SIMULATION OF SEDIMENT AND NITRATE LOSS ON A VERTISOL WITH CONSERVATION TILLAGE PRACTICES

K. W. King, C. W. Richardson, J. R. Williams

ABSTRACT. *Shrinking and swelling clay soils are dominant in the Blackland Prairie of Central Texas and comprise a vast majority of agricultural production land in the area. An agricultural field scale simulation model (EPIC) was applied on six small watersheds located in Riesel, Texas. A non-calibrated model performance evaluation of the runoff, sediment yield, nutrient transport, and crop growth components was completed. Management practices included no-till and conventional till systems. Annual and monthly predicted parameter values were compared with measured data for a 5-year period. Annual comparisons indicate close agreement between means and standard deviations for runoff, erosion, and nitrate-nitrogen. Significant correlation existed between monthly measured and simulated runoff and erosion. Significant correlation for nitrate-nitrogen was present in a majority of the cases studied. Prediction efficiency was significant for all elements except nitrate-nitrogen on two watersheds. The results of this study indicate EPIC's ability to simulate natural processes without calibration on shrinking and swelling clay soils with varying management practices.*
Keywords. *Modeling, Vertisols, Nitrate, Simulation.*

Traditional agricultural practices have accelerated erosion rates thus increasing nutrient loading to streams and waterways. Nutrients which exit the field in runoff or are attached to eroded sediment potentially threaten aquatic life and potable water supplies. Past emphasis has been placed on adopting best management practices (BMPs) which would decrease sediment and nutrient loss and preserve surface water quality. While BMP implementation is an ultimate goal, studying different BMP implementations can be analyzed by computer modeling to identify optimum practices. These methodologies and practices are essential to the conservation and protection of natural resources in the Blackland Prairie where shrink/swell soils are predominant.

BACKGROUND

In the mid 1930s, the Soil Conservation Service (SCS) determined a need to understand and analyze hydrologic data from natural field and watershed areas. A provision was made to create the Hydrologic Division of the SCS and also to establish a number of experimental watersheds across the United States. One of those watersheds was located near Riesel, Texas, in the heart of the Blackland Prairie. The primary function of the facility was to collect hydrologic data (precipitation, percolation, evaporation, runoff, etc.) from watersheds which were influenced by different land management practices. Data collected can be used to determine the effect of long-term management practices on surface water quality.

Since the Clean Water Act of 1972, research efforts have concentrated on identifying and reducing non-point source pollution (Schuman et al., 1973; Jackson et al., 1973; Kissel et al., 1976; Chichester et al., 1979; Angle et al., 1984; Wendt and Burwell, 1985; Berg et al., 1988; Sharpley et al., 1991; Smith et al., 1991). The primary non-point source pollutants associated with agriculture include fertilizers (commercial and animal waste), pesticides, and sediment. Previous work indicates tillage intensity as a major factor driving agricultural non-point source pollution (Kissel et al., 1976; Blevins et al., 1990). Conservation tillage measures have been cited as one means of reducing sediment (Blevins et al., 1990; King et al., 1995) and nutrient loss (Sharpley et al., 1991; Chichester and Richardson, 1992).

Field studies have often been the primary means of evaluating and quantifying non-point sources. As a result of enhancements in computing, modeling has been adopted as another technique to evaluate non-point source pollution. Models often serve as a tool for evaluating management practices on large field size areas (Cooper et al., 1992; Richardson and King, 1995). But model use is often limited by the amount of detailed data required for simulation (Sharpley and Meyer, 1994).

Model performance and evaluation studies on vertisols are limited, in part due to the challenge that these unique soils present. Vertisols are mineral soils comprised of more than 30% clay and exhibit a large potential for shrinking and swelling. Cracks extending to 98 cm (Dasog and Shashidhara, 1993) are common after long periods of dry weather. Precipitation after extensive dry periods can result in little or no runoff because of the large water holding capacity of the soil and preferential flow through residual soil cracks. The objective of this study was to evaluate the Erosion Productivity Impact Calculator's (EPIC) capability for predicting runoff, sediment loss, and nitrate transport

Article was submitted for publication in April 1996; reviewed and approved for publication by the Soil and Water Div. of ASAE in August 1996.

The authors are **Kevin W. King,** ***ASAE Member Engineer,*** Hydraulic Engineer, **Clarence W. Richardson,** ***ASAE Member Engineer,*** Agricultural Engineer, and **Jimmy R. Williams**, Hydraulic Engineer, USDA-ARS, Temple, Texas. **Corresponding author:** Kevin W. King, USDA-ARS, 808 East Blackland Rd., Temple, TX 76502; telephone: (817) 770-6616; fax: (817) 770-6561; email: <king@brcsun0.tamu.edu>.

on a Houston Black (fine, montmorillonitic, thermic udic, haplustert) shrink/swell soil located in the Blackland Prairie with varying management strategies.

