# An Evaluation of the EPIC Model for Soybeans Grown in Southern Piedmont Soils

S. M. Martin, M. A. Nearing, R. R. Bruce
MEMBER ASAE  MEMBER ASAE

**ABSTRACT.** *The Erosion Productivity Impact Calculator (EPIC) model was designed to evaluate the loss of crop productivity due to soil erosion. EPIC uses information on weather, soils, nutrients, topography, and other site characteristics to estimate crop growth and yields. In this study, the EPIC model was applied to the problem of estimating soybean yields from the Southern Piedmont of Georgia. Measured yields from a two-year period with 24 farm fields per year were compared to predicted yields. The measured data included triplicated results from slight, moderate, and severe erosion class soils on each field. The model predicted correctly relative differences in crop yields between erosion classes and between years. However, the model tended to under predict for high yields and over predict for low yields. Within treatment variances were higher for the measured data than for the predicted data, indicating that the model did not represent the natural variability present in the data. The model was shown to be insensitive to certain soil variables which had been previously shown to be correlated to yields using the same data set as in this study, suggesting a possible avenue for improving soybean yield predictions for conditions in the Southern Piedmont.* ***Keywords.*** *Erosion, Crop productivity, Soils, Models, Soybeans.*

The main conservation problem occurring on about half of the cultivated cropland in the United States is soil erosion (Larson, 1981). As a consequence, productivity losses in the form of reduced crop yields due to erosion can usually be expected. The effect of erosion on soil productivity, however, varies by physiographic province, climate, and with different soils depending on the properties of the soil (White et al., 1985). Although we may intuitively suspect that erosion affects productivity, the relationship is not well defined. Therefore, until that relationship is understood, choosing a management strategy that will maximize sustained crop production will be difficult.

One tool for evaluating the effect of soil erosion on crop production is EPIC [the Erosion Productivity Impact Calculator (Williams et al., 1983)]. The EPIC includes components for simulating erosion, plant growth, and related processes. It also includes economic components for assessing the cost of erosion and components for determining optimal management strategies.

Thorough testing of the EPIC model for the Piedmont region of Georgia is lacking. The purpose of this study, therefore, is to evaluate the EPIC model using soybean yield data from the Southern Piedmont in Georgia. The basic purpose of model evaluation is to gain knowledge that should ultimately lead to revised and better approximations of reality (Beck, 1983).

Article was submitted for publication in January 1993; reviewed and approved for publication by the Soil and Water Div. of ASAE in May 1993.

The authors are **Steve M. Martin**, Graduate Student, **Mark A. Nearing**, former Assistant Professor, Biological and Agricultural Engineering Dept, University of Georgia, Athens; and **R. R. Bruce**, Soil Scientist, USDA Southern Piedmont Conservation Research Center, Watkinsville, GA.

The specific objective of this study was to evaluate EPIC using soybean yield data and site-specific soils information from the Southern Piedmont area of Georgia. Model generated soybean yields based on the soil conditions in each plot and regional weather data were compared to measured yields from low, moderate, and severely eroded parts of the fields. The Duncan Multiple Range Test was used to determine if statistical differences exist for predicted yields by erosion class and year as were evidenced in the measured yields.

## The EPIC Model

The EPIC is a collection of sub-models of the factors that determine how soil erosion affects productivity.

The plant growth sub-model of EPIC operates on a daily time step to simulate water and nutrient uptake and the interception and conversion of energy to above ground biomass, crop yield, and root growth for most common crops. Plant growth is constrained by water, nutrient, and air temperature stresses. EPIC describes the soil as a series of layers of varying thickness, each with its own bulk density, hydraulic conductivity, available water capacity, and other characteristics. Cultivation is modeled such that soil layers within the depth of cultivation are mixed to produce a zone of modified properties. Climatic sequences including temperature, wind, precipitation, and solar radiation may be read as input or generated within the model. The hydrology sub-model uses daily rainfall to estimate runoff volume using the Soil Conservation Service curve number method and to estimate peak discharge using a modified rational formula method.

