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APPLICATION OF SIMPLIFIED PHOSPHORUS TRANSPORT MODELS TO PASTURE FIELDS IN NORTHWEST ARKANSAS

D. R. Edwards, C. T. Haan, A. N. Sharpley, J. F. Murdoch, T. C. Daniel, P. A. Moore Jr.

ABSTRACT. *Runoff transport of phosphorus (P) is often predicted from simple equations with parameters determined from data applicable primarily to row-cropped and fallow cover conditions. The applicability, accuracy, and precision of such P transport prediction equations under pasture situations are less well defined. The objectives of this study were to determine parameters of simplified runoff P transport equations for pasture fields and to assess the accuracy and precision of the equations. Runoff, sediment yield, soluble P transport, and particulate P transport data were collected from four pasture fields in northwestern Arkansas. Runoff event enrichment ratios and extraction coefficients were computed, and confidence limits on respective predicted particulate and soluble P transport were determined. An inverse linear relationship between the natural logarithms of enrichment ratio and sediment yield was found significant for all fields, but the slopes were lower than values reported earlier for general use. Runoff event extraction coefficients were considerably higher than those typically used and were highest for runoff occurring shortly following animal manure application. The 95% confidence limits on predicted soluble and particulate P transport varied in some cases by more than an order of magnitude, indicating that significant imprecision was associated with those predictions. The data suggested that the simplified model of soluble P transport might be a reasonable description of the processes for the fields, but that modification to the particulate P transport prediction method might be necessary to improve the prediction accuracy for low event sediment yields (< 10 kg/ha).* ***Keywords.** Runoff, Water quality, Phosphorus, Modeling.*

Runoff from agricultural source areas can contain nutrients, organic matter, soil, and microorganisms in quantities sufficient to threaten beneficial uses of receiving waters. Of the different classes of potential pollutants in agricultural runoff, nutrients have received the most research attention, and nitrogen (N) has traditionally been the single nutrient that is most often the subject of water quality investigations. There is an increasing awareness, however, that the nutrient limiting some uses of water bodies is phosphorus (P) rather than N. Eutrophication rates of inland water bodies, for example, are often limited by P rather than N inputs (e.g., Daniel et al., 1993). Slowing the rate of eutrophication in such cases would be more effectively accomplished by reducing P inputs than by reducing N inputs. Efforts to reduce the impact of agricultural runoff on P-limited waters should therefore be oriented, at least initially, toward minimizing P transport.

Specific agricultural management practices that reduce runoff P transport are often identified by a combination of simulation modeling results and experimental data. Simulation modeling uses general mathematical expressions to describe runoff transport of P as functions of variables such as soil P content, runoff, sediment yield, and enrichment ratio. Values of these variables can be structured to reflect particular management practices. The effects of different management practices on runoff P transport can be assessed, at least in relative terms, by comparing P transport predictions associated with the respective practices. While models can be flexible and give quick results, experimental data are critical in validating the relationships used in models and in determining values of sensitive model input parameters.

Runoff P transport models span the spectrum of complexity. Comprehensive, theoretically based P transport models have been developed and reported, for example, by Novotny et al. (1978), Lee et al. (1989), and Storm et al. (1988). Sharpley and Smith (1989) developed a more easily applicable model of runoff soluble P transport based on the kinetics of P desorption in soil. When a component of larger simulation models, however, runoff P transport models usually consist of simple equations to decrease input data requirements and facilitate widespread use. In the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980); Erosion/Productivity Impact Calculator (EPIC) (Sharpley and Williams, 1990); and Agricultural Non-Point-Source (AGNPS) (Young et al., 1987) models, for example, particulate P transport is predicted from an equation of the form:

$$\mathrm{YPP} = \mathrm{YSED} \times \mathrm{PSOIL} \times \mathrm{ER} \qquad (1)$$

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where

YPP = event particulate P transport (kg/ha)

YSED = event sediment yield (kg/ha)

PSOIL = concentration of P in the soil (kg/kg)

ER = enrichment ratio

The enrichment ratio is defined as:

$$ER = PSED/PSOIL \quad (2)$$

where PSED is the P concentration in the sediment. Values of ER are normally greater than one, reflecting the selective transport of smaller soil particles with a higher P content than the larger soil particles. The terms PSED and PSOIL in equation 2 should be consistent with respect to the particular form of P that they represent. The variables PSED and PSOIL are usually defined as the total P contents of the sediment and soil, respectively, and determined through, for example, perchloric acid digestion (e.g., Sharpley, 1985).

