USE OF THE EPIC MODEL TO PREDICT RUNOFF TRANSPORT OF SURFACE-APPLIED INORGANIC FERTILIZER AND POULTRY MANURE CONSTITUENTS

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ABSTRACT. *The Erosion Productivity Impact Calculator (EPIC) model was applied to four fields established in "tall" fescue (*Festuca arundinacea *Schreb.) in northwestern Arkansas to predict runoff and transport of nitrogen, phosphorus, and sediment. Fertilizer form varied among the fields with two receiving inorganic fertilizer, one receiving poultry (*Gallus gallus domesticus*) litter, and one receiving poultry manure. Soil and grazing parameters also differed among fields. Runoff and nutrient/sediment transport observed over 20 months were compared to EPIC predictions generated without calibration. Significant correlation between event predictions and observations were found in half the cases. There was significant correlation between observed and predicted calendar year total transport for all outputs except nitrate-nitrogen. The findings indicate that EPIC can accurately reflect runoff quality trends when executed without calibration for pasture fields in northwestern Arkansas.*

Keywords. *Water quality, Modeling, Pasture, Poultry, Manure, Litter.*

Poultry (*Gallus gallus domesticus*) production dominates Arkansas' agricultural economy. The value of Arkansas' 1991 broiler and egg production was nearly 1.7 billion dollars—more than the combined production value of all cotton, rice, and soybean for that year (Arkansas Agricultural Statistics Service, 1992). Large quantities of poultry and poultry products are also produced in other southern states, California, and the Delaware-Maryland-Virginia region.

Poultry manure and poultry litter (the combination of manure and bedding material) are by-products of broiler and egg production, and are typically used in Arkansas to fertilize forage crops such as tall fescue (*Festuca arundinacea* Schreb.). Agronomic benefits of applying poultry litter to forage grasses have been documented by Hileman (1965, 1973) and Huneycutt et al. (1988). The transport of manure and litter constituents off application sites and into downstream rivers and lakes, however, is of increasing concern in regions having concentrated poultry production. Scientists (e.g., Westerman and Overcash, 1980; Westerman et al., 1983; Edwards and Daniel, 1992, 1993) have demonstrated the potential for high losses of nutrients and organic matter from land areas recently treated with poultry manure and litter.

Potential downstream water quality impacts of poultry manure/litter (as well as other organic and inorganic fertilizers) application can be reduced by implementing appropriate management options. The goal in implementing such management options is to minimize off-site runoff transport of manure/litter constituents. Off-site transport can be reduced by practices that reduce manure/litter constituent concentrations in the interacting surface soil layer and/or that alter the hydraulic characteristics of the receiving sites. Examples of such management options include incorporation, timing applications to avoid runoff-producing storms shortly after application, installation of terraces, and installation of vegetated filter strips.

Practical, effective management options for reducing runoff transport of potential pollutants have traditionally been identified on the basis of experimental results and then communicated to end users through customary dissemination channels. Experimental results are often site-specific to some degree, and it might not be possible in all cases to directly extend experimental results from a small number of research scenarios to all conceivable situations. Since the number of variables and permutations of variables influential in runoff transport of pollutants is simply too large to rely solely on experimental techniques for identification of effective management options, indirect methods must be used to at least some degree as a surrogate for experimental observations. Mathematical simulation models are increasingly used as an indirect method of assessing the effectiveness of potential management options in reducing off-site pollutant transport. Simulation modeling can be a very cost-effective approach provided that the equations and parameters used adequately reflect physical reality (i.e., if model predictions consistently emulate observations of the predicted variables).

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The objective of this study was to assess the performance of the Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1983a, b) model in predicting transport of sediment and nutrients in runoff from fertilized pasture areas in northwest Arkansas. The EPIC model was selected because of its comprehensive nature, flexibility with respect to management options, ability to describe fate and transport of organic as well as inorganic fertilizer constituents, and demonstrated accuracy in other applications (Jones and Williams, 1986). The model was applied to fields that varied significantly in terms of fertilizer source, physical parameters, and management so that EPIC's capabilities would be rigorously tested. The larger goal of the study was to identify a mathematical simulation model that can produce reasonable off-site sediment and nutrient transport estimates for the pasture situations typical of northwestern Arkansas. Such a simulation model could then be used to aid in identification and/or implementation of management practices to reduce off-site transport of both organic and inorganic fertilizer constituents.