EPIC estimates erosion with one of three equations: Williams' (1982) modification of the USLE (MUSLE), Onstad and Foster's (1975) modification of the USLE, and the USLE itself (Wischmeier and Smith 1978). Soil depth removed by erosion is subtracted from the top layer of soil assuming that no sorting of sediment occurs and that removal of nutrients is proportional to the depth of eroded soil. Sediment enrichment ratio is calculated to account for enrichment of adsorbed N and P as a result of deposition processes. As the surface soil erodes, subsoils, which usually have higher bulk density and lower nutrient status, come within the potential root zone of the crop. As a result, water uptake may be restricted by the decreased moisture availability of the subsoil and restricted root growth.

EPIC considers fertilizer input, immobilization and uptake of nitrogen and phosphorous in the soil profile, movement of nitrogen and phosphorous in runoff, within the root zone, and from the root zone, and finally transport of nitrogen and phosphorous on sediment. The tillage submodel simulates row height, surface roughness, and mixing of soil, nutrients, and crop residue by tillage. The EPIC allows for management by considering drainage, irrigation, fertilizer and lime application, and pest control measures. Different types of tillage, soil conservation practices, management alternatives, and crops may be analyzed with EPIC.

## FIELD INVESTIGATIONS

Field tests were conducted in 1982 and 1983 on 40 farm fields (24 different fields each year with 8 of these fields included in both years) located within a 40 km radius of Watkinsville, Georgia (White et al., 1984; White et al., 1985). The soils were classified in the Cecil-Pacolet soil series. Plots were established on each of three degrees of erosion, slight, moderate, and severe, as defined by USDA Soil Survey standards. Triplicated plots were established on each class for a total of 216 plots each year. The fields selected contained conventional culture soybeans, similar soil genesis and classification (clayey, kaolinitic, thermic Typic Hapludults), and a range of soil erosion according to USDA-Soil Conservation Service criteria.

The study plots consisted of three 3.0-m-long rows spaced 1 to 3 rows apart. The triplicate plots were all located within a 15 × 15 m area. Soil pedon descriptions (taken to a depth of 152 cm) revealed that eroded areas had thinner surface (Ap) horizons, on average, ranging from 19 cm on slightly eroded plots to less than 11 cm on severely eroded plots. The Bt horizon on the severely eroded plots averaged 34.3 and 35.8 cm shallower than slightly eroded soils in 1982 and 1983, respectively (White et al., 1984).

Extensive characterization of the crop-soil system was made. Slope, landscape position, depth to base Ap, Bt, and BC horizons were measured along with clay, silt, and sand at 0 to 0.1 m, 0.2 to 0.3 m, and 0.45 to 0.55 m. Also measured were the seasonal variables of soil water, pH, Ca, P, K, Mg, and Al at 0 to 0.1 m, 0.2 to 0.3 m, and 0.45 to 0.55 m; carbon at 0 to 0.1 m; and daily rainfall amounts from day 214 to 280 of each year (Bruce et al., 1988). Mean soil pH values for topsoils for the slight, moderate, and severe erosion conditions were 6.4, 6.3, 6.2, respectively, for the 1982 data and 6.3, 6.3, and 6.1, respectively, for the 1983 data.

Crop information for 1982 and 1983 included cultivar, row spacing, planting and harvest dates, and fertilization records.

The average slopes for the 1982 farm fields in the study were 2.8%, 4.2%, and 4.3% for slightly, moderately, and severely eroded areas, respectively. The 1983 farm fields had average slopes of 2.5%, 3.9%, and 4.1% for slightly, moderately, and severely eroded, respectively.

