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Sediment Loss Prediction with DRAINMOD-CREAMS[1]

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ABSTRAK

Data dari petak yang mempunyai saliran bawah tanah dan petak yang tidak mempunyai saliran bawah tanah yang berdekatan dengan Baton Rouge, Louisiana telah digunakan untuk menilai keupayaan model DRAINMOD-CREAMS menganggar mendapan dari kawasan pertanian yang rata. Data yang telah dikumpulkan selama tujuh tahun (1981-87) telah dibandingkan dengan data yang diperolehi melalui proses simulasi. Anggaran mendapan yang dicadangkan oleh model adalah lebih rendah sebanyak 10.1% bagi petak yang mempunyai saliran bawah tanah dan 11.0% bagi petak yang tidak mempunyai saliran bawah tanah berbanding dengan jumlah mendapan sebenar yang direkodkan. Secara umumnya, model DRAINMOD-CREAMS berupaya untuk menganggar jumlah mendapan dari kawasan pertanian yang rata di Louisiana, USA.

ABSTRACT

Data from a subsurface-drained plot and a non-subsurface-drained plot near Baton Rouge, Louisiana, were used to evaluate the DRAINMOD-CREAMS model for simulating sediment loss from flat agricultural land. Simulated and measured sediment losses were compared for 7 years (1981-87). The model underestimated sediment loss by 10.1% and 11.0% from a subsurface-drained plot and non-subsurface-drained plot, respectively. In general, the performance of the DRAINMOD-CREAMS model in simulating sediment loss from flat agricultural land in Louisiana, USA is satisfactory.

Keywords: DRAINMOD-CREAMS model; CREAMS model; DRAINMOD model; sediment simulation

INTRODUCTION

The water management simulation model, DRAINMOD, was developed at North Carolina State University for shallow water table soils. The model was developed for design and evaluation of multi-component water management systems which could include facilities for subsurface drainage, surface drainage, subirrigation and sprinkler irrigation (Skaggs 1978).

The model is a computer simulation program which predicts, on a hour-by-hour, day-by-day basis, the water table position, soil water content,

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

evapotranspiration, drainage, and surface runoff for given climatological data, soil and crop properties, and water management system design parameters.

CREAMS (chemical, runoff, and erosion from agricultural management systems) model was developed by a team of United States Department of Agriculture-Agricultural Research Service (USDA-ARS) scientists to simulate the effect of management systems on nonpoint source water pollution (Knisel 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 plant nutrients and pesticides. Stormloads and average concentrations of sediment-associated and dissolved chemicals in the runoff, sediment, and percolate fractions are estimated. DRAINMOD-CREAMS model was developed by Parson and Skaggs (1988) by combining the DRAINMOD model and the CREAMS erosion submodel. They replaced the CREAMS hydrology component with DRAINMOD and modified DRAINMOD to create a pass file of hydrologic parameters for input to the CREAMS erosion submodel. This approach allows DRAINMOD and CREAMS to remain unchanged at the process level.

The DRAINMOD-CREAMS model predicts the water table depth below the soil surface, soil-water content, evapotranspiration, surface runoff, subsurface drainage volume, and sediment loss.

DESCRIPTION OF THE CREAMS EROSION SUBMODEL

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 or the amount of sediment available for transport. If sediment load is less than transport capacity, detachment by flow may 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.

$$D_{Li} = 0.210\ EI\ (s + 0.014)\ KCP\ (\sigma_p/V_u) \tag{1}$$

$$D_{Fr} = 37983\ mV_u\, p^{1/3}(x/72.6)^{m-1}\ s^2\ KCP\ (\sigma_p/V_u) \tag{2}$$

where

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

When daily rainfall amounts are used, rainfall erosivity (EI) is estimated from equation (3):

$$EI = 8.0\, V_R^{1.51} \tag{3}$$

where

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

Equation (3) is very approximate. It was developed by regression analysis from about 2,700 data points used in the development of the USLE and has a coefficient of determination (R^2) of 0.56 (Knisel 1980). When breakpoint rainfall is used, storm EI is computed using standard USLE procedures. Storm energy per unit of rainfall is given by:

$$e = 916 + 331 \log_{10} i \tag{4}$$

where

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

Interrill erosion is primarily a function of raindrop impact on areas between the rills and is not a function of runoff. Rill erosion is a function of runoff rate. Sediment transport capacity for overland flow is estimated by the Yalin equation (Yalin 1963) modified for non-uniform sediment having a mixture of sizes and densities.

