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Error Assessment in the Universal Soil Loss Equation

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ABSTRACT

Although nearly three decades of widespread use have confirmed the reliability of the Universal Soil Loss Equation (USLE), very little work has been done to assess the error associated with it. This study was conducted to develop a set of statistics that would measure the performance of the USLE. Estimates of soil loss using the USLE were compared with measured values on 208 natural runoff plots, representing >1700 plot years of data, to assess the error associated with the USLE predictions. The overall Nash–Sutcliffe model efficiency was determined to be 0.75 on an average annual basis and 0.58 when compared on a yearly basis. The USLE overpredicted soil loss on plots with low erosion rates while the plots with higher rates were underpredicted. Of the USLE parameters, the topographic factor (*LS*) and the cover and management factor (*C*) had the most influence on the model efficiency. Confidence intervals for USLE predictions were developed and showed that the accuracy of the USLE in terms of percentage difference between predicted and expected values increases with increasing values of total soil loss. It was also shown that there was no significant difference between the average magnitude of error for pre- and post-1960 data sets and that the use of rainfall and runoff factor (*R*) values instead of calculated erosion index (EI) values resulted in a drop in model efficiency of 0.02. One must use caution in applying the results of this error analysis to conditions in which they may not be applicable, due to the limited nature of this data set.

THE USLE is the most widely used of all soil erosion models. To develop it, small plot data from 49 U.S. locations representing >10 000 plot years of runoff and soil erosion were summarized (Wischmeier and Smith, 1978). Using this information, the following equation was developed that estimates average annual erosion using rainfall, soil, topographic, and management data:

$$A = R\,K\,LS\,C\,P \qquad [1]$$

where A = computed soil loss per unit area, R = the rainfall and runoff factor, K = the soil erodibility factor, LS = the topographic factor, C = the cover and management factor, and P = the support practice factor. Although this equation has been used for a variety of purposes, Wischmeier (1976) cautioned against using the USLE for purposes other than those for which it was designed. First of all, it was designed to predict soil loss resulting from erosion and deposition on slope segments but not deposition on the lower parts of the fields. Therefore, one must be careful in distinguishing between sediment yield and soil loss. Secondly, the equation was designed to predict long-term average annual values. The user must realize that the equation is predicting the average soil loss for numerous reoccurrences of this event so the soil loss from any single event may differ appreciably. Finally, he cautioned the user that the greatest potential source of error is in the selection of inappropriate factor values and that the conditions to be evaluated must be clearly defined.

Since the USLE uses empirically derived relationships, it is expected to give the most reliable estimates of erosion for conditions that closely resemble those from which the relationships were developed: medium-textured soils with slopes from 3 to 18% and <122 m in length. Wischmeier (1976) stated that nearly two decades of widespread use in soil conservation district programs have confirmed the reliability of the USLE when used as designed. It has been used throughout the world for a variety of purposes and under many different conditions simply because it seems to meet the need better than any other tool available. Although much research has been done in developing numerical factor values for use in the equation and in suggesting changes and modifications to the equation to better suit it for specific purposes, few attempts have been made at quantifying the reliability or confidence in the predictions obtained from it. While it is generally understood that the error associated with any model output will be dependant on model uncertainty, parameter uncertainty, and measurement error, more information about the parameter and model uncertainty of the USLE is required.

Details of the most comprehensive study concerning the accuracy of the USLE may be found in Wischmeier (1972). His study used the equation and the published isoerodent maps, EI distribution curves, slope effect charts, and soil loss ratio tables to predict long-term average annual soil losses for 189 plots for which there was a total of about 2300 plot years of soil loss records. His results indicated that, for the 189 individual plot predictions, the average deviation between the measured and predicted soil loss was 0.31 kg m^{-2} yr^{-1}. For the 2300 plot years, the equation overpredicted by an average of 0.09 kg m^{-2} yr^{-1}. He also stated that approximately 53% of the deviations were within 0.22 kg m^{-2} and 84% of the deviations were within 0.45 kg m^{-2}, and that the variance indicated that about 5% of the measurements may be in error by as much as 1.03 kg m^{-2}. Much of this type of information is desirable and useful; however, since the time of this study, the USLE and its factor values have been refined and improved. Additional work is required to determine the improvement in accuracy that these changes may have supplied.