Plant growth, yields, and stands were a function of erosion class in 1982 and 1983 (White et al., 1984). Although the 1982 and 1983 seasons differed, with 1983 having lower rainfall and a severe drought, yield responses to degree of erosion were similar. White et al. (1984) found that the 1982 soybean yields averaged 2.73, 1.85, and 1.31 t/ha for the slightly, moderately, and severely eroded areas, respectively. The study showed a 52% reduction in both stover and bean yields on severely eroded sites when compared to slightly eroded sites. The 1983 stover and bean yields averaged about 30% and 25% lower, respectively, than in 1982.

Rainfall data analyzed during the study (White et al., 1984) for 1982 and 1983 indicated a 0.071 kg/ha yield increase per centimeter of rainfall on the slightly eroded soils. It was also observed that rainfall did not have a significant affect on moderately and severely eroded soils.

## METHODS

A total of 144 EPIC simulations were conducted to estimate soybean yield on slightly, moderately, and severely eroded soils on each of the 24 fields monitored each year.

The simulation began by setting the title and program control codes. The codes include the number of years the simulation is to run, starting year, month, and day. For this study, the simulation was set at one year beginning 1 January 1982 or 1983 depending on the field under study. The weather code was set to zero to indicate that all weather variables are to be generated by EPIC. Monthly measurements of precipitation were made at the USDA-Agricultural Research Service, Southern Piedmont Conservation Research Center in Watkinsville, Georgia. The simulated monthly mean precipitation amounts were forced to agree with the input monthly amounts.

Areas for each field within the three erosion classes were supplied by the USDA-Agricultural Research Service, Southern Piedmont Conservation Research Center in Watkinsville, Georgia. A runoff curve number of 78 was chosen for the Cecil soil series (Soil Conservation Service, 1972). Channel length and slope were input based on site information from the Conservation Research Center records. Manning's n for channel and surface roughness were chosen to be 0.09 based on tables for conventional tillage and overland flow in the *EPIC User Manual*. The latitude and average elevation of the watershed was taken from U.S.G.S. 7.5 min quadrangle maps.

The average concentration of nitrogen in rainfall was set at the minimum allowable in the program (0.5 ppm). The number of years of cultivation prior to the beginning of simulations (used to estimate the fraction of the organic N pool that is mineralizable) was estimated to be 30 years, based upon historical evidence.

Slope length and steepness data were available from the Southern Piedmont Conservation Research Center records. The soil erosion equation was set, using a flag in the model input file, to the Modified Universal Soil Loss Equation and the erosion control practice factor set to 1.0. The wind erosion adjustment factor was set to zero indicating that wind erosion was not to be considered during the study.

Soil data were initially determined using the files within EPIC for the Cecil soil series. Soil profile information was then modified for each field based on the extensive data base provided by the Southern Piedmont Conservation Research Center. Soil horizon depth, bulk density, sand, silt, and clay content, and pH were input for each field and erosion class within each field.

Information on planting and harvesting dates and regimens was supplied by the Southern Piedmont Conservation Research Center for each field.

The soybean yields predicted by the model were compared to the 1982-1983 measured yield data on a field-by-field basis using standard linear regression techniques. The statistical analyses of yield data were conducted using the SAS/STAT software system for data analysis. In addition, the coefficient of efficiency as described by Nash and Sutcliffe (1970) provided another means of evaluating the results. The Nash and Sutcliffe coefficient of efficiency, E, is computed as:

$$E = 1 - \left[ \sum (Y_{obs} - Y_{pred})^2 / \sum (Y_{obs} - Y_{mean})^2 \right]$$

where $Y_{obs}$ is observed crop yield, $Y_{pred}$ is the model predicted crop yield, and $Y_{mean}$ is the mean observed yield.