SIMULATION MODEL

The Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1984; Williams, 1995) is a comprehensive field scale model which operates on a daily time step. Inputs for EPIC include climatic data, topographic information, field characteristics, management practices, and site specific parameters. Climate, soil, and management data are assumed to be homogeneous. Measured values should be used when available, however, EPIC has default measures or a means of generating data when actual parameter values are unavailable.

EPIC was developed to predict the effects of management decisions on soil and water resources and crop production for agricultural field scale areas. The major strength of EPIC is the ability to simulate agricultural management practices with a comprehensive crop growth component. The crop growth model is capable of simulating growth for both perennial and annual crops. The hydrologic component in EPIC is based on the SCS curve number method (Soil Conservation Service, 1972). Erosion in EPIC may be computed from several options which include: USLE (Wischmeier and Smith, 1978), the Onstad-Foster modification of the USLE (Onstad and Foster, 1975), MUSLE (Williams, 1975), and variations of MUSLE. Nutrients (nitrogen and phosphorus) are simulated based on research by Sharpley and Williams (1990) and documented by Williams (1995) while pesticide fate and transport is adopted from the GLEAMS model (Leonard et al., 1987).

The Modified Universal Soil Loss for Small Watersheds (MUSS) erosion algorithm was selected for this study. MUSS was developed by fitting small watershed data (no channel erosion) and is represented by:

$$Y = \chi(K)(C)(P)(LS) \qquad (1)$$

where Y is the sediment yield in $t \cdot ha^{-1}$, K is the USLE soil erodibility factor, C is the USLE crop management factor, P is the USLE erosion control factor, and LS is the USLE slope length and steepness factor. The factor χ is a runoff erosivity index represented by:

$$\chi = 0.79(Q \cdot q_p)^{0.65} A^{0.009} \qquad (2)$$

where Q is the runoff volume in mm, q_p is the peak runoff rate in $mm \cdot h^{-1}$, and A is the watershed area in ha.

STATISTICAL METHODS

Simulated values were compared to measured values using two methods: (1) Nash-Sutcliffe (1970) efficiency; and (2) prediction efficiency.

Nash-Sutcliffe efficiency is an indicator of the model's ability to predict about the 1:1 line. The Nash-Sutcliffe coefficient is calculated as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - x_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2} \qquad (3)$$

where x_i is the predicted value, y_i is the measured value, $\bar{y}$ is the mean of the measured values, n is the number of samples, and R^2 represents efficiency.

Prediction efficiency is calculated by first sorting the measured and predicted values in descending order. After sorting, prediction efficiency is calculated in the same manner as Nash-Sutcliffe efficiency (eq. 3). Prediction efficiency gives an indication of the models ability to reproduce the probability distribution function. These two methods along with simulated and measured means and standard deviations will indicate the models' ability to simulate measured data.

EXPERIMENTAL METHODS

Monitored management practices and weather data from six, small paired watersheds located near Riesel, Texas, were used as input data to simulate sediment and nutrient loss. Management and climatic (temperature and precipitation) data were collected from 1985 to 1989. The soil on each of the watersheds is a Houston Black (fine, montmorillonitic, thermic udic, haplustert) clay (57% clay, 35.7% silt, and 7.3% sand) vertisol with pronounced shrinking and swelling characteristics. Each watershed was assumed to be homogeneous with respect to soil, climate, and management. Management practices included no-till (NT) and conventional till (CT) systems. Potential evapotranspiration was estimated using the Hargreaves (1975) method.

CT management consisted of one or two plowing (chisel) operations followed by tandem disking, harrowing, and listing before planting. Essentially all previous years' crop residues were buried during these processes. The NT watersheds were conventionally managed before the study began. In 1985, crops were planted into the previous years' stubble, and weed management was conducted through herbicide application. The only surface disturbance in NT was due to planting the crop. Wheel traffic was minimized and maintained in fixed locations.

Climatic data (temperature and precipitation) was collected via a standard weather station. Precipitation for each watershed (table 1) was calculated from a weighted average based on a network of gages located over the entire watershed. Soils data was from the SOILS 5 database for a Houston Black soil and remained constant for each watershed. Management data was input corresponding to

Table 1. Watershed characteristics used in performance evaluation of EPIC

Watershed	Treatment	Precipitation (mm)	Area (ha)	Slope (m/m)	Curve Number	P-factor
Y-6	NT	963.0	6.6	0.032	82	0.2
Y-8	NT	946.5	8.4	0.022	82	0.2
Y-10	NT	963.2	7.5	0.019	82	0.2
Y-13	CT	894.8	4.6	0.023	87	0.4
W-12	CT	893.1	4.0	0.020	87	0.4
W-13	CT	893.4	4.6	0.011	87	0.4

actual records of management practices (tillage, planting, fertilization, and harvesting) and varied for each watershed. Topographic parameters were input according to measured data (table 1).