Many studies have attempted to evaluate the USLE under specific conditions at different locations. These include Onstad et al. (1976), Albaladejo and Stocking (1989), Kramer and Alberts (1986), and Freebairn et al. (1989). The results of these studies generally varied from site to site and very few conclusions could be drawn concerning the overall accuracy of the equation. Other researchers, including those reviewed in McIsaac et al. (1987) and McCool et al. (1987), have investigated the effects of the *LS* factor and generally concluded that the equation overpredicts on steep slopes.

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Many researchers have investigated the use of the USLE on rangelands. Most of these studies show that the USLE does not perform as well as under cultivated or agricultural conditions. Weltz et al. (1987), Osborn et al. (1977), and Trieste and Gifford (1980) showed that the USLE usually tended to underpredict erosion on rangeland plots, but a study by Hart (1984) contradicted these results. Although these studies do not all present the same results, they do indicate that unmodified versions of the USLE do not seem to adequately predict erosion on nonagronomic soils. Many erosion studies have been conducted using radioactive fallout Cs^{137} resulting from atmospheric testing of nuclear weapons. Ritchie et al. (1974) showed that Cs^{137} can be used effectively to estimate net soil erosion and that there was a strong logarithmic relationship (r = 0.94) between soil loss estimated by the USLE and the percentage of radionuclide loss (Ritchie and McHenry, 1990).

In order to effectively evaluate the accuracy of the USLE for a given set of conditions, we must have a well-defined data set and limit the sources of measurement error as much as possible. Once this has been accomplished, this data set can be used to compare other erosion models under the exact same conditions. The objective of this study is to develop a set of data that will measure the performance and accuracy of the USLE for conditions similar to those under which it was developed. When using the results, it must be realized that the statistics given were obtained from a restricted data set under limited conditions that may not be representative of field conditions or of current cultural and conservation practices. All of the data was obtained from natural runoff-style plots and therefore the results may not be widely applicable under larger and more varied field conditions. In addition, the bulk of the data was collected prior to 1960 and are not representative of current cultural practices. Therefore, the results may not be applicable to fields under cultural practices that may be outside of the restricted parameter range tested in this study.

MATERIALS AND METHODS

Thousands of plot-years of natural runoff data were obtained from the National Soil Erosion Research Laboratory at Purdue University. This included most of the natural runoff plot data used to develop the USLE as well as additional data from more current natural runoff plots. From this data set, >1700 plot-yr from >220 plots at 22 sites were selected for analysis. The selected plots are shown in Table 1. These plots were selected to obtain a wide variety of soils, geographic locations, cropping and management practices, slopes, and slope lengths. In addition, other selection criteria included the quality of the original data in terms of details provided and the readability of the data sheets, the availability of USLE factor values, and attempts to avoid duplication with other published studies.

Within the 1700 selected plot-years of data, 284 plot-yr consisted of plots with replicates. In this study, each of the replicates was treated as an individual value. The average difference in soil loss between the replicates was 32 ± 35% with absolute differences ranging from 0 to 7.23 kg m^{-2}. The USLE does not account for this unexplained variability in soil loss. However, since this is a natural phenomena and the error would be inherent to all models, no corrections were made.

Once the sites were selected, factor values for each of the parameters in the equation were determined and entered on a spreadsheet. Each factor and the methods used to determine it are discussed below. The USLE in the form of Eq. [1] was then used to calculate the soil loss on an annual basis for each plot-year.

Rainfall and Runoff Factor

The rainfall and runoff factor (R value) is designed to quantify the raindrop impact effect and provide relative information on the amount and rate of runoff likely to be associated with the rain. When the USLE is used as a predictive tool, R values are determined directly from isoerodent maps developed from long-term climatic records at various locations across the USA. This technique, however, is only applicable to making long-term predictions and should not be used to compare measured soil losses with USLE calculations on an event or annual basis. To compare soil losses within a given time period, the energy times the maximum 30-min intensity value (EI value) for each storm within the time period should be summed to obtain the R value for the given time period. In this study, soil loss predictions were made on an annual basis using R values obtained from both the isoerodent maps and from summing the EI values on an annual basis. Wwe will refer to the values from the isoerodent charts as R values and the sum of the calculated EI values as EI values. Unless otherwise stated, all of the soil loss predictions were made using the calculated EI values as opposed to the R values.