Several scientists (e.g., Massey and Jackson, 1952; Menzel, 1980; Sharpley, 1980) found that the natural logarithm of ER was well described as a linear function of the natural logarithm of YSED; i.e.:

$$\ln(ER) = a_0 + a_1 \times \ln(YSED) \quad (3)$$

The coefficients a_0 and a_1 of equation 2 were reported by Menzel (1980) and Sharpley (1980) to vary with soil and land use, but with approximate values of 2.2 for a_0 and -0.24 for a_1 representing a variety of soil and cover conditions. Sharpley (1980) concluded that ER depended more strongly on PSOIL and the energies associated with runoff and rainfall than on soil physical properties. Given observed values of YSED, equation 3 can therefore be used to predict ER, which can in turn be used with PSOIL observations to predict YPP. However, equations 1 and 3 have provided less accurate predictions of YPP for several grassed and cropped watersheds in Oklahoma and Texas (Sharpley et al., 1988) when event YSED was low (< 10 kg/ha). As the relationship between ER and YSED is logarithmic (eq. 3), estimation of ER is relatively sensitive to low (particularly < 10 kg/ha) values of YSED.

Runoff transport of soluble P is also predicted in the three earlier-mentioned models using an equation of the form:

$$YSP = 0.01 \times Q \times PSOIL \times XC \quad (4)$$

where

YSP = event soluble P transport (kg/ha)

Q = event runoff (mm)

XC = extraction coefficient (dimensionless)

The coefficient 0.01 is necessary to ensure consistent units. While soil samples are routinely collected from 0 to 15 cm depth, the value of PSOIL in equation 4 is usually taken as applicable to the top 1 cm of the soil. The variable XC is considered to represent the mixing of soil and runoff as well as the P desorption properties of the soil. High soil-runoff interaction and easily desorbed soil P would be reflected in an increase in XC. Values of XC reportedly used in various forms of equation 4 differ depending on the P form represented by PSOIL. In the EPIC model, for example, PSOIL is taken as referring to labile soil P (rather than total P as in eq. 1), and the default value of XC used is 0.0057 (1/175).

Some of the issues of concern to model developers and users relative to equations 1 through 4 involve parameter values and accuracy of predictions. The majority of previous work on determining values of ER and XC was performed using data from row-cropped and fallow conditions (Menzel, 1980; Sharpley, 1980; Timmons and Holt, 1980; McDowell et al., 1980), while there are less data available for pasture/range situations. More information on P transport parameters from pasture/range situations would improve predictions for those land uses and broaden the applicability of simplified prediction methods. Apart from the appropriateness of the transport parameter values, however, it is apparent such simplified models provide reliable predictions of P transport only within the range of conditions for which the models were developed. Equations 1 through 4 are (as other models) incomplete representations of the general process of runoff P transport, and many influential processes are lumped into the various parameters in the interests of simplicity and ease of application. As a result, there is inherent uncertainty regarding the accuracy of predictions relative to observations.

Water quality models are generally qualitative rather than quantitative tools. Model developers recognize this, and so should model users. However, most models predict only one value of a given output variable for a particular set of parameters and variable values with little indication of the precision of that prediction. Precision of predictions could be conveyed in the form of complete distribution functions or simply confidence limits within which the observations could be expected to fall with some quantifiable likelihood. Determining and reporting measures of the precision of model predictions under certain runoff or management conditions could aid model developers in deciding between competing models while conveying important information on the practical limitations of model-generated data to model users.

The objectives of this study were to:

- Determine P transport parameters (ER and XC) for pasture fields in Northwest Arkansas.
- Evaluate the precision of P transport estimates obtained from equations 1 through 4 in the form of confidence intervals.

The results can facilitate the use of models such as CREAMS, EPIC, and AGNPS in identifying P-oriented management practices and provide insight into the precision and accuracy that can reasonably be expected when using simplified methods of P transport prediction.

MATERIALS AND METHODS

Runoff from four fields (referred as RA, RB, WA, and WB) in northwestern Arkansas was monitored from October 1991 to April 1994. All the fields are located near Lincoln, Arkansas (approximately lat 36°N long 94°W) and are at a mean elevation of 460 m. Each field had a well-established stand of forage grass, predominately fescue grass (*Festuca arundinacea* Schreb.). Selected field characteristics are shown in table 1. Fields RA and RB were contiguous, while fields WA and WB were separated by approximately 500 m.

Table 1. Monitored field characteristics

Field	Area (ha)	Average Slope (%)	Soil(s)
RA	1.23	3	Captina silt loam
RB	0.57	2	Fayetteville fine sandy loam
WA	1.46	4	Linker loam
WB	1.06	4	Hector-Mountainburg stony fine sandy loam/Allegheny gravelly loam

Table 3. Schedule of phosphorus (P) applications

Field	Date	P Source	Rate (kg P/ha)
RA	3/15/92	Poultry Manure	120
	7/13/93	Poultry Manure	210
WB	3/23/92	Poultry Litter	62
	8/13/92	Poultry Litter	59
	4/13/93	Poultry Litter	43
	7/20/93	Poultry Litter	71
	3/29/94	Poultry Litter	71

Soil samples (five per field, 0 to 15 cm depth) were collected quarterly and analyzed by the University of Arkansas Agricultural Diagnostic Services Laboratory for various parameters, including extractable soil P (Mehlich, 1984). Average soil P concentrations measured during the study were 177, 246, 364, and 187 mg P/kg soil for fields RA, RB, WA, and WB, respectively.