Other input parameters were held constant with the exception of hydrologic curve number, slope, and soil loss P-factor (table 1). Curve number was based on a hydrologic soil group D with good practice. Selected curve numbers were 87 and 82 for CT and NT watersheds, respectively. Soil loss P-factor was selected at 0.2 and 0.4 for no-till and conventional till respectively. The 0.4 P-factor for conventional tilled watersheds was chosen because of a grassed waterway entry to the runoff station. In addition to the grassed inlets, NT watersheds were managed on the contour. Thus, a reduced P-factor of 0.2 was selected. Measured annual and monthly runoff, sediment, and soluble nitrate losses, along with annual crop yields were compared with predicted values.

Results and Discussion

A comparison of mean annual simulated and observed runoff, sediment loss, and soluble nitrate loss is presented in table 3 for each watershed. A comparison of annual standard deviations of measured and simulated runoff, sediment loss, and soluble nitrate loss is presented in table 4. Correlation and efficiency statistics were completed on monthly results for runoff, sediment loss, and nitrate loss (table 5). Measured annual crop yields compared with predicted yields are presented in table 6.

Table 2. Comparison of measured and EPIC predicted runoff to precipitation ratios for six watersheds located at Riesel, Texas

Watershed	Measured (%)	Predicted (%)
Y-6 (NT)	14.02	14.95
Y-8 (NT)	14.26	13.84
Y-10 (NT)	19.31	14.43
Y-13 (CT)	19.89	17.66
W-12 (CT)	12.99	17.80
W-13 (CT)	15.00	17.46

Table 3. Comparison of predicted and measured mean annual runoff, sediment loss, and soluble nitrate in surface runoff

Watershed	Area (ha)	Meas. Runoff (mm)	Pred. Runoff (mm)	Meas. Sediment Loss ($t \cdot ha^{-1}$)	Pred. Sediment Loss ($t \cdot ha^{-1}$)	Meas. Soluble Nitrate Loss ($kg \cdot ha^{-1}$)	Pred. Soluble Nitrate Loss ($kg \cdot ha^{-1}$)
Y-6 (NT)	6.6	135	144	0.21	0.22	2.48	2.48
Y-8 (NT)	8.4	135	131	0.27	0.18	1.94	1.76
Y-10 (NT)	7.5	186	139	0.10	0.09	5.04	6.05
Y-13 (CT)	4.6	178	158	1.13	1.08	12.40	8.57
W-12 (CT)	4.0	116	159	1.63	2.34	1.89	2.37
W-13 (CT)	4.6	134	156	2.84	2.33	5.51	5.35

Table 4. Comparison of predicted and measured standard deviations of annual runoff, sediment loss, and soluble nitrate in surface runoff

Watershed	Area (ha)	Meas. Runoff (mm)	Pred. Runoff (mm)	Meas. Sediment Loss ($t \cdot ha^{-1}$)	Pred. Sediment Loss ($t \cdot ha^{-1}$)	Meas. Soluble Nitrate Loss ($kg \cdot ha^{-1}$)	Pred. Soluble Nitrate Loss ($kg \cdot ha^{-1}$)
Y-6 (NT)	6.6	69.2	92.5	0.19	0.13	1.66	3.30
Y-8 (NT)	8.4	86.4	87.1	0.26	0.15	1.91	2.03
Y-10 (NT)	7.5	98.2	94.7	0.11	0.07	6.66	9.59
Y-13 (CT)	4.6	110.6	70.8	0.77	0.71	14.85	11.05
W-12 (CT)	4.0	82.6	65.0	1.87	1.52	2.90	2.60
W-13 (CT)	4.6	58.4	55.7	2.37	1.53	6.24	4.43

Runoff

During the simulation period, runoff to precipitation ratios (Q/P) ranged from 12.99% to 19.89% on measured data and 13.84% to 17.80% for predicted data (table 2). An analysis of the predicted Q/P data indicates that EPIC was able to simulate a reduction in runoff associated with NT management. The consistency of the simulated ratios with respect to management practice when compared to measured ratios (table 2) is an indication of EPIC's limited ability to simulate the varying soil conditions (shrink/swell) that occur on vertisols. However, the relatively close agreement between annual measured and simulated means (table 3) and standard deviations (table 4) indicates similar frequency distributions. For the model to be considered applicable on shrinking and swelling soils under varying management practices, it must be able to reproduce a realistic frequency distribution similar to that of the measured data. In this case, EPIC was able to reproduce realistic runoff statistics and similar frequency distributions and it is expected that a length of record greater than five years would tend to bring the measured and predicted means and standard deviations in closer agreement.