At all of the sites used in this study, records of recording or weighing rain gauge data were available. This data usually contained storm dates, times, total precipitation, and 5-, 15-, 30-, and 60-min intensities. In addition, storms causing runoff usually had detailed breakpoint data that included time and accumulation for irregular intervals within the storm duration. Using this data, the individual storm EI values were computed and summed across the year using methods described in Wischmeier and Smith (1978, appendix) to obtain an annual EI value.

Soil Erodibility Factor

The soil erodibility factor (K) is used to represent the differences in the natural susceptibilities of soils to erosion. Values for K were experimentally evaluated using USLE plot data for 23 benchmark soils by Wischmeier and Smith (1965) and are listed in Wischmeier and Smith (1978). Sixteen of the 24 different soils used in this study were listed in these tables and the K values were chosen from this data. Other sources of experimentally determined K values were publications, correspondence between Wischmeier and personnel at the site where the soil was located, and state soil maps. Five of the remaining eight soils had K values that were chosen from this type of information. On the remaining three soils (Egan, Grantsberg, and Caribou) K values had to be calculated using the nomograph developed in Wischmeier et al. (1971) and listed in Wischmeier and Smith (1978). The inputs required for the nomograph were obtained through the plot data literature and the Soil Conservation Service soils database.

Topographic Factor

The slope length (L) and slope steepness (S) factors were designed to account for the slope of the land and its length. They are defined as the expected ratio of soil loss per unit area from a particular slope length or slope steepness to that from a 22.13-m (72.6-ft) length with a uniform 9% slope under otherwise identical conditions. The equation given in Wischmeier and Smith (1978) was used to calculate the combined LS factor for each of the plots.

Since all of the plots used in this study have essentially uniform slopes ranging from 3 to 20.7% and from 10.67 to 192.02 m, the equation was not used outside the range for which it was developed.

Table 1. Universal Soil Loss Equation validation sites with soil erodibility factors (*K*) for each soil.