METHODS

DESCRIPTION OF MONITORED FIELDS

Runoff and associated quality data were collected from four fields in northwestern Arkansas (36°N Lat, 94°W Long) over the period from 1 September 1991 to 30 April 1993 and used in validating the EPIC model. Selected physical characteristics of the fields are summarized in table 1. The crop cover for all fields is predominantly tall fescue. All fields are situated at an elevation of approximately 460 m. Management of the fields differed in terms of grazing, hay cutting, and fertilizer application.

Field RA was used for grazing. Grazing density was five animal units (AU)/ha from September 1991 to March 1992 and 3.6 AU/ha from September 1992 to April 1993. The field was ungrazed from April to August 1992. Poultry manure slurry was surface-applied as fertilizer on 15 March 1992 at 363 kg nitrogen (N)/ha and 120 kg phosphorus (P)/ha. The composition of the poultry manure is given in table 2. No poultry manure was applied in early spring 1993 because of unusually wet conditions.

Field RB was grazed at the same schedule as for field RA (the fields were adjacent). Inorganic fertilizer (ammonium nitrate) was surface-applied on 23 March 1992 at 67 kg N/ha and on 25 April 1993 at 115 kg N/ha.

Field WA was used for both grazing and hay production during the study period. The field was grazed at 0.8 AU/ha from September 1991 to January1992 and at 2.6 AU/ha from September to December 1992. Field WA was cut for hay on 7 July 1992. Inorganic fertilizer (ammonium nitrate) was surface-applied on 23 March 1992 at 138 kg N/ha and on 13 April 1993 at 226 kg N/ha.

Table 1. Selected characteristics of monitored fields

Field Name	Area (ha)	Soil*	Curve† Number	Average Slope	Slope Length (m)	Erodibility‡ (Mg/ha/yr)
RA	1.23	Captina silt loam	74	0.03	137	0.97
RB	0.57	Fayetteville fine sandy loam	61	0.02	142	0.54
WA	1.46	Linker loam	79	0.04	194	0.54
WB	1.06	Hector-Mountainburg stony fine sandy loam/ Allegheny gravelly loam	64	0.04	180	0.49

* Harper et al., 1969.
† Soil Conservation Service, 1986.
‡ Soil Conservation Service, 1983.

Table 2. Compositions of applied poultry manure and litter

	Fertilizer	Application	Mean Concentration				
			H_2O	Total-N	NH_4-N	NO_3-N	Total-P
Field	Source	Date	(%)	(mg/L)			
RA	Manure	3/15/92*	88.1	7 483	4 847	72	2 683
				(mg/kg)			
WB	Litter	3/23/92†	19.1	44 500	5 843	241	12 700
		9/11/92†	36.1	27 925	243	5	11 650
		4/13/93†	18.7	34 225	5 928	651	9 150

* Data for this date are means of six samples.
† Data for this date are means of four samples; "as-is" basis.

Field WB was grazed continuously at grazing densities of 0.8 AU/ha from September 1991 to January 1992, 2.4 AU/ha from February to June 1992, 4.1 AU/ha from July to August 1992, 2.6 AU/ha from September to December 1992, and 3.7 AU/ha from January to April 1993. Dry poultry litter was surface-applied on 23 March 1992 at 195 kg N/ha and 63 kg P/ha and on 11 September 1992 at 138 kg N/ha and 59 kg P/ha. Poultry litter was again surface-applied on 13 April 1993 at 158 kg N/ha and 52 kg P/ha. The composition of the poultry litter used is given in table 2. Field WB is located approximately 500 m west of field WA.

Instrumentation was installed prior to the beginning of the study to monitor rainfall and to monitor and sample runoff. Tipping bucket rain gages (one for fields WA and WB and one for fields RA and RB) and datalogging software were used to record rainfall occurring during 5-min increments. Runoff rates were determined based on stage within type "H" flumes installed at the field outlets. Stage was measured by pressure transducers installed in the flume stilling wells and recorded at 5-min increments by dataloggers. Automatic flow samplers (American Sigma model 800SL) were used to collect runoff samples. Details regarding sample analysis procedures are given by Edwards et al. (1993). A weather station was installed at an approximately central location (approximately 10 km from each pair of fields) to measure and record hourly temperature, relative humidity, wind velocity, and solar radiation. The weather station was operational beginning 22 September 1992.