Table 5. Parameters from linear regression* of measured versus EPIC predicted monthly outputs

Watershed	Runoff	Sediment	NO_3-N
Y-6	a = −1.95 b = 1.10 r^2 = 0.78 N-S R^2 = 0.77 Pred. R^2 = 0.90	a = 0.01 b = 0.70 r^2 = 0.47 N-S R^2 = 0.18 Pred. R^2 = 0.78	a = 0.11 b = 0.46 r^2 = 0.39 N-S R^2 = −0.13† Pred. R^2 = 0.26
Y-8	a = −1.14 b = 1.14 r^2 = 0.74 N-S R^2 = 0.73 Pred. R^2 = 0.88	a = 0.01 b = 1.20 r^2 = 0.66 N-S R^2 = 0.63 Pred. R^2 = 0.79	a = 0.14 b = 0.11 r^2 = 0.02‡ N-S R^2 = −1.66† Pred. R^2 = −0.10†
Y-10	a = 1.29 b = 1.23 r^2 = 0.79 N-S R^2 = 0.74 Pred. R^2 = 0.89	a = 0.01 b = 0.52 r^2 = 0.15 N-S R^2 = 0.02 Pred. R^2 = 0.83	a = 0.07 b = 0.70 r^2 = 0.89 N-S R^2 = 0.73 Pred. R^2 = 0.84
Y-13	a = −3.21 b = 1.36 r^2 = 0.80 N-S R^2 = 0.74 Pred. R^2 = 0.83	a = 0.03 b = 0.76 r^2 = 0.23 N-S R^2 = 0.20 Pred. R^2 = 0.77	a = 0.29 b = 1.03 r^2 = 0.78 N-S R^2 = 0.78 Pred. R^2 = 0.94
W-12	a = −4.14 b = 1.04 r^2 = 0.79 N-S R^2 = 0.77 Pred. R^2 = 0.89	a = −0.02 b = 0.79 r^2 = 0.72 N-S R^2 = 0.66 Pred. R^2 = 0.92	a = 0.15 b = 0.04 r^2 = 0.05 N-S R^2 = −1.67† Pred. R^2 = 0.71
W-13	a = −2.82 b = 1.07 r^2 = 0.82 N-S R^2 = 0.81 Pred. R^2 = 0.90	a = −0.02 b = 1.27 r^2 = 0.67 N-S R^2 = 0.64 Pred. R^2 = 0.80	a = 0.24 b = 0.48 r^2 = 0.31 N-S R^2 = −0.03† Pred. R^2 = 0.86

* Coefficients a and b follow from the expression $Y = a + bX$, where X is the predicted value and Y is the observed value; r^2 is the coefficient of determination; N-S R^2 is the Nash-Sutcliffe efficiency; and Pred. R^2 is the prediction efficiency.

† Negative values of efficiency have no statistical meaning and are no different from zero.

‡ Coefficient of determination is not significantly different from zero ($\alpha = 0.05$).

Table 6. Simulated and measured crop yields for each year and each watershed

Watershed	Year	Crop	Measured Yield ($t \cdot ha^{-1}$)	Simulated Yield ($t \cdot ha^{-1}$)
Y-6 (NT)	1985	Sorghum	5.1	5.5
	1986	Corn	2.9	6.0
	1987	Sorghum	2.5	7.8
	1988	Wheat	2.0	1.6
	1989	Corn	3.7	6.4
Y-8 (NT)	1985	Corn	4.7	5.1
	1986	Sorghum	2.7	4.9
	1987	Wheat	1.4	2.7
	1988	Corn	5.2	5.3
	1989	Sorghum	1.5	6.1
Y-10 (NT)	1985	Sorghum	4.4	5.4
	1986	Wheat	2.2	1.2
	1987	Corn	4.0	5.3
	1988	Sorghum	2.6	6.6
	1989	Wheat	0.0	1.4
Y-13 (CT)	1985	Sorghum	6.4	5.4
	1986	Wheat	2.7	1.2
	1987	Corn	4.4	5.9
	1988	Sorghum	6.4	6.7
	1989	Wheat	0.2	0.0
W-12 (CT)	1985	Corn	4.8	5.5
	1986	Sorghum	4.7	5.0
	1987	Wheat	1.7	2.7
	1988	Corn	7.3	5.3
	1989	Sorghum	5.6	6.6
W-13 (CT)	1985	Sorghum	6.3	5.6
	1986	Corn	6.1	6.2
	1987	Sorghum	5.8	8.7
	1988	Wheat	3.3	1.6
	1989	Corn	6.3	6.7