Plot†	Size	Slope	Tillage‡	Crop§	Years
	m	%			
			Morris, MN, Barnes loam, $K = 0.28$		
I-2,9	4.05 by 22.13	5.9	U/D	Corn–oat–hay	1962–1971
I-10,13	4.05 by 22.13	6.5	U/D	Fallow	1962–1971
			Hollysprings, MS, Grenada silt loam, $K = 0.41$		
3-1	4.05 by 22.13	5.0	U/D	Meadow–meadow–corn	1963–1968
3-3	4.05 by 22.13	5.0	U/D	Corn–meadow–meadow	1963–1968
3-5,7	4.05 by 22.13	5.0	U/D	Fallow	1963–1968
			Castana, IA, Monona silt loam, $K = 0.33$		
1-3,4	3.20 by 22.13	14.0	U/D	Fallow	1960–1969
1-7	3.20 by 22.13	14.0	Contour	Oat–meadow–meadow–corn	1960–1969
1-8	3.20 by 22.13	14.0	Contour	Corn–oat–meadow–meadow	1960–1969
			Tifton, GA, Tifton loamy sand, $K = 0.10$		
1-1,2-6	7.99 by 25.30	3.0	Contour	Meadow–meadow–corn–peanut	1952–1966
1-2,2-4	7.99 by 25.30	3.0	Contour	Peanut	1952–1958
1-2,2-4	7.99 by 25.30	3.0	U/D	Fallow	1959–1966
1-3,2-5	7.99 by 25.30	3.0	Contour	Peanut–corn (rye)–oat	1952–1966
1-8,2-1	7.99 by 25.30	3.0	Contour	Meadow	1952–1955
1-8,2-1	7.99 by 25.30	3.0	Contour	Corn	1955–1966
			Presque Isle, ME, Caribou gravelly silt loam, $K = 0.23$		
1-2,14,16	3.66 by 22.13	8.0	U/D	Potato	1961–1965
1-3,8,18	3.66 by 22.13	8.0	U/D	Fallow	1961–1965
1-6,13,17	3.66 by 22.13	8.0	U/D	Potato (RR)	1961–1965
			Temple, TX, Austin silty loam, $K = 0.29$		
I-1	1.83 by 11.06	4.0	U/D	Corn	1931–1945
I-2	1.83 by 44.26	4.0	U/D	Corn	1931–1945
I-3	1.83 by 22.13	4.0	U/D	Corn	1931–1945
I-4	1.83 by 22.13	4.0	U/D	Corn–oat–cotton	1931–1945
I-9	1.83 by 22.13	4.0	U/D	Oat–cotton–corn	1931–1945
I-7	1.83 by 22.13	4.0	U/D	Cotton–corn–oat	1931–1945
			Geneva, NY, Ontario loam, $K = 0.27$		
1-2	1.83 by 22.13	8.0	Broadcast	Fallow (rye)	1937–1947
1-4	1.83 by 22.13	8.0	Broadcast	Soybean	1937–1947
1-5	1.83 by 22.13	8.0	U/D	Fallow	1937–1947
1-6	1.83 by 22.13	8.0	Broadcast	Meadow	1937–1947
1-2,4,5,6	1.83 by 22.13	8.0	U/D	Corn	1947–1948
			Geneva, NY, Dunkirk silt loam, $K = 0.69$		
2-1	1.83 by 22.13	5.0	U/D	Fallow	1938–1946
			Madison, SD, Egan silty clay loam, $K = 0.22$		
1-2,6,9	4.05 by 22.13	5.8	U/D	Corn (mulch tillage)	1962–1970
1-4,7,10	4.05 by 22.13	5.8	U/D	Corn (plowed)	1962–1970
1-5,12	4.05 by 22.13	5.8	U/D	Fallow	1962–1970
			Clarinda, IA, Marshall silt loam, $K = 0.33$		
I-1	1.83 by 11.06	9.0	U/D	Corn	1932–1943
I-2	1.83 by 44.26	9.0	U/D	Corn	1932–1943
I-3	1.83 by 22.13	9.0	U/D	Corn	1932–1943
I-4	1.83 by 22.13	9.0	U/D	Corn–oat–meadow	1932–1943
I-5	1.83 by 22.13	9.0	U/D	Oat–meadow–corn	1932–1943
I-6	1.83 by 22.13	9.0	U/D	Meadow–corn–oat	1932–1943
I-7	1.83 by 22.13	9.0	BC	Alfalfa	1932–1943
I-8	1.83 by 22.13	9.0	BC	Bluegrass	1932–1943
II-1¶	3.20 by 22.13	9.0	U/D	Corn (36 Mg ha^{-1} sweetclover added)	1933–1939
II-2¶	3.20 by 22.13	9.0	U/D	Corn (18 Mg ha^{-1} sweetclover added)	1933–1939
II-3¶	3.20 by 22.13	9.0	U/D	Corn (36 Mg ha^{-1} manure added)	1933–1939
II-4¶	3.20 by 22.13	9.0	U/D	Corn (18 Mg ha^{-1} manure added)	1933–1939
II-5¶	3.20 by 22.13	9.0	U/D	Corn	1933–1939
II-6¶	3.20 by 22.13	9.0	U/D	Fallow (36 Mg ha^{-1} sweetclover added)	1933–1939
II-7¶	3.20 by 22.13	9.0	U/D	Fallow (18 Mg ha^{-1} sweetclover added)	1933–1939
II-8¶	3.20 by 22.13	9.0	U/D	Fallow (36 Mg ha^{-1} manure added)	1933–1939
II-9¶	3.20 by 22.13	9.0	U/D	Fallow (18 Mg ha^{-1} manure added)	1933–1939
II-10¶	3.20 by 22.13	9.0	U/D	Fallow	1933–1939
III-1	12.8 by 192	8.0	U/D	Corn (rye)	1933–1939
III-2	12.8 by 96	8.0	U/D	Corn (rye)	1933–1939
III-3	12.8 by 48	8.0	U/D	Corn (rye)	1933–1939

Table 1. Continued.

