	0.445 *bc*	0.560 *b*	0.335 *c*
Particulate P, mg L^{-1}	1.776 *a*	1.226 *b*	2.499 *c*	1.881 *a*
Total P, mg L^{-1}	2.542 *a*	1.671 *b*	3.059 *c*	2.216 *d*
Sediment, g L^{-1}	1.20 *a*	0.68 *b*	1.57 *c*	1.24 *d*
Watson - Mehlich-3 P of 120 mg kg^{-1}				
Response time, min	3 *a*	1 *a*	1.5 *a*	0.5 *b*
Flow, L m^{-2}	24.0 *a*	26.2 *a*	12.5 *b*	12.6 *b*
Peak flow rate, L m^{-2} min^{-1}	1.09 *a*	1.03 *a*	0.62 *b*	0.63 *b*
Dissolved P, mg L^{-1}	0.139 *a*	0.095 *b*	0.107 *b*	0.068 *c*
Particulate P, mg L^{-1}	0.783 *a*	0.540 *b*	1.064 *c*	0.715 *a*
Total P, mg L^{-1}	0.922 *a*	0.635 *b*	1.171 *c*	0.783 b
Sediment, g L^{-1}	2.96 *a*	1.71 *b*	3.21 *c*	2.28 *a*

† Parameters followed by the same letters are significantly different ($p > 0.05$) between simulator types and day of rainfall, as determined by analysis of variance.

particulates and associated P (Table 1). It is also likely that the selective erosion of fine particulates increased with plot size and length, as noted by Le Bissonnais et al. (1998). For a separate study on the Watson soil, McDowell and Sharpley (2002) observed that particulates eroded from $10\ m^2$ plots were comprised of 34% clay (<0.2 μm), while from $2\ m^2$ plots were only 24% clay. This likely explains the wider DRP to particulate P ratio for WEPP than NPRP simulator for Berks (4.5 and 2.3, respectively) and Watson soils (9.9 and 5.6, respectively) (Table 1), as P associated with clay-sized particles is less desorbable compared to P sorbed onto sand-sized particles.

The effect of plot flow-path length on P transport in dissolved forms requires further investigation to substantiate or disprove the above processes and is the subject of ongoing research at this location.

Relationship between Overland Flow P and Soil P

The concentration of overland flow DRP increased with Mehlich-3 soil P (surface 5-cm sample), although concentration were greater from the smaller NPRP plots than the WEPP plots (Fig. 4). In spite of this difference, the relationship between overland flow DRP and Mehlich-3 soil P was similar for both Berks and Watson soils (Fig. 4). For the Berks soil, relationship slopes using the NPRP simulator (0.0021) were similar to that with WEPP simulator (0.0019). For the Watson soil, slopes were 0.0006 for both NPRP and WEPP simulators (Fig. 4).