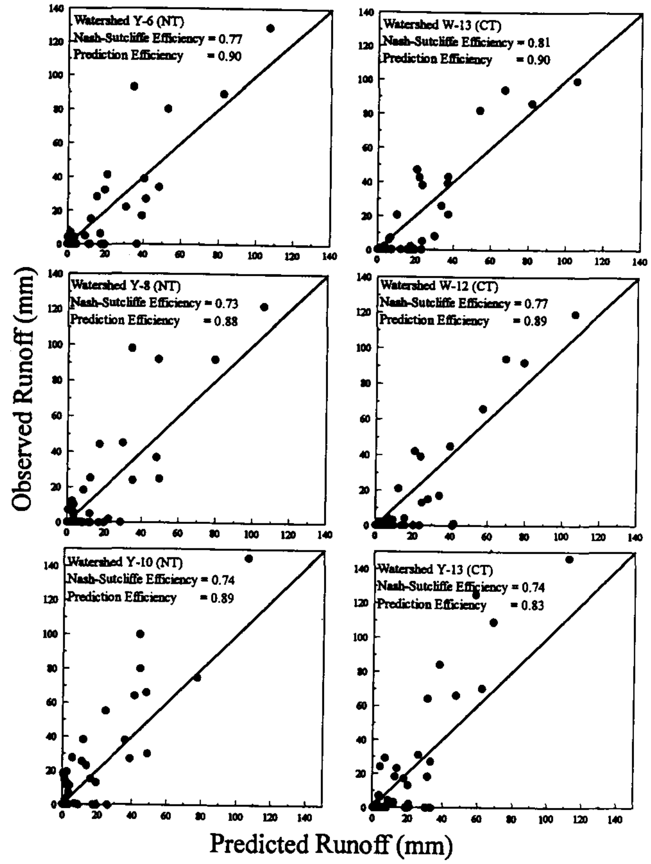

Figure 1–Scattergram and 1:1 line of 60 monthly observed vs. predicted runoff events for each watershed.

A scattergram of measured versus predicted monthly runoff about a 1:1 line for the six watersheds (fig. 1) shows that EPIC performs realistically in its ability to reproduce runoff from this vertisol soil. Nash-Sutcliffe efficiency coefficients ranged from 0.73 to 0.77 for the three NT watersheds and 0.74 to 0.81 for the three CT watersheds. Prediction efficiencies (an indicator of the model's ability to reproduce a similar probability distribution) varied from 0.88 to 0.90 for the NT watersheds and 0.83 to 0.90 for the CT watersheds. Based on Nash-Sutcliffe and prediction efficiencies (table 5), monthly runoff from NT and CT managed watersheds were realistically simulated with similar efficiency and similar frequency distributions. EPIC was able to explain an average of 79% of the variance associated with monthly runoff.

A time series plot (fig. 2) of runoff indicates the model's ability to reproduce the seasonal fluctuations of the water balance. Seasonal fluctuations in runoff are in part due to soil water and evapotranspiration. Time plots of runoff (fig. 2) indicate month 14 as wet (222-mm and 201-mm average precipitation for NT and CT sites). Average measured runoff for month 14 was 121 mm and 132 mm for CT and NT managed sites, respectively. Mean predicted runoff for month 14 was 108 mm and 106 mm for the CT and NT managed watersheds' respectively. While this is only one month in the season, it is critical in terms of percent of annual runoff. EPIC also performs well during dry periods. An analysis of year 4 (months 37-48) (fig. 2) shows little or no measured runoff for this time period. EPIC runoff predictions for this same time period were also small but greater than measured, indicating a limitation for predicting preferential flow after an extended dry period.

Sediment Loss

Measured annual average sediment loss was 0.19 $t \cdot ha^{-1}$ and 1.87 $t \cdot ha^{-1}$ compared with simulated annual average sediment losses of 0.16 $t \cdot ha^{-1}$ and 1.92 $t \cdot ha^{-1}$ for NT and CT, respectively (table 3). An analysis of annual sediment loss standard deviations (table 4) also indicates close agreement between measured and simulated values. However, all predicted standard deviations for sediment loss are less than measured standard deviations. This indicates an inability of the model to simulate extreme events on both high and low ends. But, this is more a function of the under-estimation of runoff rather than any deficiency in the erosion component of the model. The ability to handle breakpoint rainfall data would make the model more data intensive, but may allow a better estimation of the rainfall intensity and thus peak runoff rate for use in the MUSS equation.