Plot†	Size	Slope	Tillage‡	Crop§	Years
	m	%			
LaCrosse, WI, Fayette silt loam, *K* = 0.38					
I-1	1.83 by 11.06	16.0	Con	Corn	1933–1938
I-2	1.83 by 44.26	16.0	Con	Corn	1933–1938
I-3	1.83 by 22.13	16.0	Con	Corn	1933–1938
I-8	1.83 by 22.13	16.0	U/D	Fallow	1933–1938
I-10	1.83 by 22.13	16.0	Con	Bluegrass (protected)	1933–1938
I-12	1.83 by 22.13	30.0	Con	Bluegrass (protected)	1933–1938
I-14	1.83 by 22.13	30.0	Con	Corn	1933–1938
II-1,9	4.27 by 22.13	16.0	Con	Hay–hay–corn–barley, no OM††	1940–1951
II-2,6	4.27 by 22.13	16.0	Con	Hay–hay–corn–barley, +OM fall	1940–1951
II-4,10	4.27 by 22.13	16.0	Con	Hay–hay–corn–barley, +OM spring	1940–1951
3S1,2,3	4.27 by 11.06	3.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
3L1,2,3	4.27 by 22.13	3.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
8S1,2,3	4.27 by 11.06	8.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
8L1,2,3	4.27 by 22.13	8.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
13S1,2,3	4.27 by 11.06	13.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
13L1,2,3	4.27 by 22.13	13.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
18S1,2,3	4.27 by 11.06	18.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
18L1,2,3	4.27 by 22.13	18.0	U/D	Barley 3 yr, hay–corn–barley	1939–1946
Watkinsville, GA, Cecil sandy loam, *K* = 0.23					
1-2	6.32 by 21.34	3.0	Con	Cotton	1953–1960
Watkinsville, GA, Cecil sandy clay loam, *K* = 0.36					
2-24	6.32 by 21.34	7.0	Con	Cotton	1953–1960
3-34	6.32 by 21.34	11.0	Con	Cotton	1953–1960
2-7,9,11	6.32 by 21.34	7.0	Con	Meadow–meadow–corn	1953–1960
3-27,29,30	6.32 by 21.34	11.0	Con	Meadow–meadow–corn	1953–1960
3-25,26,28	6.32 by 10.67	11.0	Con	Meadow–meadow–corn	1953–1960
2-13,19,21,22	6.32 by 21.34	7.0	Con	Meadow–meadow–corn–cotton	1953–1960
Clemson, SC, Cecil sandy loam, *K* = 0.25					
5-1,12	1.83 by 18.2	7	U/D	Fallow	1940–1942
Bethany, MO, Shelby silt loam, *K* = 0.39					
1-7	1.83 by 22.13	8.0	U/D	Alfalfa	1931–1940
1-9	1.83 by 22.13	8.0	U/D	Fallow	1931–1940
Bethany, MO, Shelby silt loam, *K* = 0.41					
5-1,3,5	13.32 by 82.3	6.6	Strip	Meadow–wheat–corn strips	1937–1941
5-2,4,6	13.32 by 82.3	6.6	Con	Meadow–corn–wheat	1937–1941
Arnot, NY (Ithaca), Bath flaggy silt loam, *K* = 0.02					
1-5	1.83 by 22.13	18.3	Con	Corn	1935–1945
1-7	1.83 by 22.13	18.9	Con	Corn 1935–1938, fallow (RR)	1935–1940
1-8	1.83 by 22.13	19.2	U/D	Fallow	1935–1940
1-9	1.83 by 22.13	19.5	BC	Meadow	1935–1940
1-14	1.83 by 22.13	20.7	Con	Potatoes-Scl	1935–1940
Dixon Springs, IL, Grantburg silt loam, *K* = 0.36					
11,15	12.8 by 10.67	5.4	Con	Wheat–meadow (grazed)–corn	1940–1945
12,17	12.8 by 21.34	5.2	Con	Wheat–meadow (grazed)–corn	1940–1945
13,18	12.8 by 42.67	5.5	Con	Wheat–meadow (grazed)–corn	1940–1945
14,19	12.8 by 64.01	4.9	Con	Wheat–meadow (grazed)–corn	1940–1945
21,26	12.8 by 10.67	10.1	Con	Wheat–meadow (grazed)–corn	1940–1945
22,27	12.8 by 21.34	9.5	Con	Wheat–meadow (grazed)–corn	1940–1945
23,28	12.8 by 42.67	10.0	Con	Wheat–meadow (grazed)–corn	1940–1945
24,29	12.8 by 64.01	9.7	Con	Wheat–meadow (grazed)–corn	1940–1945
Guthrie, OK, Stephensville fine sandy loam, *K* = 0.22					
1-1	1.83 by 11.06	7.7	U/D	Cotton	1930–1956
1-2	1.83 by 44.26	7.7	U/D	Cotton	1930–1956
1-3	1.83 by 22.13	7.7	U/D	Cotton	1930–1956
1-8	1.83 by 22.13	7.7	U/D	Fallow	1930–1956
3-1	39 by 103.6	4.5	Con	Cotton with alfalfa strips	1935–1939
3-2	39 by 103.6	4.0	Con	Cotton with oat strips	1935–1939
3-4	39 by 103.6	3.0	Con	Oat with cotton strips	1935–1939
5-1	18.53 by 103.6	4.5	Con	Cotton with grass strips	1942–1946
5-2	18.53 by 103.6	4.5	Con	Cotton	1942–1946
5-3	18.53 by 103.6	4.0	Con	Cotton	1942–1946
5-4	18.53 by 103.6	4.0	Con	Cotton with grass strips	1942–1946
5-5	18.53 by 103.6	3.5	Con	Cotton with grass strips	1942–1946
5-6	18.53 by 103.6	3.5	Con	Cotton	1942–1946