SIMULATION MODEL

The EPIC model is a comprehensive, continuous, lumped parameter, field-scale simulation model capable of estimating runoff and runoff transport of nitrate-N (NO_3-N), organic-N (ORG-N), soluble-P (SP), total-P (TP), and sediment yield (Y). Numerous influential processes such as crop growth, soil nutrient dynamics, leaching, and management operations (tillage, harvest, grazing, etc.) are mathematically described within the model. The model and input data requirements have been fully documented (Sharpley and Williams, 1990; Williams et al., 1990), and the model has been demonstrated to produce reasonable results under a variety of site/management conditions (Steiner et al., 1990; Cooley et al., 1990; Smith et al., 1990; Kiniry et al., 1990). The model version used in this study contained recently-added animal manure N mineralization and volatilization algorithms based on those described by Reddy et al. (1979a, b).

An EPIC input data file was constructed for each monitored field. Values of parameters such as runoff curve number, erodibility, surface roughness factor, and general soil physical characteristics were determined from readily available, published sources (e.g., Soil Conservation Service, 1986; Harper et al., 1969). Soil surface chemical parameters and poultry litter/manure characteristics were determined by analyses of the respective materials. All rainfall data were obtained by the tipping bucket rain gauges near the fields. Maximum and minimum daily air temperature for the period before the weather station become operational were taken from data observed at the University of Arkansas Main Agricultural Experiment Station in Fayetteville (approximately 30 km from the fields). Remaining data for that period (solar radiation, relative humidity, wind speed) were generated within EPIC based on the observed temperature and rainfall data. All weather data were taken from the weather station for the period after the station became operational.

Daily predictions of runoff (Q) and runoff losses of Y, NO_3-N, ORG-N, SP, and TP were generated by EPIC based on the constructed data sets for the period of 1 September 1991 to 30 April 1993. Those predictions were then compared to the observed data to assess the performance of EPIC on both an event-by-event loss basis as well as on a calendar year total loss basis. No calibration was attempted. The study constituted a fairly rigorous test of EPIC's capabilities since (a) no parameters were calibrated, and (b) the fields differed significantly in terms of soils, grazing, and fertilizer application.

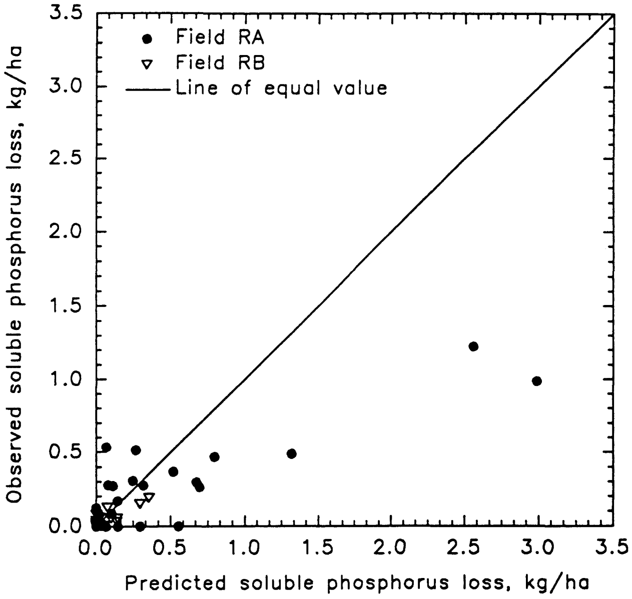

Figure 2–Observed and predicted event soluble phosphorus loss for fields RA and RB (1991-1993).

RESULTS AND DISCUSSION

EVENT PERFORMANCE

The performance of EPIC when assessed on an event basis varied among output variables and fields. Figures 1 and 2 demonstrate the performance of EPIC for event predictions of Q and SP, both of which were significantly ($p = 0.05$) correlated to corresponding observations. In other cases, as demonstrated in figure 3 for ORG-N, the relationships between predicted and observed event outputs were not statistically significant ($p = 0.05$). The correspondence between event predictions and observations is summarized in table 3, which lists regression parameters obtained by regressing observed against predicted model outputs. Predicted values of