Explained variance associated with monthly sediment loss ranged from 15% at watershed y-10 to 72% on watershed w-12 (table 5). An r^2 value of 0.72 is good for simulation of natural processes; however, improvements could be made. Possible improvements could be made by means of a simple calibration and the inclusion of breakpoint

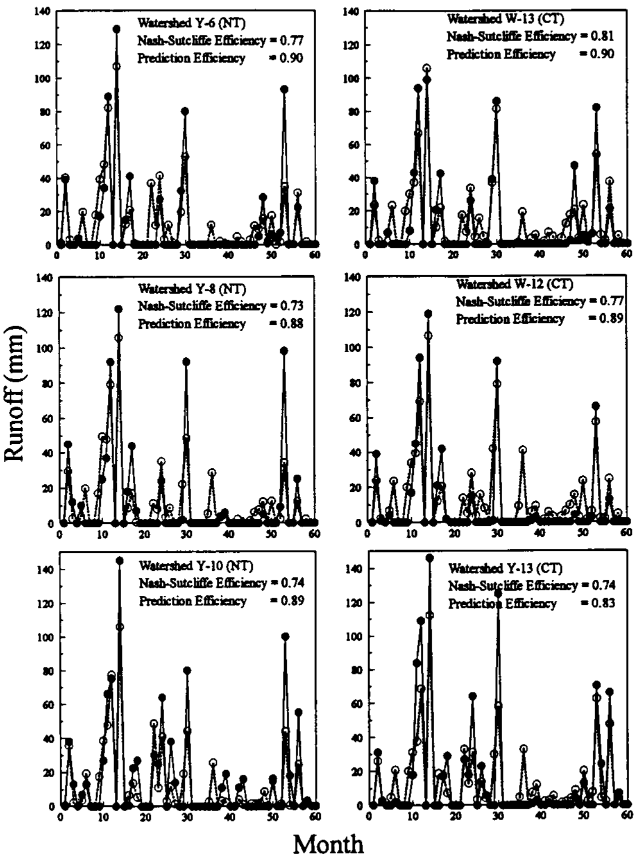

Figure 2–Time series of runoff for each watershed: solid line represents measured runoff, and broken line represents predicted runoff.

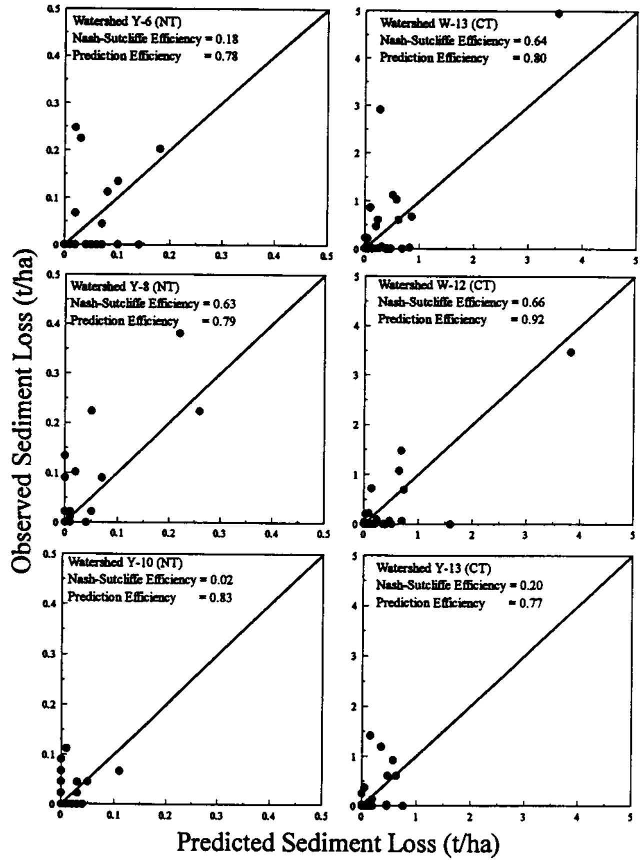

Figure 3–Scattergram and 1:1 line of 60 monthly observed vs. predicted sediment loss events for each watershed.

rainfall for intensity calculations. An evaluation of figures 3 and 4 indicates underprediction for large events and overprediction for small events. This under-prediction signifies damped peak runoffs which could be improved with breakpoint rainfall data. Overprediction could be improved with better routines for managing preferential flow.

Even though explained variance was small on two of the watersheds, prediction efficiencies were quite high (table 5). Average prediction efficiency for all watersheds was 0.82. In other words, EPIC was able to explain 82% of the variance between the measured and predicted frequency distributions. Hence, for environmental and agricultural policy decisions which are made on probability statistics, EPIC simulations are realistic for predicting outcomes from conservation tillage management on clay soils for annual or monthly analyses.