All fields were grazed and fertilized during the study. Monthly grazing densities are shown in table 2. Grazing densities were the same for fields RA and RB because there was no fence to separate the fields. Fields RB and WA received only ammonium nitrate fertilizer (i.e., no P amendment) during the study, applied at an average rate of 140 kg/ha/year. Fields RA and WB, however, were amended with P through the application of poultry manure and poultry litter, respectively. The schedule and rates of manure application to fields RA and WB are given in table 3.

Rainfall and runoff instrumentation was installed on the fields in the fall of 1991. Each field was instrumented with an "H" flume (Agricultural Research Service, 1979) and stilling well, a water depth sensor, an automated water sampler, and a datalogger. The instruments were interfaced so that when water height within the flume reached 25 mm, runoff samples (approximately 1 L) were collected at a constant time increment until either all 24 sample containers were filled or water height fell below 25 mm. Two tipping bucket rain gages were also installed to measure and record rainfall. One rain gage was installed between fields WA and WB, and the other was installed at the outlet of field RB.

Storm runoff samples were retrieved for analysis as soon as possible (≤ 24 h) following their collection. The Arkansas Water Resources Center Water Quality Laboratory analyzed the samples for total P (TP), ortho-P (PO_4-P), and total suspended solids (TSS) concentrations according to standard methods of analysis (Greenberg et al., 1992). Total P was determined from the ascorbic acid colorimetric method following sulfuric acid-nitric acid digestion. Concentrations of PO_4-P were measured using ion chromatography after filtration through 0.45 µm pore diameter filter paper. The data on runoff rates and concentrations of TP, PO_4-P, and TSS were used to compute storm event sediment yield, particulate P transport and soluble P transport.

Table 2. Grazing schedule

	Field		
	RA/RB	WA	WB
Month/Year	Animal Units/ha		
8/91-1/92	2.0	0.3	0.3
2/92-3/92	2.0	0.0	1.0
4/92-6/92	0.0	0.0	1.0
7/92-9/92	0.0	0.0	1.7
9/92-12/92	1.5	1.1	1.1
1/93-4/93	1.5	0.0	1.5
5/93	0.0	0.0	1.5
6/93	0.0	0.0	0.9
7/93	0.0	0.0	0.0
8/93-10/93	1.4	1.0	0.0
11/93-1/94	1.4	0.5	0.5
2/94-3/94	0.0	0.5	0.5
4/94	0.0	0.0	1.0

Values of ER were calculated for each storm event using equation 2. The value of PSOIL used in equation 2 was soil total P as estimated from:

$$\text{PSOILT} = 412 + 1.9 \times \text{PSOILM} \qquad (5)$$

where PSOILT is soil total P (mg/kg) and PSOILM is soil Mehlich P (mg/kg). Equation 5 was developed from data reported by Sharpley et al. (1985) and is applicable to a "slightly weathered" soil grouping. Storm event values of ER were then related to YSED (taken as storm event TSS transport) through equation 3 using simple linear regression. Values of YPP were taken as the difference between storm event TP and PO_4-P transport. Event values of XC were determined by rearranging equation 4 and solving directly for XC as a function of observed Q, YSP (taken as storm event PO_4-P transport), and soil P. Soil P in equation 4 was taken as labile P and estimated from:

$$\text{PSOILL} = 0.134 \times \text{PSOILM} + 10.9 \qquad (6)$$

where PSOILL is labile soil P (mg/kg) (Sharpley et al., 1985). Equation 6 also applies to slightly weathered soils. Values of PSOILM corresponding to a particular storm event were linearly interpolated from the two most recent soil sampling dates.

The value of ln(ER) predicted from equation 3 for a particular value of ln(YSED) was taken as normally distributed. The mean of ln(ER) was calculated as the output of equation 3. The variance of ln(ER) was calculated as a function of the particular value of ln(YSED) and regression statistics as described by Haan (1977). A normal distribution of ln(ER) leads to a log-normal distribution of ER and therefore YPP as calculated from equation 1. The mean of YPP was taken as the result of equation 1. The variance of a particular value of YPP was calculated using methods described by Haan (1977) as a function of the corresponding values of both YSED and PSOIL. This procedure thus enabled the distribution of YPP to be specified for one particular value of YSED. Confidence limits on a particular value of YPP were determined as the YPP values that corresponded to 0.025 and 0.975 cumulative probability. The procedure was repeated for a range of YSED values, resulting in a relationship between mean and 95% confidence limits on YPP as a function of YSED. Values of PSOIL for the four fields were held equal to their respective means in developing the confidence limits.