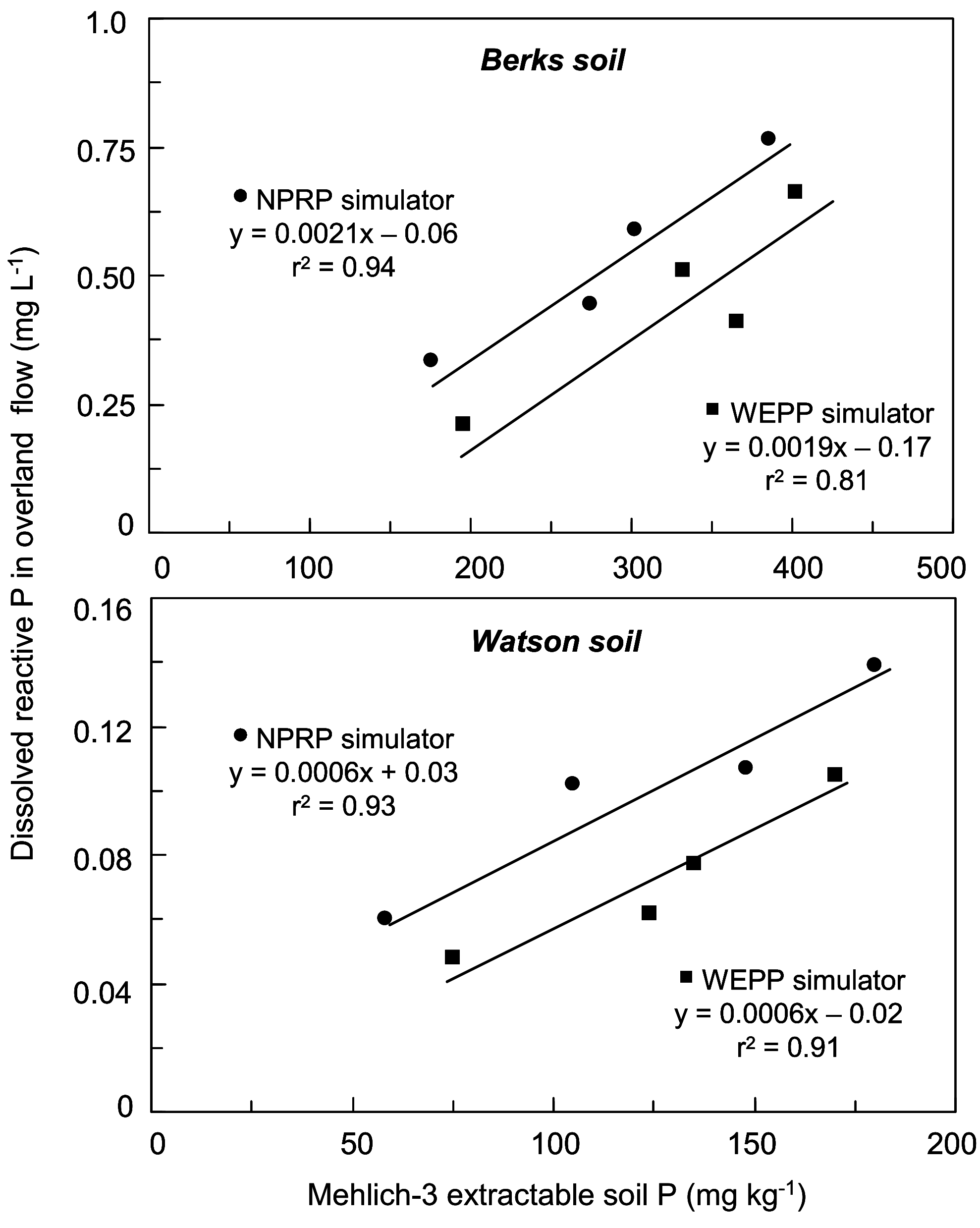

Figure 4. Relationship between the dissolved reactive P concentration of overland flow generated by the NPRP and WEPP rainfall simulators for grassed Berks and Watson soils

The similarity in DRP – Mehlich-3 P regression slopes between NPRP and WEPP simulators (Fig. 4), suggests that overland flow processes controlling soil P release and transport are independent of simulator type, flow-path length, and plot size. However, differences in DRP concentration and overland flow volumes between simulators, limits their use in quantifying P loss from agricultural landscapes, due to the obvious effects of scale on P loss. This in not inconsistent with NPRP objectives, which are not to quantify P losses as a function of field-scale agricultural management, but to determine the factors controlling the relationship between overland flow P and soil P and then define this relationship for a wide range of soils. Rainfall simulators and small plots cannot reproduction flow process occurring over a landscape or hillslope and as such must be limited to elucidating flow – soil P interdependencies.

Other studies have also found differences in overland flow and P transport as a function of plot size and flow-path length. Gascho et al. (1998) found no difference in overland flow volumes between 662 m^2 (42.9 m path length) and 5.6 m^2 (3.05m path length) plots as the result of a 25 mm h^{-1} rainfall for 2 h. Concentrations of DRP were greater for the large (2.2 mg L^{-1}) than small plot (1.5 mg L^{-1}). The fact that rainfalls immediately followed an ammoniated superphosphate application (45 kg P ha^{-1}) may partly account for the different trend in scale effect to the present study. In a more detailed analysis of scale effects, McDowell and Sharpley (2002) found DRP concentrations in overland flow from a 2 m^2 plot (2 m flow-path length) were greater than from a 10 m^2 plot (2 m flow-path length).

In spite of the effect of scale on overland flow and P transport observed in this preliminary study, the NPRP can be used to quantify the relationship between overland flow and soil P, assuming that the WEPP simulator is the standard protocol, which provides baseline data. Clearly, the NPRP is more portable, accessible to a wider range of fields, easier to install and requires much less labor to operate (two people are required to operate the NPRP and seven the WEPP simulator) (Figure 5).

Ongoing research

Research under the NPRP continues to compare the overland flow response and P transport processes as reflected by the NPRP and WEPP rainfall simulators. Simulations will be conducted on additional sites along with a comparison of with and without manure application effects on flow and P loss.

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The NPRP simulator is compact

The NPRP simulator is mobile

Overland flow plots are simple to install

Figure 5. NPRP rainfall simulator and plot construction in FD-36, Klingerstown, PA.

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