Nash and Sutcliffe (1970) describe model efficiency, E, as the proportion of the initial variance of the observed values accounted for by the model, where initial variance is relative to the mean observed value of the sample set. Thus, E can range from 1 to $-\infty$. If E = 1, the model is producing exact predictions. A value of E = 0 indicates that the sum of squares of difference between model predicted values and measured values (of yield, in this case) is equal to the sum of squares difference between measured values and the average of the measured yield. This implies that a single mean measured value of yield was as good an overall predictor as the model. Negative values of E indicate that the observed mean is a better predictor of $Y_{obs}$ than the model.

## Results

The means and standard deviations for the measured and predicted yields for each erosion class in 1982 and 1983 are listed is table 1. Results of the Duncan's multiple range test showed that there was a statistical difference between mean measured yields by erosion class for each year. The predicted yields were also statistically different by erosion class except for the moderate and severe classes in 1983.

The Duncan multiple range test also showed that the measured yields were statistically different by year for each erosion class. Predicted yields were statistically different by year, also, except for the severe erosion class.

Values of measured soybean yields were greater than those for predicted soybean yields for both years in both the slight and moderate erosion classes. For the severe erosion class, values of measured yields were not statistically different than those for predicted yields in 1982, and values for 1983 measured soybean yields were greater than those for predicted yields.

**Table 1. Means and standard deviations for measured and predicted soybean yields**

| Year | Erosion Class | Meas. Mean Yield (t/ha) | Meas. S. D. (t/ha) | Pred. Mean Yield (t/ha) | Pred. S. D. (t/ha) |
|---|---|---|---|---|---|
| 1982 | slight | 2.79a* | 0.40 | 1.86c | 0.18 |
| | moderate | 1.87c | 0.52 | 1.65d | 0.26 |
| | severe | 1.32f | 0.56 | 1.41f | 0.27 |
| 1983 | slight | 2.03b | 0.46 | 1.64d | 0.32 |
| | moderate | 1.54d | 0.36 | 1.35f | 0.25 |
| | severe | 1.04g | 0.48 | 1.30f | 0.26 |

* Means within each yield class (both for predicted and measured values) followed by the same letter are not statistically different at P = 0.05 as determined by Duncan's multiple range tests.

The model did not reflect the natural variation that was present in the measured soybean yield data (table 1). Standard deviations associated with the measured data range from 0.36 to 0.56 T/ha while those for the predicted yield range from 0.18 to 0.32 T/ha. This conclusion is also reflected in the difference between mean values of measured versus predicted soybean yields. Mean soybean yields for treatments within the measured data ranges from 1.04 to 2.79 t/ha, while the means by treatment for predicted yields range from 1.30 to 1.86 t/ha.

The linear regression relationship between measured and predicted soybean yields was:

$$Y_{pred} = 0.207\ Y_{obs} + 1.17 \quad (1)$$

revealing a significant positive slope in the regression line and a positive, significant intercept (fig. 1). This result reveals that a bias is present in the data: the model over predicts for low measured yields and under predicts for high measured yields. The coefficient of determination, $R^2$, for equation 1 was 0.58.

The coefficient of efficiency, E, of the model as applied to this data set was –0.055. As discussed above in the Methods section, this indicated that using the mean value of the measured yield as the "model" for predicting yield on each plot would explain variation in yields on individual fields as well as did the EPIC model predictions.

## Discussion

Whether the EPIC model is appropriate for predicting soybean yields in the Southern Piedmont area is dependent upon the specific questions being investigated. Overall, the difference between average measured and average predicted yield was 14%. A more complete data set might give more accurate results, but such data are not often available.