The process of determining confidence limits on the value of YSP predicted for a particular set of Q and PSOIL values was similar, but more straight forward since XC was taken as independent of any observed variables (in contrast to ER, which was taken as a function of YSED). Gamma distributions were chosen to represent the distributions of XC for the fields because of the statistics of the computed XC values and the flexibility of the gamma distribution.

The value of YSP predicted for particular values of Q and PSOIL thus followed a gamma distribution. The mean of a particular prediction of YSP was calculated from equation 4, and the variance was calculated from:

$$S^2_{YSP} = (0.01 \times Q \times PSOIL)^2 \, S^2_{XC} \tag{7}$$

where S^2_{YPP} is the variance of YPP and S^2_{XC} is the variance of XC. Confidence limits for a particular prediction of YSP determined as the YSP values corresponding to 0.025 and 0.975 cumulative probability. The process of calculating mean YSP values and 95% confidence limits was repeated for a range of Q values while holding PSOIL equal to its respective mean.

Results and Discussion

Observed Storm Event Runoff, P Transport, and Sediment Transport

Observed storm event values of Q, TSS, TP, and PO_4-P are summarized in table 4. The data are characterized by significant between-field variability. As expected for pasture fields, mean event TSS transport was relatively low (ranging from 2.7 to 9.2 kg/ha. Table 4 indicates that the majority (an average of 86%) of the P transported off the fields was in soluble form, which is consistent with findings reported by Edwards and Daniel (1994) for grassed plots in northwestern Arkansas.

Storm Event Runoff Values

The inverse relationship between ln(ER) and ln(YSED) found in earlier studies (Massey and Jackson, 1952; Menzel, 1980; Sharpley, 1980) held for the four fields investigated in this study, as demonstrated in figure 1 for field RB. The coefficient of determination obtained from regressing ln(ER) against ln(YSED) was significant ($p < 0.05$), ranging from 0.15 to 0.54 (table 5), for each field. The values of a_0 in equation 3 (average of 2.4, table 5) were very comparable to the value of 2.2 reported by Menzel (1980) and Sharpley (1980), while the values of a_1 in equation 3 (average of −0.46, table 5) were approximately twice as low as the reported values. In this study, therefore, ER declines at a relatively rapid rate with increasing YSED. Sharpley et al. (1991) have also noted that ER values for reduced-tillage land uses declined more rapidly than for tilled land uses with increasing YSED values. This result was due to solids eroded from reduced-tillage land uses containing a higher proportion of organic matter (and thus a lower proportion of inorganic particulate P) than solids eroded from tilled land uses. Knoblauch et al. (1942) and Neal (1944) observed higher ERs for organic matter (4.32) and total N (4.2; mainly as organic N) than total P (1.84) in runoff from a Collington sandy loam in New Jersey. Similarly, Sharpley (1985) found ERs for organic particulates (2.00 and 1.61 for organic carbon and total N, respectively) to be greater than for inorganic particulates (1.56 and 1.52 for clay and particulate P, respectively) for six soils varying in physical and chemical properties. This accounted for significantly ($p < 0.05$) greater a_0 and lesser a_1 values for grassed (1.73 and −0.28, respectively) than cropped watersheds (1.18 and −0.14, respectively) in the Southern Plains over a 10-year study.

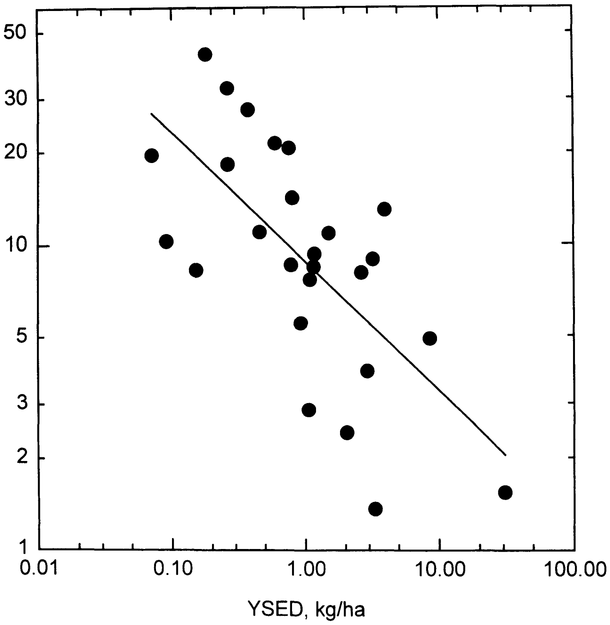

Figure 1–Relationship between ER and YSED for field RB.