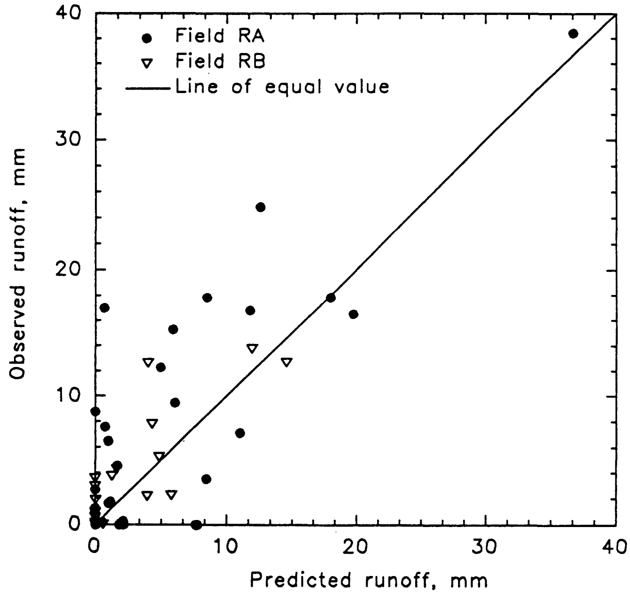

Figure 1–Observed and predicted event runoff for fields RA and RB (1991-1993).

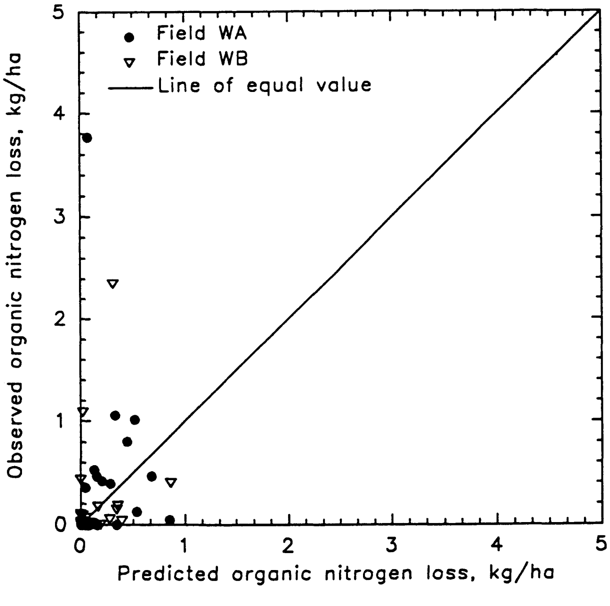

Figure 3–Observed and predicted event organic nitrogen loss for fields WA and WB (1991-1993).

Table 3. Parameters from linear regressions of observed against predicted EPIC outputs

Field	Output					
Name	Q	Y	NO_3-N	ORG-N	SP	TP
RA	a = 1.40* b = 1.14 r^2 = 0.86 n = 35	a = 1.77 b = 0.42 r^2 = 0.34 n = 30	NS† n = 31	NS n = 31	a = 0.07 b = 0.35 r^2 = 0.74 n = 31	a = 0.08 b = 0.26 r^2 = 0.67 n = 31
RB	a = 1.27 b = 0.90 r^2 = 0.69 n = 22	NS n = 19	NS n = 19	NS n = 19	a = 0.01 b = 0.44 r^2 = 0.69 n = 19	a = 0.02 b = 0.41 r^2 = 0.67 n = 19
WA	a = 3.47 b = 0.61 r^2 = 0.15 n = 37	NS n = 34	a = 0.10 b = 0.92 r^2 = 0.71 n = 34	NS n = 34	NS n = 34	a = 0.06 b = 0.79 r^2 = 0.18 n = 34
WB	a = 1.00 b = 0.47 r^2 = 0.30 n = 32	a = 0.06 b = 1.23 r^2 = 0.44 n = 30	NS n = 30	NS n = 30	NS n = 30	NS n = 30

* Coefficients a and b estimated for the relationship $V_o = a + bV_p$, where V_o is the observed value of the parameter and V_p is the predicted parameter value. n is the number of data points for which the regression was performed, and r^2 is the coefficient of determination.

† Coefficient of determination not significantly ($p = 0.05$) different from zero.

Q were significantly ($p = 0.05$) correlated with observed values for all four fields. Significant ($p = 0.05$) relationships between predicted and observed outputs were also found for Y, SP, and TP for at least two of the four validation fields. The less successful event predictions for N forms is likely due to the relatively large number of operative loss mechanisms and transformations. The difficulty of accurately predicting a particular model output can be expected to increase with the number of intermediate results necessary for computing that output.