Soluble Nitrate Loss

Measured mean annual soluble NO_3-N (table 3) was 6.60 kg·ha^{-1} and 3.15 kg·ha^{-1} for CT and NT compared with annual average EPIC predicted values of 5.43 kg·ha^{-1} and 3.43 kg·ha^{-1} for CT and NT, respectively. A comparison of annual standard deviations for soluble nitrate loss (table 4) also indicates relatively close agreement between measured and predicted values. The implied similarity in frequency distributions from these values suggests EPIC's acceptability for annual evaluation of soluble nitrate losses on this clay soil with conservation tillage practices.

Monthly statistics of soluble nitrate losses for the five year period studied are presented in table 5. Explained variance decreased considerably on average for the six watersheds compared to runoff. Prediction efficiency was very high on 4 of 6 watersheds which implies reproduction of the frequency distribution. However, Nash-Sutcliffe efficiencies were not significantly different from zero on 4 of 6 watersheds implying that temporal distribution of events was poor. The poor statistical results for simulated versus measured soluble nitrate loss are attributed to prediction errors in crop growth simulation (table 6).

Crop Growth

Crop growth, residue cover, and water use efficiency all have a role in determining runoff, sediment loss, and nutrient uptake. Thus, crop growth, as indicated by yield should be in an acceptable range for the study region. Even though some scatter was present, simulated crop yields were in the range of observed values for this region (table 6). Overprediction of crop yield for NT was attributed to a considerable amount of weed infestation which was not accounted for in the model simulation. Under-prediction of crop yields was not expected but may be a result of sensitive temperature and water stress relationships. Both underprediction and overprediction of crop growth play a vital role in determining nutrient uptake.

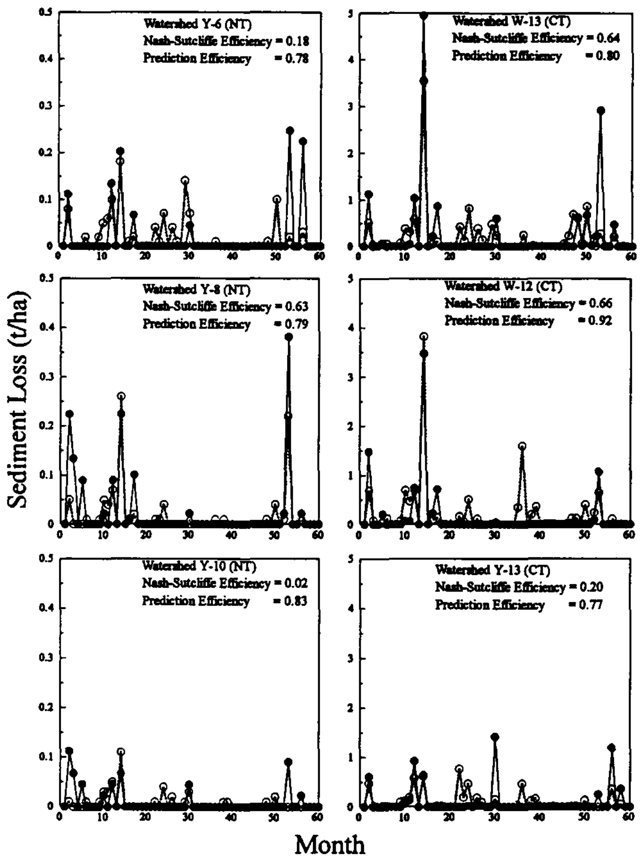

Figure 4–Time series of sediment loss for each watershed: solid line represents measured sediment loss and broken line represents predicted sediment loss.

Conclusions

The hydrology, erosion, nutrient (nitrate), and crop growth components of EPIC were evaluated on a clay soil with conservation tillage practices. A total of six watersheds (3 NT and 3 CT) were used in the evaluation. Crop rotations and thus tillages and fertilization dates varied on all six watersheds. Uncalibrated model predictions were compared with measured data over a 5-year period. Evaluation was completed on monthly and annual totals.

Measured and predicted annual means of runoff, sediment loss, and NO_3-N were in close agreement for the 5-year study period. Standard deviations were not as close in agreement, but nevertheless realistic. Yearly crop growth, indicated by yield, was simulated in the range of expected values but did not match with measured values due to plant competition with weeds in the natural setting.

Significant (α = 0.05) correlation between simulated and observed runoff and sediment loss was measured. There was little to no correlation between measured and predicted NO_3-N. The lack of correlation between measured and predicted NO_3-N was a function of the number of processes involved in the nutrient cycle. Monthly prediction efficiencies indicated a significant ability of EPIC to reproduce like frequency distributions for runoff, sediment, and NO_3-N.

Overall, EPIC performed very well on an annual basis while maintaining differences between conventional and no-till management practices on this clay soil. Evaluation on a monthly basis yielded similar findings with the exception of NO_3-N. A calibration procedure could have improved the evaluation results for NO_3-N as well as runoff and sediment loss. Enhancements in modeling crackflow dynamics could also improve simulation results.

