Simulating Soil Erosion in a Warm, Humid Climate[1]

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ABSTRACT

Erosion is one of the most serious agricultural problems in the world. It is a primary source of sediments that pollutes streams and fills reservoirs. Erosion also adds to the removal of valuable plant nutrients lost with runoff. There are many model developed to estimate the soil loss. All erosion models try to simulate the movement of sediment on a field or watershed. The Universal Soil Loss Equation (USLE) is an erosion model designed to predict the longtime average soil losses in runoff from specific field areas in specified cropping and management system. The objective of the study was to evaluate the capability of the CREAMS model to simulate soil erosion from in a warm, humid climate.

CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) model was developed by a team of USDA-ARS scientists to simulate the effect of management system on nonpoint source water pollution (Knisel et al., 1980). The model consists of three components which describe field hydrology, erosion and sedimentation, and chemistry.

The CREAMS model was used to simulate erosion from an experimental plot, located 5.5 km south of Louisiana State University, Baton Rouge, Louisiana, USA. Surface runoff was sampled at 20-minute intervals and analyzed for sediment. Seven years of observed data (1981to 1987) were used to evaluate the capability of the model in simulating the sediment loss. In general the performance of the CREAMS model in simulating the sediment loss from a flat agricultural field with warm, humid climate is satisfactory.

Keywords: erosion, sediment, CREAMS model

INTRODUCTION

Soil erosion is a two-phase process consisting of the detachment of Individual particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles a third phase, deposition, occurs. Erosion is one of the most serious agricultural problems in the world. It is a primary source of sediments that pollutes streams and fills reservoirs. Erosion also adds to the removal of valuable plant nutrients lost with runoff. The Major variables affecting soil erosion are climate, soil, vegetation, and topography. Of these the vegetation and to some extent the soil may be controlled. The climatic factors and the topographic factors, except slope length, are beyond the power of man to control (Schwab, 1996).

All erosion models try to simulate the movement of sediment on a field or watershed (Bingner, 1990). The Universal Soil Loss Equation (USLE) is an erosion model designed to predict the longtime average soil losses in runoff from specific field areas in specified cropping and management systems (Wischmeier and Smith, 1965). Generally, it should not be used to estimate soil loss for specific storm events or time periods. The USLE equation is expressed as :

$$A = RKCPSL \tag{1}$$

Where,

A = estimated soil loss (ton/acre),
R = rainfall and runoff factor (100 of ft-ton-in/acre-hour-year),
K = soil erodibility factor (ton-acre-hour/100 of acre-ft-ton-in),
C = cover and management factor (dimensionless),
P = support practice factor (dimensionless),
S = slope length factor (dimensionless), and
L = slope length factor (dimensionless)

The USLE, an empirical equation based on more than 10,000 plot years of data, is widely used and each of the factors has been determined for many soils and situations throughout the United States. Williams (1975) modified the USLE (MUSLE) by replacing the rainfall and runoff factor with an empirically derived term based only on flow characteristics for a particular storm event. The MUSLE increases sediment yield prediction accuracy, eliminates the needs for delivery ratio, and is applicable to individual storms (Williams and erndt, 1977). The MUSLE is expressed as :

$$G = 95\,(Qq_p)^{0.56}KCPLS/A \tag{2}$$

Where,

K, C, P, S, L = USLE factors,
G = the sediment yield from an individual storm (ton/acre),
Q = runoff volume (act-ft),
q_p = peak flow rate (cfs), and
A = drainage area (acre)

The USLE and MUSLE represent the two extremes with regard to energy required to initiate detachment, in that one utilizes rainfall energy entirely and the other runoff entirely.

The objective of the study was to evaluate the capability of the CREAMS model to simulate soil erosion from in a warm, humid climate.

DESCRIPTION OF THE CREAMS MODEL

CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) model was developed by a team of USDA-ARS scientists to simulate the effect of management system on nonpoint source water pollution (Knisel et al., 1980). The model consists of three components which describe field hydrology, erosion and sedimentation, and chemistry.

The hydrology component estimates runoff volume and peak rate, infiltration, evapotranspiration, soil water content, and percolation on a daily basis. The erosion component estimates erosion and sediment yield including particle distribution at the edge of the field on a daily basis. The chemistry component include elements for plat nutrients and pesticides. Stormloads and average concentrations of sediment-associated and dissolved chemicals in the runoff, sediment, and percolate fractions are estimated.