Table 1. Continued.

Plot†	Size	Slope	Tillage‡	Crop§	Years
	m	%			
			Hayes, KS, Colby silt loam, $K = 0.32$		
1-1	1.83 by 11.06	5	U/D 1931–1939, contour 1939–1946	Wheat	1931–1946
1-2	1.83 by 44.26	5	U/D 1931–1939, contour 1939–1946	Wheat	1931–1946
4-1,4	33.19 by 60.96	7		Meadow moderately grazed	1933–1938
4-2,3	33.19 by 60.96	7		Meadow heavily grazed	1933–1938
			Marcellus, NY, Honeoye silt loam, $K = 0.28$		
A-1,4	6.40 by 22.13	18.9	BC	Meadow 3 yr–corn	1940–1943
A-2,3	6.40 by 22.13	18.4	U/D	Fallow 3 yr–corn	1940–1943
B-5	6.40 by 11.06	16.4	Con	Corn‡‡	1957–1963
B-2	6.40 by 22.13	16.8	Con	Corn‡‡	1957–1963
B-3	6.40 by 64.01	17.6	Con	Corn‡‡	1957–1963
C-9	6.40 by 11.06	4.5	Con	Corn‡‡	1957–1963
C-2	6.40 by 22.13	3.9	Con	Corn‡‡	1957–1963
C-7	6.40 by 64.01	5.0	Con	Corn‡‡	1957–1963
D-9	6.40 by 11.06	8.8	Con	Corn‡‡	1957–1963
D-2	6.40 by 22.13	9.4	Con	Corn‡‡	1957–1963
D-3	6.40 by 64.01	9.4	Con	Corn‡‡	1957–1963
			Raleigh, NC, mixture of Applying, Vance, and Durham series, $K = 0.23$		
2-5	4.88 by 41.61	4	Con	Tobacco	1944–1948
2-6	4.88 by 41.61	4	Con	Tobacco–ryegrass	1944–1948
			Statesville, NC, Cecil sandy clay loam, $K = 0.36$		
1-4	1.83 by 22.13	10	Con	Fallow	1931–1938
1-10	1.83 by 22.13	10	Con	Cotton	1931–1938
1-11	1.83 by 44.26	10	Con	Cotton	1931–1938
1-12	1.83 by 11.06	10	Con	Cotton	1931–1938

† Plot numbers usually designated by series-plot number. Multiple plot numbers indicate replicates.
‡ Primary direction of tillage: U/D, up and down slope; Con, contour; BC, broadcast; Strip, strip-cropped.
§ Primary cropping system. Crop rotations designated by dash, parentheses indicate winter cover crop or other special treatment, RR = rocks removed.
¶ 0.304 m of topsoil was removed from these plots.
†† OM = organic matter.
‡‡ Winter cover crop.

Cover and Management Factor

The factor C is the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled, continuous fallow conditions. The correspondence of periods of highly erosive rainfall with periods of poor or good plant cover differs appreciably between climatic areas; therefore, the value of C for a particular cropping and management system will not be the same for all parts of the country. Locational C values are derived using specific rainstorm-timing probabilities and research data that reflects the erosion-reducing effectiveness of crops and management during successive periods within a rotation cycle (Wischmeier, 1972).