References

Angle, J. S., G. McClung, M. S. McIntosh, P. M. Thomas and D. C. Wolf. 1984. Nutrient losses in runoff from conventional and no-till corn watersheds. *J. Environ. Qual.* 13(3):431-435.

Berg, W. A., S. J. Smith and G. A. Coleman. 1988. Management effects on runoff, soil, and nutrient losses from highly erodible soils in the Southern Plains. *J. Soil and Water Conserv.* 43(5): 407-410.

Blevins, R. L., W. W. Frye, P. L. Baldwin and S. D. Robertson. 1990. Tillage effects on sediment and soluble nutrient losses from a Maury silt loam soil. *J. Environ. Qual.* 19(4):683-686.

Chichester, F. W. and C. W. Richardson. 1992. Sediment and nutrient loss from clay soils as affected by tillage. *J. Environ. Qual.* 21(4):587-590.

Chichester, F. W., R. W. VanKeuren and J. L. McGuinnes. 1979. Hydrology and chemical quality of flow from small pastured watersheds: 2. Chemical Quality. *J. Environ. Qual.* 8(1):167-171.

Cooper, A. B., C. M. Smith and A. B. Bottcher. 1992. Predicting runoff of water, sediment, and nutrients from a New Zealand grazed pasture using CREAMS. *Transactions of the ASAE* 35(1):105-112.

Dasog, G. S. and G. B. Shashidhara. 1993. Dimension and volume of cracks in a vertisol under different crop covers. *Soil Science* 156(6):424-428.

Hargreaves, G. H. 1975. Moisture availability and crop production. *Transactions of the ASAE* 18(5):980-984.

Jackson, W. A., L. E. Asmussen, E. W. Huaser and A. W. White. 1973. Nitrate in surface and subsurface flow from a small agricultural watershed. *J. Environ. Qual.* 2(3):480-482.

King, K. W., D. C. Flanagan, L. D. Norton and J. M. Laflen. 1995. Rill erodibility parameters influenced by long-term management practices. *Transactions of the ASAE* 38(1):159-164.

Kissel, D. E., C. W. Richardson and E. Burnett. 1976. Losses of nitrogen in surface runoff in the Blackland Prairie of Texas. *J. Environ. Qual.* 5(2):288-293.

Nash, J. E. and J. E. Sutcliffe. 1970. River flow forecasting through conceptual models, Part 1 — A discussion of principles. *J. Hydrol.* 10(3):282-290.

Onstad, C. A. and G. R. Foster. 1975. Erosion modeling on a watershed. *Transactions of the ASAE* 18(2):288-292.

Richardson, C. W. and K. W. King. 1995. Erosion and nutrient losses from zero tillage on a clay soil. *J. Agric. Eng. Res.* 61(1):81-86.

Schuman, G. E., R. E. Burwell, R. F. Piest and R. G. Spomer. 1973. Nitrogen losses in surface runoff from agricultural watersheds on Missouri Valley loess. *J. Environ. Qual.* 2(2):299-302.

Sharpley, A. N., S. J. Smith, J. R. Williams, O. R. Jones and G. A. Coleman. 1991. Water quality impacts associated with sorghum culture in the Southern Plains, U.S.A. *J. Environ. Qual.* 29(1):239-244.

Sharpley, A. N. and M. Meyer. 1994. Minimizing agricultural non-point-source impacts: A symposium overview. *J. Environ. Qual.* 23(1):1-3.

Smith, S. J., A. N. Sharpley, J. W. Naney, W. A. Berg and O. R. Jones. 1991. Water quality impacts associated with wheat culture in the Southern Plains, U.S.A. *J. Environ. Qual.* 29(1):244-249.

U.S. Department of Agriculture, Soil Conservation Service. 1972. *National Engineering Handbook.* Hydrology Section 4. Ch. 4-10. Washington, D.C.

Wendt, R. C. and R. E. Burwell. 1985. Runoff and soil losses for conventional, reduced, and no-till corn. *J. Soil and Water Conserv.* 40:450-454.

Williams, J. R. 1975. Sediment yield prediction with universal equation using runoff energy factor. ARS-S-40. Washington, D.C.: USDA, Agric. Res. Serv.

Williams, J. R., C. A. Jones and P. T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Transactions of the ASAE* 27(1):129-144.

Williams, J. R. 1993. The EPIC model. In *Computer Models for Watershed Modeling*, ed. V. P. Singh. CRC Press.

Wischmeier, W. H. and D. D. Smith. 1978. *Predicting Rainfall Erosion Losses, A Guide to Conservation Planning.* Agric. Handbook No. 537. Washington, D.C.: USDA.