The erosion component considers the basic processes of soil detachment, transport, and deposition . The concept of the model is that sediment load is controlled by lesser transport capacity, detachment load is less than transport capacity, detachment by flow my occur, whereas deposition occurs if sediment load exceeds transport capacity. The model represents a field comprehensively by considering overland flow over complex slope shapes, concentrated channel flow, and small impoundments or ponds. The model estimates the distribution of sediment particles transported as primary particles-sand, silt, and clay-and as large and small aggregates, which are conglomerates of primary particles.

Detachment is described by a modification of the USLE (Foster et al., 1977) for a single storm event.

$$D_{Li} = 0.21\ EI\ (s + 0.014)\ KCP\ (\sigma_p/V_u) \qquad (3)$$

$$D_{Fr} = 37983\ mV_u\ {}_{\sigma}p^{1/3}\ (x/72.6)^{m-1}\ s^2\ KCP\ (\sigma p/V_u) \qquad (4)$$

Where,
D_{Li} = interrill detachment rate ($lb/ft^2/s$),
D_{Fr} = rill detachment capacity rate ($lb/ft^2/s$),
EI = Wichmeier's rainfall erosivity [100(ft-tons/acre)(in/hrl)],
x = distance downslope (ft),
s = sine of slope angle,
m = slope length exponent,
K = USLE soil erodibility factor [(ton/acre)(acre/100 ft-tons)(hr/in)],
C = soil loss ratio of the USLE cover-management factor,
P = USLE contouring factor,
V_u = runoff volume [volume/unit time (ft/s)]
${}^{\sigma}{}_{p}$= peak runoff rate [volume/unit time (ft/s)]

When daily rainfall amounts are used, rainfall erosivity (EI) is estimated from equation (5):

$$EI = 8.0\ V_R\ 1.51 \qquad (5)$$

Where,

EI = storm EI [(100 ft-tons/acre) (in/hr)], and
V_R = volume of rainfall (in.).

When breakpoints rainfall is used, storm EI is computed using standard USLE procedures. Storm energy per unit of rainfall is given by :

$$e = 916 + 331 \log_{10} i \qquad (6)$$

Where,

e = rainfall energy per unit of rainfall (ft-tons/acre-in), and
i = rainfall intensity (in/hr).

METHODS

The CREAMS model was used to simulate erosion from an experimental plot, located 5.5 km south of Louisiana State University, Baton Rouge, Louisiana, USA. Surface runoff was sampled at 20-minute intervals and analyzed for sediment. Seven years of observed data were used to evaluate the performance of the CREAMS model.

Results and Discussion

The annual values of observed and simulated sediment loss are shown in Table 1. The model simulated accurately the sediment loss for the year 1986, overestimates the total sediment loss for the years 1981, 1982, and 1983 and underestimates for the years 1984, 1985, and 1987.

TABLE 1
OBSERVED AND SIMULATED ANNUAL SEDIMENT LOSS

Year	Observed (kg/ha)	Simulated (kg/ha)	% Error
1981	412.5	1729.0	319.2
1982	2587.5	3285.7	27.0
1983	5469.7	4865.9	-11.0
1984	1494.7	963.3	-35.6
1985	5162.0	2939.3	-43.1
1986	3574.1	3606.2	1.0
1987	3826.4	2865.2	-25.1
Total	22526.9	20254.6	-10.1

The regression analysis gave the following relationship between monthly simulated and observed sediment loss.

$$S_{sm} = 36.54 + 0.76\ S_{om} \qquad (7)$$
$$r = 0.75$$

[1] The experimental work was carried out at Louisiana State University, USA

Where,

S_{sm} = simulated monthly sediment loss, kg/ha, and
S_{om} = observed monthly sediment loss, kg/ha.

The ANOVA TEST demonstrated that a significant linear relationship exists between the simulated and observed monthly sediment loss (p-value=0.0001). A t-test demonstrated that the slope of the regression line was statistically different from 1.0 and the intercept was not statistically different from zero (p-value=0.0001). The total simulated sediment loss was 10.1 percent less than the total observed sediment loss.

CONCLUSION

The CREAMS model underestimated the sediment loss by 10.1% for 7 years period. In general the performance of the CREAMS model in simulating the sediment loss from a flat agricultural field with warm, humid climate is satisfactory.

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