For each of the plots in this study, C factors were determined on an annual basis. Since individual event predictions were not made, the C values were not broken down by stage of growth. Tables of the statewide C values were obtained from state Soil Conservation Service offices. These tables were assumed to represent the most current technology, as they contain the most recently revised C values. Each condition listed on these tables was studied and the one that most nearly duplicated the described conditions at the test plot was chosen. Several assumptions were made in the selection process. Many states gave C values as a function of yield. For most plots, yields were given on an annual basis; however, if no yield was given, an average yield was assumed. No attempt was made to correct historic yields due to scientific advances made over the last few decades that have increased average yields. Some states listed C values as a function of surface residue (percentage of the soil surface covered at planting). This type information was not usually recorded in the plot data so assumptions were made to estimate the surface cover based on tillage and previous crop yields. When crop rotations were used, the C values for the rotation were usually listed as such in the Soil Conservation Service C value tables; however, if a specific rotation could not be found, either a similar rotation value was chosen, or a specific value for each crop was chosen based on the proceeding crop. Many tillage practices used on the older sites were no longer in use and a modern tillage practice was assumed. Examples of these assumptions include using plowing as an alternative to hand hoeing, and disking as an alternative to raking.

The variety of crops under different treatments that were tested in this study represent most agromonic practices; however, many of these crops were of different varieties and used in different management scenarios than those currently employed. With the current emphasis on tillage and residue management, the importance of determining the proper value of C and the research in determining factor values under a variety of conditions is a continuously evolving process. The limited range of C factors that were used in this study may not be entirely representative of those that are currently being used.

Support Practice Factor

The support practice factor, P, is similar to C except it is intended to account for additional effects such as contour farming, terraces, and strip cropping. By definition, P is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-downslope culture. Research has shown that the practice of tillage and planting on the contour can be ef-

Table 2. Summary statistics for average and average annual values of soil loss predicted by the Universal Soil Loss Equation (USLE).

Parameter	Annual values†	Average annual values‡
	kg m^{-2}	
Soil loss	3.51 ± 7.00	3.47 ± 5.64
Avg. measured soil loss		
Avg. predicted soil loss	3.22 ± 5.36	3.13 ± 5.00
Avg. error	−0.28 ± 4.48	−0.34 ± 2.83
Avg. magnitude error§	2.13 ± 3.96	1.36 ± 2.50
Regression results		
Slope	0.59	0.77
Intercept	1.16	0.42
Correlation coefficient	0.58	0.75
Model efficiency	0.58	0.75

† n = 1 638 observations.
‡ n = 208 observations.
§ Average magnitude of error represents the absolute value of the difference between the USLE prediction and the measured soil loss.

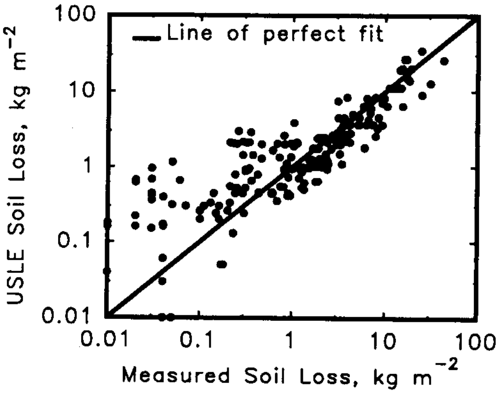

Fig. 1. Soil loss on an average annual basis measured and predicted by the Universal Soil Loss Equation.

fective in reducing erosion and that the degree of effectiveness relates to the slope and the slope length of the land. The values of P for contouring that vary with slope percentage were developed in a joint Agricultural Research Service and Soil Conservation Service workshop in 1956 and are given in Wischmeier and Smith (1978, Table 13). The valuesof P used to represent contouring in this study were obtained from that table except for a limited number of plots that had locally derived P values included in the state C value tables. None of the plots in this study had slope lengths exceeding the maximum recommended slope lengths given in Table 13.

Nine plots located in Guthrie, OK, and Bethany, MO, were contour strip-cropped. The P values for these plots were chosen using Table 14 of Wischmeier and Smith (1978). This table gives P values for three cropping systems as a function of slope. If the exact cropping system used at the plot was not listed in the table, the most appropriate system given was assumed.

Model Efficiency

After predictions for each plot were made, they were compared with measured results in several ways. One of the most useful methods for comparing model results with measured values was defined in Nash and Sutcliffe (1970) and is calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Q_{mi} - Q_{ci})^2}{\sum_{i=1}^{n} (Q_{mi} - \overline{Q_m})^2} \qquad [2]$$

where R^2 = the efficiency of a model, Q_{mi} = the measured value of event i, Q_{ci} = the computed value of event i, and $\overline{Q}_m$ = the mean of the measured values. Using this method of calculating efficiency, a value of one indicates a perfect model, a value of zero indicates the model results are no better than the mean, and a value less than one indicates that using model predictions would be worse than using the mean. This measure of efficiency is much like the correlation coefficient (r^2) from linear regression; however, it compares the measured values to the 1:1 line of measured equals predicted rather than to the best-fit regression line. Therefore, it not only considers the linearity of the data but also the relative differences between the measured and predicted values.