The implications of accurately specifying the relationship between ER and YSED are significant. On field RA, for example, using a_0 equal to 2.2 and a_1 equal to

Table 4. Statistics of observed storm event variables

		Q		YSED		TP		PO_4-P	
Field	n*	Mean (mm)	CV† (mm)	Mean (kg/ha)	CV (kg/ha)	Mean (kg/ha)	CV (kg/ha)	Mean (kg/ha)	CV (kg/ha)
RA	19	12.1	0.8	4.5	1.7	0.32	1.04	0.30	1.08
RB	26	3.4	1.1	2.7	2.3	0.06	1.12	0.05	1.21
WA	18	15.2	1.2	9.2	3.3	0.21	1.12	0.18	1.13
WB	27	4.5	1.2	5.4	2.0	0.15	0.70	0.12	1.52

* n is number of events, Q is runoff, YSED is sediment yield, TP is total phosphorus, and PO_4-P is ortho-phosphorus.

† Coefficient of variation.

Table 5. Results of regressing the natural logarithm of ER against the natural logarithm of YSED

Field	a_0*	a_1	SE	r^2
RA	2.56	−0.63	1.20	0.34
RB	2.16	−0.42	0.67	0.45
WA	2.50	−0.49	0.85	0.54
WB	2.30	−0.29	1.14	0.16

* a_0 and a_1 are the intercept and slope, respectively, of the regression line relating ln(ER) to ln(YSED); SE is standard error of estimate; and r^2 is the coefficient of determination for the regression.

−0.24 along with mean YSED and PSOIL predicts a mean event YPP value of 0.01 kg/ha, which is more than three times the mean event YPP value of 0.003 kg/ha obtained using the values of table 5.

There were no apparent relationships between ER and grazing density. There were also no consistent relationships between ER and application of poultry litter or manure, although the highest values of ER for fields RA and WB occurred during the first runoff events following manure and litter application (figs. 2 and 3). Some adjustment to account for the effect of recent animal manure application on ER might be justified to better reflect the presence of the relatively high amount of P at the soil surface, but the data of this study do not indicate the appropriate adjustment.

STORM EVENT XC VALUES

The extraction coefficient was not significantly correlated with Q or YSED. Statistics of the storm event XC values computed for the fields are given in table 6. There is wide variability in XC values, both within and between fields. In general, the XC values found in this study were considerably higher than that used (0.006), for example, in the EPIC model (Sharpley and Williams, 1990). Earlier studies suggest that the relatively high XC values of table 6 are not the result of increased interaction under grassed conditions (in comparison to tilled conditions) between runoff and soil. The depth of runoff-soil interaction, representing the degree of mixing, can be calculated for a given runoff event using the YSP predictive equation of Sharpley and Smith (1989). The average depth of interaction during runoff from nine grassed watersheds (1.05 mm; ranging from 0.02 to 13.47 mm) was significantly ($p < 0.05$) less than for six wheat watersheds (3.74 mm; ranging from 0.03 to 57.85 mm) in the Southern Plains over 10 years (Sharpley et al., 1988). If anything, then, XC values for grassed conditions should be lower than for tilled conditions. The relatively high XC values might have resulted in part from using values of PSOIL averaged over 0 to 15 cm depth. Since PSOIL is known to be considerably higher near the soil surface than at greater depths for manured pasture land uses (e.g., Sharpley et al., 1991), the P content of soil actually interacting with runoff was likely much higher than the averaged value. It is also possible, as discussed in the following paragraph, that XC should be adjusted upward to reflect enhanced desorption of P from (especially recently) manured soils in comparison to unmanured soils.

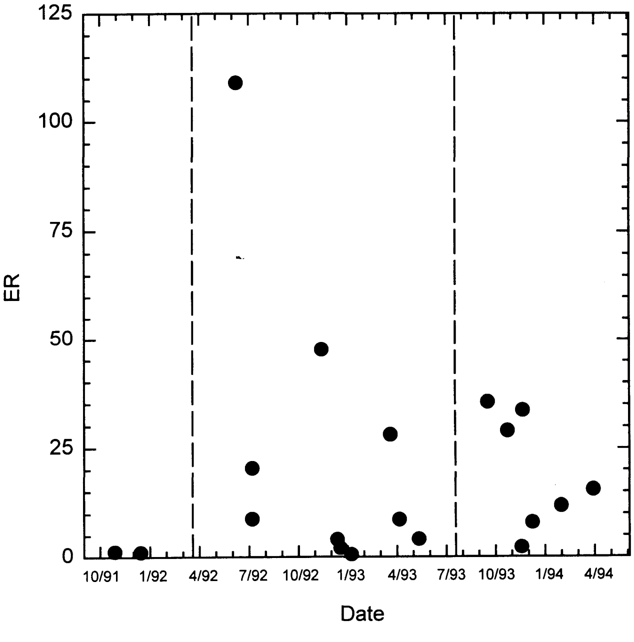

Figure 2–Storm event ER values for field RA. Dashed lines indicate poultry manure application.