The information presented in table 3 and figures 1 through 3 should be interpreted in light of the facts that (a) the model was executed without benefit of calibration, and (b) EPIC was originally developed to reflect trends in runoff quality on a long-term basis, not an event basis. In several cases where the relationship between predicted and observed model outputs was significant, the slope of the regression curve was different from unity (table 3), indicating that accuracy would be improved with calibration of perhaps a small number of model parameters. Event performance would likely have improved if the time step on rainy days were shortened. Models with daily time steps have obvious, significant limitations with regard to event predictions. Specifically, such models are unable to accurately account for the temporal distribution of rainfall within a particular day or to appropriately combine rainfall events that occur through midnight. The sacrifices in runoff prediction accuracy that accompany use of a daily time step model are transferred (and perhaps even magnified) to predictions of other variables that depend on runoff. Any decision to conduct model adaptations to handle temporal distribution of rainfall, however, should balance the expected increased prediction accuracy against increased input data requirements. Data input would certainly be more time-consuming with a shorter within-rainfall event time step, and the modifications to improve event performance would possibly make EPIC less well-suited to its intended use of long-term analyses. The generally (11 cases out of 16) significant correlation between predicted and observed event Q, Y, SP, and TP suggests that notwithstanding its development as a tool for long-term analyses, EPIC can reasonably reflect the behavior of those water quality parameters on an event basis for the situation of this study. Model performance with regard to ORG-N and NO_3-N, however, suggests that modifications to the accounting and transport algorithms for these parameters might be warranted to improve event predictions.

CALENDAR YEAR TOTAL PERFORMANCE

Predicted and observed calendar year sums of EPIC outputs for calendar years 1991 through 1993 are shown in tables 4, 5, 6, and 7 for fields RA, RB, WA, and WB, respectively. No correlations between predicted and observed outputs were computed for individual fields because of the low number of degrees of freedom. Predictions of parameters such as SP and TP (which were consistently overestimated) and ORG-N (which was consistently underestimated) could have been improved significantly through a fairly simple calibration process. It is noteworthy, however, that observed losses of sediment and nutrients were quite low (typical of a range/pasture

Table 4. Observed and predicted EPIC outputs for field RA

	Total											
	Q		Y		NO_3-N		ORG-N		SP		TP	
Year	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.
	---(mm)----		---(kg/ha)---									
1991	30.4	15.6	22.8	15.9	0.05	0.02	0.72	0.29	0.38	0.20	0.33	0.27
1992	253.3	184.5	94.3	186.3	0.33	2.62	7.49	5.44	5.48	9.97	5.28	12.11
1993	50.5	51.6	37.4	33.6	0.04	1.17	0.90	1.01	0.68	1.61	0.67	1.93
Sum	334.2	251.7	154.5	235.8	0.42	3.81	9.11	6.74	6.54	11.78	6.28	14.31

Table 5. Observed and predicted EPIC outputs for field RB

	Total											
	Q		Y		NO_3-N		ORG-N		SP		TP	
Year	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.
	---(mm)----		---(kg/ha)---									
1991	4.4	1.6	30.8	0.7	0.03	0.00	0.37	0.02	0.06	0.03	0.11	0.03
1992	53.8	46.8	17.6	24.4	0.25	0.11	1.45	0.64	0.62	1.07	0.73	1.24
1993	18.0	4.6	11.9	2.1	0.04	0.02	0.47	0.06	0.16	0.09	0.18	0.10
Sum	76.2	53.0	60.3	27.2	0.32	0.13	2.30	0.72	0.84	1.19	1.02	1.37

Table 6. Observed and predicted EPIC outputs for field WA

	Total											
	Q		Y		NO_3-N		ORG-N		SP		TP	
Year	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.
	---(mm)----		---(kg/ha)---									
1991	86.1	92.4	105.6	108.7	3.12	0.04	2.50	2.04	2.03	0.57	1.53	0.87
1992	148.6	140.0	156.3	124.6	0.71	0.36	5.75	2.46	2.15	1.37	2.40	1.78
1993	21.6	31.9	2.6	32.4	2.45	2.54	0.83	0.64	0.18	0.30	0.20	0.40
Sum	256.3	264.3	264.5	265.7	6.28	2.94	9.08	5.14	4.36	2.24	4.13	3.05