LITERATURE REVIEW

Bengtson and Carter (1985) tested the performance of the CREAMS model by applying the model to a 1.6 ha field located at Baton Rouge, Louisiana. They found that the model underestimated runoff by 38% during the cool months and overestimated runoff by 49% during the warm months, underestimated soil erosion by 61%, underestimated phosphorus loss by 36%, and overestimated nitrogen loss by 380%.

Bingner *et al.* (1989) compared the simulated results from the models CREAMS, SWRRB (simulator for water resources in rural basin), EPIC (erosion-productivity impact calculator), ANSWERS (areal nonpoint source watershed environment response simulation), and AGNPS (agricultural nonpoint source) with measured data of runoff and sediment yield from three Mississippi watersheds. They concluded that no one model worked well in every situation of runoff and sediment yield on the watersheds. Overall, CREAMS and SWRRB produced results that were similar to the measured values more often than the other models.

MATERIALS AND METHODS

Experimental Site Description

The Ben Hur research farm is located 5.5 km south of Louisiana State University, Baton Rouge, Louisiana. The farm is operated jointly by the Louisiana State University Agricultural Center and the United States Department of Agriculture (USDA). The soil, a Commerce clay loam, fine silty, mixed, non-acid, thermic aeric fluvaqent, has a saturated hydraulic conductivity of approximately 1 mm/h just below the plough depth and increases only slightly to a depth of about 0.6 m. Between 0.6 and 1.3 m depth there is a layer of approximately 0.3 m thickness that has a saturated hydraulic conductivity of up to 80 mm/h (Rogers *et al.* 1985). More information about this soil may be obtained in Camp (1976) and Dance *et al.* (1968).

The field experiment was installed in 1977 and partitioned into 4 plots. Two plots (Plot E and Plot G) were 200 m long and 60 m wide. Plot E was surface-drained and contained subsurface–drainage tubing (104 mm diameter) 1 m deep spaced 20 m apart, and installed on a grade of 0.1%. Plot G was surface-drained only. Earth dikes at least 0.3 m high were constructed around the plots to define the plot boundaries and to ensure that runoff passed through an H-flume where it could be measured and sampled (Bengtson *et al.* 1987). The plots were not replicated.

Rainfall was measured with a weighing-type recording rain gauge. Surface runoff was measured with an H-flume and FW-1 water stage recorder, and was sampled at 20-minute intervals with an automatic water sampler installed at the flume. The samples were analysed in the laboratory for sediment.

Silage corn was grown using conventional tillage, a sequence of disc and harrow, and planting up and down the slope in April. The plots were fertilized with 217, 38, and 76 kg/ha/year of nitrogen, phosphorus, and potassium, respectively. Nitrogen was applied at 109 kg/ha at planting (disced in) and 108 kg/ha (side dressed) 3 to 4 weeks after emergence. The corn was cultivated once each year in May for weed control, and was harvested for silage in July. The field was fallow the remainder of the year.

Experimental Procedures

The DRAINMOD-CREAMS model was used to simulate sediment loss from the subsurface-drained plot and the non-subsurface-drained plot. Seven years (from 1981 to 1987) of observed data were used to evaluate the performance of the model.

The model was evaluated by three methods. First, a linear regression analysis was used to determine the closeness of observed and simulated values. The data were fitted to a simple linear regression model with the simulated data as the dependent variable and the observed data as the independent variable. The correlation coefficient, slope, and intercept were used to evaluate the capability of the model.

Secondly, a t-test was done on the intercept and slope of the relationship obtained from regression analysis between the observed and simulated data. The closer the slope of the regression line to unity, the better the model predicts the observed data. All statistical tests were carried out for a significance level of 0.05.