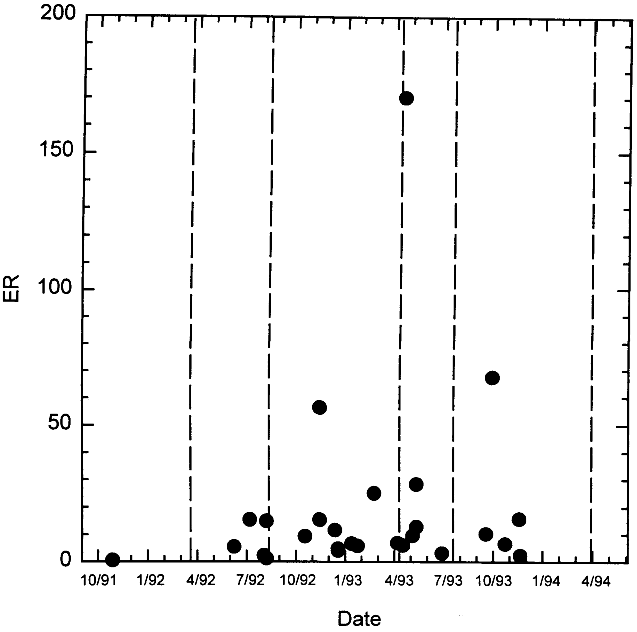

Figure 3–Storm event ER values for field WB. Dashed lines indicate poultry litter application.

Storm event XC values appeared to be closely related to the application of animal manures. Figures 4 and 5 show that storm event XC values were generally higher (as much as a factor of 8) for storms occurring shortly after application of animal manure, decreasing thereafter. Some method of accounting for recent animal manure application effects on XC appears to be justified. This adjustment should likely be a function of, at a minimum, manure application rate and time and/or rainfall since application. The justification for such a modification is strengthened by the fact that the solubility of manure P is two to four times that of soil P (Edwards and Daniel, 1992; Robinson and Sharpley, 1995).

CONFIDENCE LIMITS ON YPP AND YSP PREDICTIONS

The 95% confidence limits on YPP and YSP are demonstrated in figures 6 and 7, respectively, for field RA.

Table 6. Statistics of storm event extraction coefficients

Field	Mean	CV*	Skewness
RA	0.067	0.537	2.064
RB	0.037	0.435	0.917
WA	0.027	0.377	0.688
WB	0.097	1.595	4.344

* Coefficient of variation.

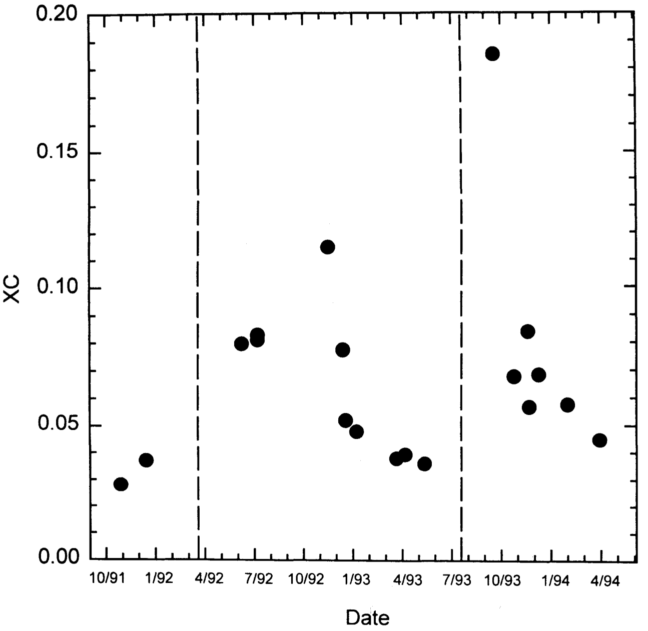

Figure 4–Storm event XC values for field RA. Dashed lines indicate poultry manure application.