If the user wishes to differentiate between soybean yields from slightly, moderately, and severely eroded soils in the Southern Piedmont, then the usefulness is less clear. The model under predicted yields for slightly eroded soils and over predicted for slightly eroded soils. Also, the Nash and Sutcliffe efficiency parameter would indicate that the model does not predict soybean yields on an individual

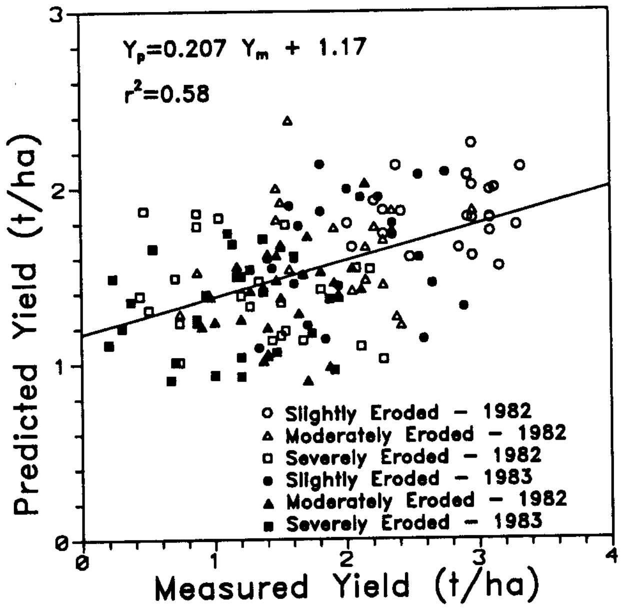


**Figure 1–Measured vs. predicted soybean yields for all erosion classes 1982-1983.**

field better than using the mean measured yield value. Nonetheless, the results of the comparison of means test indicated that the model does reflect differences by erosion class and by year, even if not to the degree measured in the field. This would indicate that the model is useful for making relative comparisons between productivity on different erosion class soils for soybeans on Southern Piedmont soils. That the slope of the regression line is significantly greater than zero, but less than one, also indicated that the model is sensitive to some of the environmental factors which influence soybean yields, but that unknown influencing factors were probably not represented. That the predicted variances within treatments were less than the measured variances also leads to the same conclusion.

Factors which possibly influence productivity as measured in the field study may be gained by comparing the statistical analyses of the data, as reported by the investigators, and the model's sensitivity to various input parameters. Studies conducted by Bruce et al. (1988), and White et al., (1985), revealed that sand, silt, and clay content, and particularly clay and sand content at 0.1-m soil depth, correlated significantly to soybean yield from the 1982-1983 erosion productivity study. However, when sand and clay contents were modified within EPIC, predicted soybean yields were not affected. This sensitivity analysis was conducted on each of the three erosion classes in each year for two separate fields to determine if a change in clay content would affect yield. There was no change in the output for any case.

Sensitivity analyses were also conducted on organic carbon and phosphorous. Bruce et al. (1988) and White et al. (1985) found these to be significantly correlated to soybean yield. Bruce et al. (1988) suggested that carbon (and clay) in the surface 0.1-m affected infiltration and deep soil recharge. White et al. (1985) found that extractable P was less available as the severity of erosion increased. For these reasons, careful consideration was given to each of these variables within EPIC. Again, no significant change in soybean yield was observed as a function of changes in these variables.

Correlation does not necessarily imply cause and effect, and the lack of sensitivity of EPIC output to these soil variables which correlated to yields may indicate only that variability in yields are accounted for by the model in other ways (i.e., through sensitivity to other variables). However, the correlations discussed by Bruce et al. (1988) and White et al. (1985) might serve as a guide for model improvements for Piedmont conditions.

The greatest changes in the EPIC model output resulted from the changes in input pH values and soil horizon depth. Very small changes in pH resulted in large changes in predicted yield when compared to other variables. A 1% change in pH resulted in a 2.7% change in predicted yield. A similar effect on model output, although not quite as significant, was observed when the depth to the top of the Bt horizon was modified. A 10% change in this depth resulted in a 1.8% change in predicted yield.