Thirdly, standard deviation of differences (STDD) (Chang *et al.* 1983), absolute average difference (ADIF), and percentage error (PE) were computed comparing observed and predicted data. The following equations were used:

$$\mathrm{STDD} = \sqrt{\frac{\sum (\mathrm{obs} - \mathrm{pred})^2}{n}} \qquad (5)$$

$$\mathrm{ADIF} = \frac{\sum |\mathrm{obs} - \mathrm{pred}|}{n} \qquad (6)$$

$$\mathrm{PE} = \frac{(\mathrm{pred} - \mathrm{obs}) \times 100}{\mathrm{obs}} \qquad (7)$$

where

obs = observed value,
pred = simulated value, and
n = number of observations.

The standard deviation of differences is a measure of the dispersion of the simulated data from the observed data and is expressed in the units of the observed data. The absolute difference is simply the absolute difference between the observed and the simulated data averaged over the number of observations. The percentage error is a measure of the difference between the observed and simulated data relative to the observed data and is expressed as a percentage.

MODEL INPUT PARAMETERS

This paper will provide a brief description of the various sections of the input data; however, for details of the input data one needs to refer chapters 1, 2, and 3 of the CREAMS manual (Knisel 1980). Measured data were made available by Dr. Richard Bengtson of the Agricultural Engineering Department and Dr. James Fouss of the USDA-ARS, Louisiana State University, USA.

Model Input Requirements

Two types of input files–data files and parameter files–are required to run erosion component of CREAMS. The input parameters were estimated from the CREAMS manual (Knisel 1980) and obtained from the other literature.

The data files for erosion component were created by the hydrology submodel. These data are shown in Table 1. The input parameters can be divided into two groups, non-updatable parameters and updatable parameters. Summaries of non-updatable parameters and updatable parameters are given in Table 2 and Table 3, respectively.

TABLE 1
Hydrology pass file description and data for input to the erosion/sediment yield submodel

Data	Program variable name	Dimension
Date of storm	SDATE	Julian date
Volume of rainfall	RNFALL	in.
Volume of runoff	RUNOFF	in.
Characteristic excess rainfall rate	EXRAIN	in./h
EI for the given storm	EI	(100ft.-t/ac)X(in./h)
Number of days since the last storm when percolation occurred	DP	day
Percolation below the root zone	PERCOL	in.
Average temperature between storms	AVGTMP	°F
Average soil water between storms	AVGSWC	in./in.
Actual evaporation from plant for the period between storms	ACCPEV	in.
Potential evaporation from plant for the period between storms	POTPEV	in.
Actual evaporation from soil for the period between storms	ACCSEV	in.
Potential evaporation from soil for the period between storms	POTSEV	in.

TABLE 2
Summary of the non-updatable parameters for the erosion submodel

Parameter	Variable Name	Value	Dimension
Kinematic viscosity	KINVIS	1.05E-05	ft.^{2}/sec
Manning's n for overland flow	NBAROV	0.035	-
Weight density of soil	WTDSOI	71.2	lbs./ft.^{3}
Fraction of clay	SOLCLY	0.33	-
Fraction of silt	SOLSLT	0.27	-
Fraction of sand	SOLSLT	0.40	-
Specific surface area of clay	SSCLY	750.0	m^2/g
Specific surface area of silt	SSSLT	4.0	m^2/g
Specific surface area of sand	SSND	0.05	m^2/g
Slope length	SLNGTH	656. 2	ft.
Soil erodibility	KIN	0.63	t/ac/English EI

TABLE 3
Summary of the updatable parameters for the erosion submodel

Parameter	Variable Name	Value
Cropping management factor	CIN(I)	0.4
Contouring factor	PIN(I)	1
Manning's n	MIN(I)	0.035
First date the parameter valid	PDATE	001
Last date the parameter valid	CDATE	120

SIMULATION RESULTS AND DISCUSSION

Subsurface-drained Plot

The annual values of observed and simulated sediment loss are shown in Table 4. The model simulates 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. The serious overestimation in 1981 was due mainly to overestimation in February. In this month the simulated value was 1729.0 kg/ha, compared to the observed value of 412.5 kg/ha. Rainfall in February 1981 was 20.6 cm. This was far above average February rainfall, which is 15.7 cm. Note also that the field had no cover during this month.