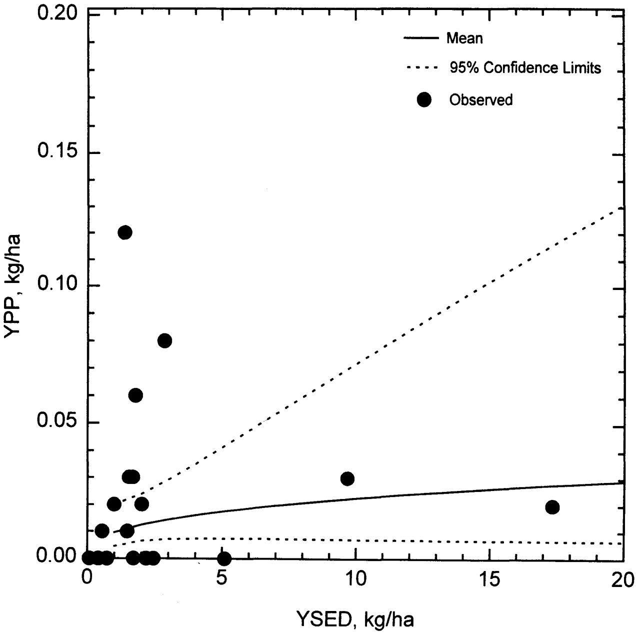

Figure 6–Observed, predicted, and 95% confidence limits on predicted YPP as a function of YSED for field RA.

Tables 7 and 8 give 95% confidence limits on YPP and YSP predictions, respectively. The confidence intervals on YPP and YSP are seen to increase with increasing values of YSED and Q, respectively. The effect is that at higher values of YSED and Q, there is less precision associated with predictions of YPP and YSP, respectively. For field RA, for example, the upper and lower confidence limits on YPP predicted for a sediment yield of 20 kg/ha are 0.130 and 0.007 kg/ha, spanning more than an order of magnitude. Similarly, the 95% confidence limits on YSP predicted for 50 mm runoff vary by a factor of approximately 8. The data of figures 6 and 7 and tables 7 and 8 thus point out that one can be less sure of predicting YSP and YPP values that are close to observed values as the magnitude of the prediction increases. While this is intuitive, the data given in tables 7 and 8 establish the limits of precision that can be expected for a given (95%, in this case) confidence level. Whether those limits are acceptable is a different issue.

Data such as shown in figures 6 and 7 might provide an indication of the suitability of the model for the intended purpose. In figure 7, for example, nearly all YSP observations fall within the 95% confidence interval about the predicted mean. This suggests that aside from the

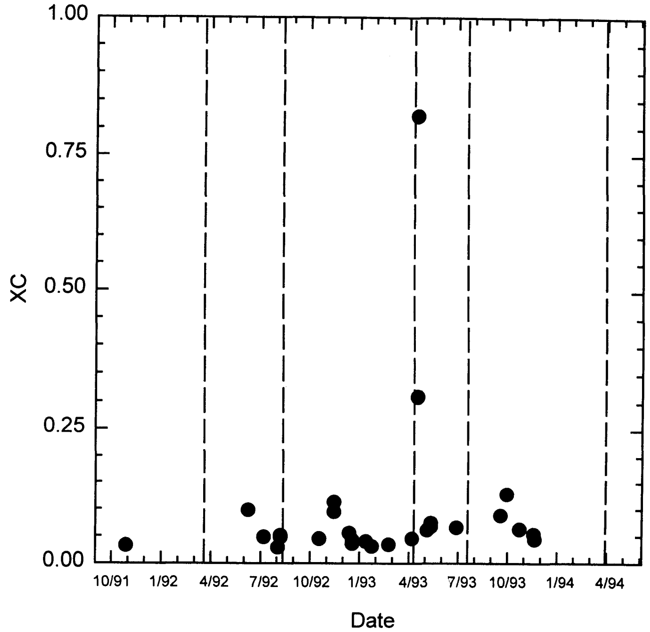

Figure 5–Storm event XC values for field WB. Dashed lines indicate poultry litter application.

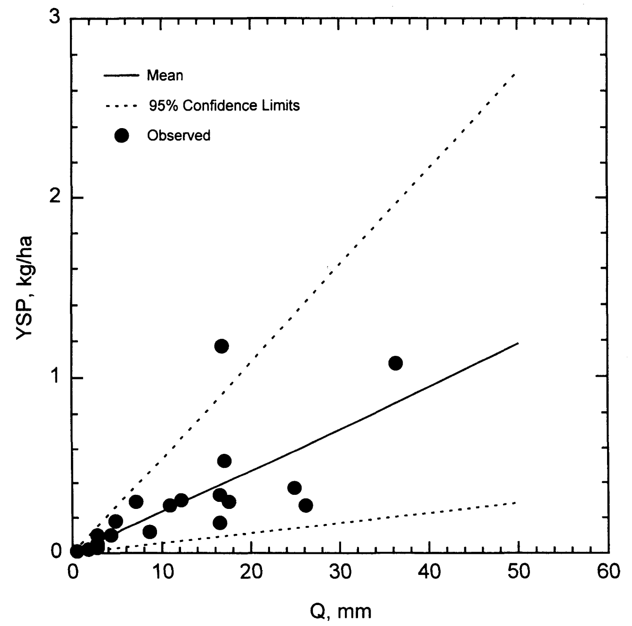

Figure 7–Observed, predicted, and 95% confidence limits on predicted YSP as a function of runoff (Q) for field RA.