Table 7. Observed and predicted EPIC outputs for field WB

	Total											
	Q		Y		NO_3-N		ORG-N		SP		TP	
Year	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.	Obs	Pre.
	---(mm)----		---(kg/ha)---									
1991	14.2	38.0	24.4	33.7	0.09	0.03	0.42	0.97	0.28	0.28	0.24	0.44
1992	64.9	83.8	88.1	60.5	0.22	0.89	2.42	2.13	1.03	3.28	1.27	3.90
1993	16.4	12.2	17.2	9.4	0.10	0.08	2.53	0.33	1.16	0.35	1.72	0.46
Sum	95.5	134.0	129.7	103.6	0.41	1.00	5.37	3.43	2.47	3.91	3.23	4.80

Table 8. Parameters* obtained from regressions of observed vs. predicted calendar year total outputs for fields receiving poultry litter/manure (RA and WB)

Regression	Output				
Parameter	Q	Y	ORG-N	SP	TP
a	−16.20	22.88	0.30	0.19	0.35
b	1.37	0.43	1.25	0.50	0.39
r^2	0.93	0.68	0.84	0.92	0.88

* Coefficients a and b estimated for the relationship $V_o = a + bV_p$, where V_o is the observed value of the parameter and V_p is the predicted parameter value. r^2 is the coefficient of determination. Six data points were used in each regression.

scenario), and that the magnitudes of prediction errors were also generally very low.

Observed total calendar year values of the EPIC outputs were combined for the fields treated with poultry manure and litter (RA and WB, respectively) over the three calendar years and regressed against corresponding predicted values to assess EPIC's performance for only the manure and litter-treated fields. The same analysis was performed on the data from the fields that received inorganic fertilizer (RB and WA). The results of the regressions are shown in tables 8 and 9. Correspondence between predictions and observations was significant ($p = 0.05$) for all model outputs for fields RA and WB except NO_3-N (not shown in table 8). Except for NO_3-N, coefficients of determination for the model outputs ranged from 0.68 to 0.93. The potential benefit of calibration is again demonstrated by the regression line slopes shown in table 8. Correspondence between observed and predicted EPIC outputs was significant ($p = 0.05$) for Q, Y, ORG-N, and TP for the fields that received inorganic fertilizer (RB and WA). Calibration appeared to be of little potential value for predicting Q, Y, and TP for the inorganically fertilized fields as evidenced by the near-zero intercepts and near-unity regression line slopes for those outputs. The available data do not support an assessment of whether EPIC worked better for poultry litter and manure-treated fields or inorganic fertilizer-treated fields, primarily because of the differences in soils.

Observed EPIC outputs were combined for all four fields and three calendar years and regressed against predicted outputs to assess EPIC's performance for the application as a whole. Results of the regression analyses are given in table 10. Except for NO_3-N, correspondence between all predicted and observed EPIC outputs significant ($p = 0.05$) with coefficients of determination ranging from 0.66 to 0.92. The overall model performance is demonstrated in figures 4 and 5 for Q and Y, respectively. The findings indicate that EPIC can be applied in an uncalibrated mode to the general situation of a fertilized pasture/range field in northwestern Arkansas and reasonably reflect trends in runoff quality parameters (Q, Y, ORG-N, SP, and TP) over periods of several months.

Table 9. Parameters* obtained from regressions of observed vs. predicted calendar year total outputs for fields receiving inorganic fertilizer (RB and WA)

Regression	Output			
Parameter	Q	Y	ORG-N	TP
a	3.14	2.10	0.13	−0.01
b	0.99	1.06	1.81	1.18
r^2	0.97	0.86	0.83	0.78

* Coefficients a and b estimated for the relationship $V_o = a + bV_p$, where V_o is the observed value of the parameter and V_p is the predicted parameter value. r^2 is the coefficient of determination. Six data points were used in each regression.

Table 10. Parameters* obtained from regressions of all observed vs. predicted calendar year total outputs

Regression	Output				
Parameter	Q	Y	ORG-N	SP	TP
a	−7.48	14.91	0.38	0.41	0.46
b	1.21	0.68	1.33	0.49	0.39
r^2	0.92	0.66	0.81	0.80	0.80

* Coefficients a and b estimated for the relationship $V_o = a + bV_p$, where V_o is the observed value of the parameter and V_p is the predicted parameter value. r^2 is the coefficient of determination. Six data points were used in each regression.