TABLE 4
Observed and simulated annual sediment loss of subsurface-drained plot

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 observed and simulated sediment loss accumulated by month for the 7-year period is shown in *Fig. 1.* The relationship between observed and simulated monthly sediment loss is shown in *Fig. 2.* Regression analysis gave the following relationship between monthly simulated and observed sediment loss:

$$\begin{aligned} S_{SM} &= 36.54 + 0.76\, S_{OM} \\ r &= 0.75 \end{aligned} \tag{8}$$

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. 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. The total simulated sediment loss was 10.1% less than the total observed sediment loss.

Non-subsurface-drained Plot

The annual values of observed and simulated sediment loss are shown in Table 5. As in the subsurface-drained plot, the DRAINMOD-CREAMS model seriously overestimated sediment loss in 1981. The observed and simulated sediment loss accumulated by months is shown in *Fig. 3.* The relationship between observed and simulated monthly sediment loss is shown in *Fig. 4.* Regression analysis gave the following relationship between simulated and observed monthly sediment loss:

$$\begin{aligned} S_{SM} &= 129.83 + 0.61\, S_{OM} \\ r &= 0.66 \end{aligned} \tag{9}$$

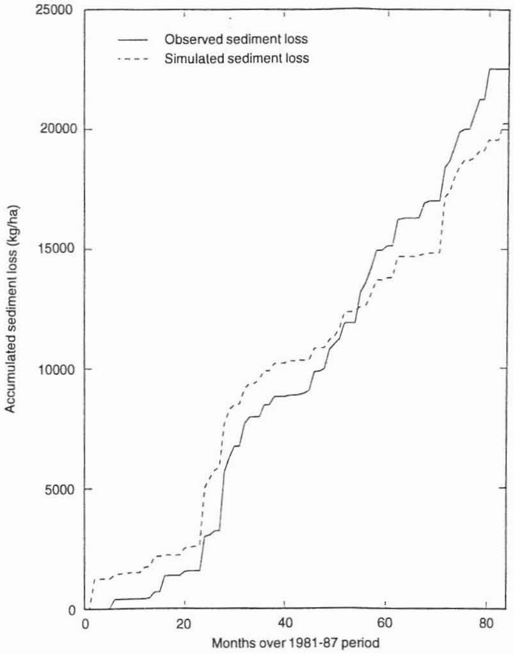

Fig. 1. Observed and simulated sediment loss accumulated by months, subsurface-drained plot (DRAINED-CREAM model)

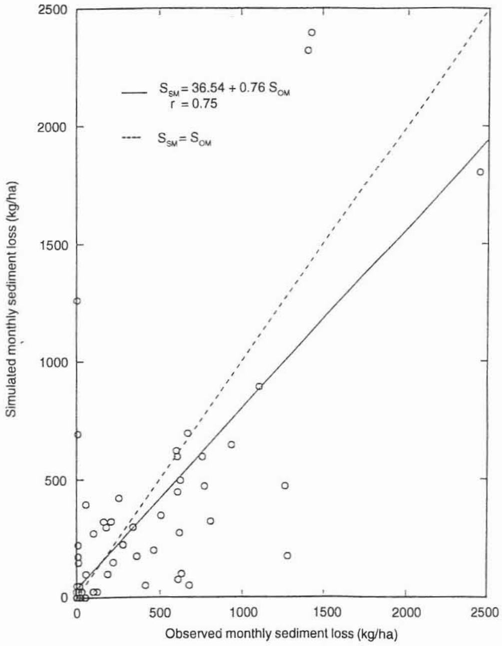

Fig. 2. Relationship between simulated and observed sediment loss, subsurface-drained plot (DRAINMOD-CREAMS model)

TABLE 5
Observed and simulated annual sediment loss of non-subsurface-drained plot