Table 7. Ninety-five percent confidence limits on predicted YPP

	Field							
	RA		RB		WA		WB	
Sediment Yield	Lower Limit (kg/ha)	Upper Limit	Lower Limit (kg/ha)	Upper Limit	Lower Limit (kg/ha)	Upper Limit	Lower Limit (kg/ha)	Upper Limit
2	0.006	0.023	0.010	0.012	0.016	0.021	0.011	0.014
4	0.007	0.035	0.014	0.021	0.020	0.036	0.017	0.024
6	0.007	0.047	0.016	0.029	0.021	0.052	0.021	0.035
8	0.007	0.060	0.017	0.038	0.021	0.069	0.024	0.046
10	0.007	0.072	0.017	0.047	0.021	0.088	0.027	0.058
12	0.007	0.084	0.018	0.056	0.021	0.107	0.029	0.069
14	0.007	0.096	0.018	0.066	0.020	0.127	0.030	0.082
16	0.007	0.108	0.019	0.075	0.020	0.149	0.032	0.094
18	0.007	0.119	0.019	0.085	0.019	0.171	0.033	0.107
20	0.007	0.131	0.019	0.095	0.019	0.195	0.034	0.121

imprecision in the estimates (i.e., the widths of the 95% confidence intervals), equation 4 appears to be a reasonable reflection of the process of soluble P transport. In figure 6, however, most observations of YPP actually fall outside the 95% confidence interval about the predicted mean, suggesting that a different method of prediction might be more appropriate for low values of YSED. For all four fields, essentially all observations of YSP fell within the 95% confidence intervals. In contrast, only about half the observed YPP values for the fields were contained by the 95% confidence intervals. The reliability of equations 1 through 3 has led to their widespread use in YPP prediction. However, those equations were generally developed to predict YPP for larger values of YSED than observed in this study. The development of other methods specifically suited to low (< 10 kg/ha) values of YSED might thus be justified to improve YPP predictions for conditions similar to those of this study.

SUMMARY AND CONCLUSIONS

Data on runoff (Q), sediment yield (Y), soluble P transport (YSP), and particulate P transport (YPP) were collected on four pasture watersheds in northwestern Arkansas. These data were used to evaluate the enrichment ratio (ER) and extraction coefficient (XC) parameters of simplified models of particulate and soluble P transport, respectively, and to develop confidence intervals for predictions of YPP and YSP.

Table 8. Ninety-five percent confidence limits on predicted YSP

	Field							
	RA		RB		WA		WB	
Runoff (mm)	Lower Limit (kg/ha)	Upper Limit	Lower Limit (kg/ha)	Upper Limit	Lower Limit (kg/ha)	Upper Limit	Lower Limit (kg/ha)	Upper Limit
5	0.03	0.27	0.03	0.17	0.03	0.13	0.00	0.95
10	0.06	0.54	0.06	0.33	0.06	0.27	0.00	1.90
15	0.08	0.81	0.08	0.50	0.09	0.40	0.00	2.85
20	0.11	1.08	0.11	0.67	0.11	0.53	0.00	3.81
25	0.14	1.35	0.14	0.83	0.14	0.66	0.00	4.76
30	0.17	1.62	0.17	1.00	0.17	0.80	0.00	5.71
35	0.20	1.89	0.20	1.17	0.20	0.93	0.00	6.66
40	0.23	2.16	0.22	1.33	0.23	1.06	0.00	7.61
45	0.25	2.43	0.25	1.50	0.26	1.19	0.00	8.56
50	0.28	2.70	0.28	1.66	0.29	1.33	0.00	9.51

An inverse linear relationship between ln(ER) and ln(YSED) was found to be significant for each field, but the slopes were lower than values reported earlier for general cases, a result that may be related to low sediment yields (< 10 kg/ha) consisting of relatively high proportion of lighter organic as opposed to heavier soil particulates. Event values of XC were uncorrelated with Q and YSED and were significantly higher than values typically used, which could have been the result of P distribution within the soil profile and/or relatively high soluble of manure P. Values of XC were higher for manured fields than for unmanured fields. For the manured fields, XC values were generally highest for runoff occurring shortly following animal manure application, declining for succeeding runoff events.

The confidence intervals established for YPP and YSP predictions demonstrated how the precision of the predicted values decreases with increasing magnitude of the prediction. The upper and lower 95% confidence limits sometimes varied by more than an order of magnitude for a given predicted value. Superimposing observed and predicted YSP values on the confidence limits for a range of input variable values suggested that, irrespective of the issue of precision, the simplified model of soluble P transport appeared to be a reasonable reflection of the influential processes. The data on particulate P transport, however, suggested that another prediction method might be more appropriate for the pasture fields studied where sediment yield is generally less than 10 kg/ha.

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