The results of this investigation into the application of the EPIC model on soybean yields in the Southern Piedmont should be considered within the context of the stated objectives for that model. The intent in developing EPIC was to produce a model which was applicable over a "wide range of soils, climates, and crops encountered in the United States" (Sharpley and Williams, 1990). There are regional and local differences in site conditions which simply cannot be accounted for in a general model. A soil property, for example, which has an important influence on productivity in the Southern Piedmont may have less influence, or in some cases a counteracting influence, in another agronomic and geographic settings. The focus in developing a comprehensive model should be on the principal effects and interactions which occur most universally across the spectrum of site and soil conditions. High sensitivity of model response to an excessive number of model input parameters could cause the model's results to be too high or too low under certain combinations of site conditions.

It is encouraging that the EPIC model followed trends, for example, in differences between erosion classes within this data set, and that the data showed a positive correlation between measured and model predicted values of yield. This study has served two principal purposes: 1) as an impetus to improvement of EPIC model predictions of soybean yield in the Southern Piedmont; and 2) as a realistic measure of confidence in the model predictions for conditions similar to those represented within the study.

## CONCLUSIONS

- The model showed differences in predicted yields by erosion class and by year found in the measured data. However, the predicted differences between average yields for erosion classes by year were not as great as the measured differences.
- Statistical significance testing of coefficients obtained from linear regression between measured and predicted for the entire data set indicate that the model over predicts low yields and under predicts high yields. This result, along with results of the model efficiency tests, indicate that the model does

not predict the degree of variation of individual plot yields across the entire range of the measured data set.

- The model did not adequately predict the amount of natural variation which was shown in the measured data. Factors which have been previously shown to be statistically correlated to yields on these fields include clay, organic carbon, and phosphorus contents of the soil. The model was not sensitive to these input parameters.
- Since the model does not predict the degree of productivity loss due to the soil degradation associated with severe erosion class soils, EPIC may under estimate the economic loss of soybean productivity associated with erosion for the Southern Piedmont.

## REFERENCES


Beck, M. B. 1983. Sensitivity analysis, calibration, and validation. *Mathematical Modeling of Water Quality: Streams, Lakes, and Reservoirs*, ed. G. T. Orlob. 425-467. A Wiley-Interscience Publication - International Institute for Applied Systems Analysis.

Bruce, R. R., A. W. White, A. W. Thomas, W. M. Snyder, G. W. Langdale and H. F. Perkins. 1988. Characterization of soil-crop yield relations over a range of erosion on a landscape. *Geoderma* 43(1988):99-116.

Larson, W. E., F. J. Pierce and R. H. Dowdy. 1983. The threat of soil erosion to long term crop production. *Science* 219:458-465.

Nash, J. E. and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models, Part 1, A discussion of principles. *J. Hydr.* 10:282-290.

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

Sharpley, A. N. and J. R. Williams, eds. 1990. *EPIC-Erosion/Productivity Impact Calculator: 1. Model Documentation.* USDA Tech. Bulletin No. 1768. Washington, DC: GPO.

Soil Conservation Service. 1972. *National Engineering Handbook.* Washington, DC: GPO.

White, W. A., Jr., R. R. Bruce, A. W. Thomas, G. W. Langdale and H. F. Perkins. 1984. Effects of soil erosion on soybean yields and characteristics of Cecil-Pacolet soils. Research Report No. IRC 060184. USDA-ARS, Southern Piedmont Conservation Research Center, Watkinsville, GA.

————. 1985. Characterizing productivity of eroded soils in the Southern Piedmont, 83-95. ASAE Publ. No. 8-85.

Williams, J. R. and A. D. Nicks. 1982. CREAMS hydrology model – Option one. Applied modeling catchment hydrology, ed. V. P. Singh, 69-86. In *Proc. Int. Symp. Rainfall-Runoff Modeling.* Miss. State, MS.

Williams, J. R., K. G. Renard and P. T. Dyke. 1983. EPIC: A new method for assessing erosion's effect on soil productivity. *J. of Soil and Water Conserv.* 38(5):381-383.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses, a guide to conservation planning USDA Agricultural Handbook No. 537. Washington, DC: GPO.