SUMMARY AND CONCLUSIONS

The EPIC model was applied to four pasture fields in northwestern Arkansas. One field was fertilized with poultry manure, one with poultry litter, and the remaining two with inorganic fertilizer. Model predictions of Q, Y, NO_3-N, ORG-N, SP, and TP were generated based on uncalibrated model parameters and compared to available observations over a 20-month period (September 1991 to April 1993). Model performance was assessed based on both a storm event basis and a calendar year basis.

The correlation between observed and predicted event Q was significant ($p = 0.05$) for each field. Observed and predicted event TP losses were significantly ($p = 0.05$) correlated for three fields, and there was significant

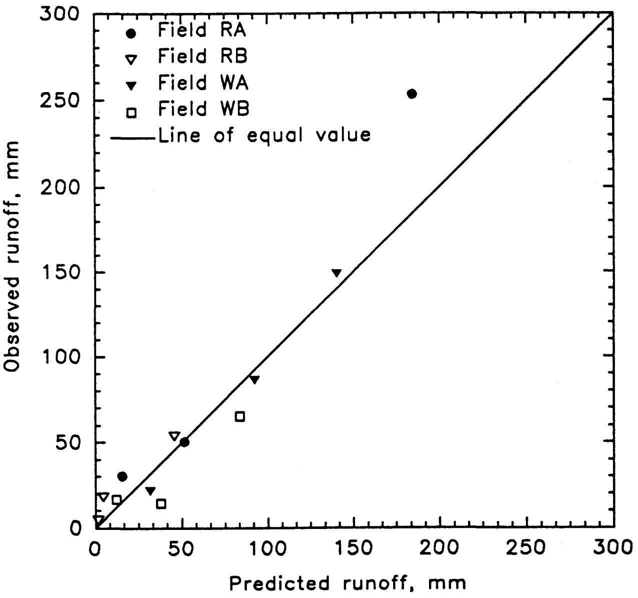

Figure 4–Observed and predicted calendar year runoff for all fields (1991-1993).

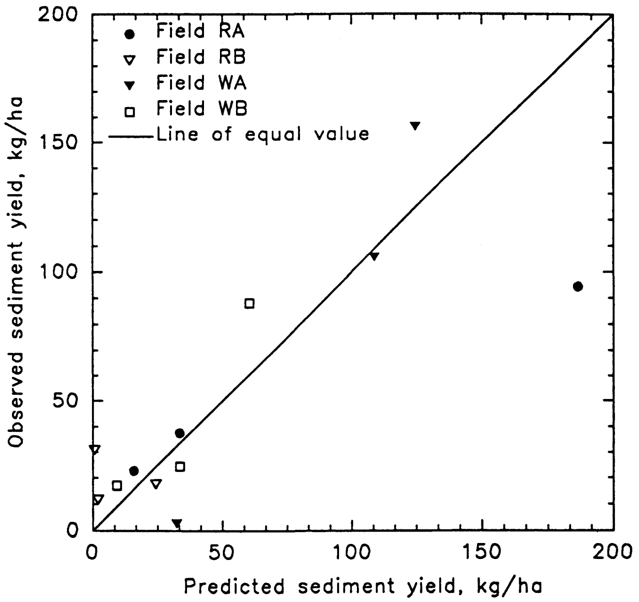

Figure 5–Observed and predicted calendar year sediment yield for all fields (1991-1993).

(p = 0.05) correlation between observed and predicted SP and Y for two fields. Model event performance with regard to NO_3-N and ORG-N might have been reflective of the relatively large number of processes that affect fate and transport of N species. Model event performance would probably have improved with a smaller time step during rainfall events (the current time step is 1d); however, increased emphasis on accurate event performance would detract from EPIC's practicality as a tool in longer-term analyses.

The overall performance of EPIC on a calendar year basis was very good for all parameters except NO_3-N, in which case the observed and predicted calendar year total losses were not significantly (p = 0.05) correlated. For other outputs, coefficients of determination ranged from 0.66 to 0.92. The slopes of the observed versus predicted output regression lines indicated that calibration would have been necessary to eliminate bias in predictions.

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