Year	Observed (kg/ha)	Simulated (kg/ha)	% Error
1981	592.5	2692.3	354.4
1982	3582.5	5532.8	54.4
1983	7200.2	8274.5	14.9
1984	2968.3	2717.0	-8.5
1985	10012.7	4569.5	-54.4
1986	5560.2	5285.8	-4.9
1987	8652.1	5261.1	-39.2
Total	38568.5	34333.0	-11.0

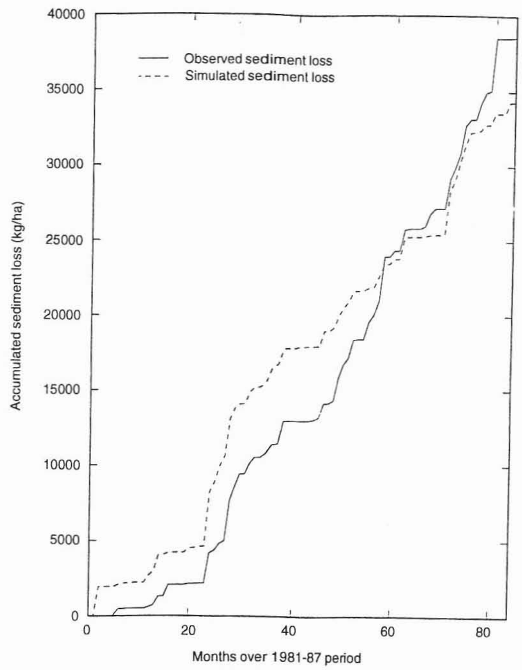

Fig. 3. Observed and simulated sediment loss accumulated by months, non-subsurface-drained plot (DRAINMOD-CREAMS model)

The ANOVA test demonstrated that a significant linear relationship exists between the simulated and observed monthly sediment loss, and the intercept was not statistically different from zero. However, the slope of the regression equation was statistically different from 1.0. The model overestimated the total sediment loss for the years 1981, 1982, and 1983, and underestimated for the years 1984, 1985, 1986, and 1987. The total simulated sediment loss was 11.0% less than the total observed sediment loss.

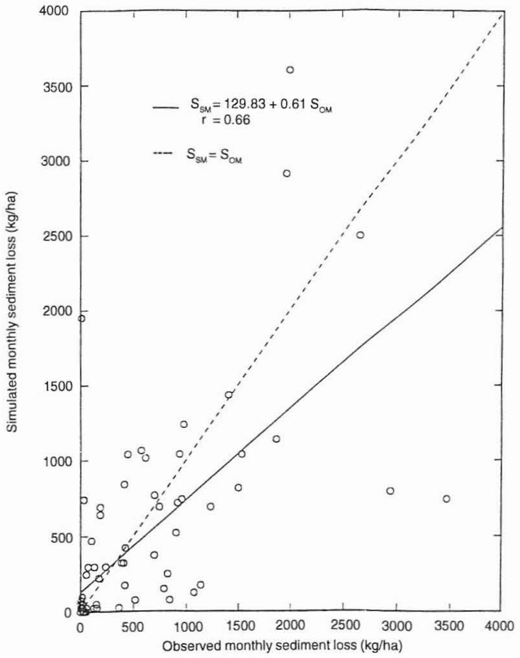

Fig. 4. Relationship between simulated and observed sediment loss, non-subsurface-drained plot (DRAINMOD-CREAMS model)

The standard deviation of differences and the absolute average difference between the observed and predicted data were computed, and are presented in Table 6. These values are smaller for the subsurface-drained plot. This shows that the simulated and observed values are closer in the subsurface-drained plot.

TABLE 6
Error statistics computed to evaluate DRAINMOD-CREAMS model predictions on sediment loss

Statistics	Sediment Loss (kg/ha)	
	Subsurface	Non-Subsurface
STDD	314.92	567.30
ADIF	164.7	289.42

CONCLUSION

The DRAINMOD-CREAMS model underestimated sediment loss by 10.1% and 11.0% from the subsurface-drained plot and the non-subsurface-drained plot, respectively. In general, the performance of the model in simulating the sediment loss from flat agricultural land in Louisiana, USA is satisfactory.

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