RESULTS AND DISCUSSION

The USLE estimates were made for each of the plots on both an annual and average annual basis and the results were compared with annual measured soil losses and average soil losses using the entire record for a given plot. Summary results for most of these tests are presented in Table 2. The overall model efficiency showed that the USLE was much more efficient at calculating average annual values (R^2 = 0.75) than it was calculating the yearly soil loss (R^2 = 0.58). This was also evident by the fact that the average magnitude of error was 0.77 kg m^{-2} less when comparing average annual values to USLE predictions. Some of the difference may be attributed to the facts that the yearly data set contained relatively more large events, which would contribute a greater amount of error, and that many of the USLE parameters are designed to predict long-term average annual values and not individual annual values.

Both the average error (−0.28 and −0.34 kg m^{-2} for the average and annual predictions, respectfully) and linear regression between the observed and predicted values show that, overall, the USLE tends to overestimate soil loss for the plots in this study. Figures 1 and 2 present plots of the measured and USLE-estimated values. In both the annual and average annual cases, there appears to be many small values that the USLE overestimates and a few large values that are underestimated. The fact that the Nash–Sutcliffe efficiency and the correlation coefficient are nearly identical indicates that the USLE is neither under- nor overpredicting soil loss on a consistent basis for all of the plots.

The frequency distribution of the error term (Fig. 3)

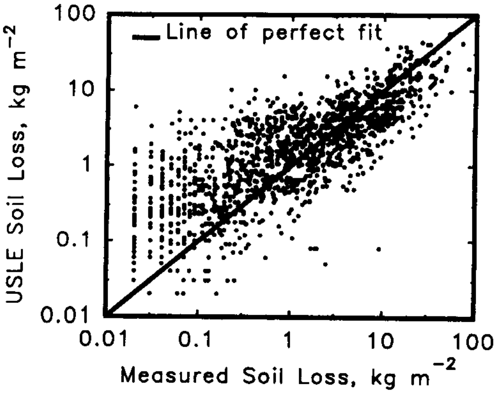

Fig. 2. Soil loss on a yearly basis measured and predicted by the Universal Soil Loss Equation.

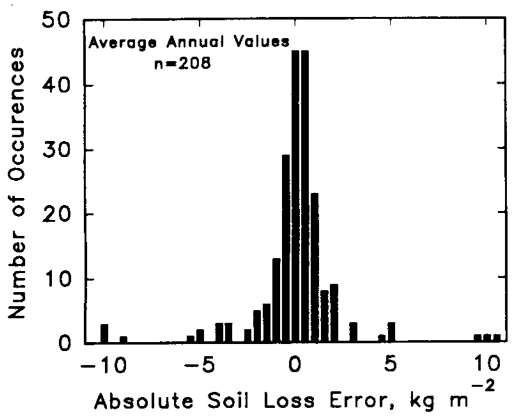

Fig. 3. Frequency distribution of error in USLE soil loss predictions.

shows that the absolute error appears to be uniformly distributed about zero (95 plots underestimated and 113 plots overestimated) but, of the plots that had average annual measured soil loss <0.90 kg m^{-2}, 80% were overestimated while, on those plots with measured values >2.0 kg m^{-2}, $<22\%$ were overestimated. Another indicator of this overprediction at lower soil loss rates is the fact that regression analysis without forcing the *y* intercept (USLE estimate) through zero gives an intercept much greater than zero and a slope less than one for both annual and average annual values. This seems to agree with other studies that have suggested that the USLE usually overestimates at sites with relativity low erosion rates and underestimates at sites with higher erosion rates.

The natural runoff plots used in this study were extremely narrow and had plot borders that prevented flow from running off the side of the slope. The narrowness of the plot borders acts to overemphasize the effectiveness of contouring since it prevents normal concentration of runoff and restricts the contribution area once overtopping has occurred. This can have a significant impact on the effectiveness of contouring. For this reason, two sets of calculations were made. In one, contouring was assumed to be ineffective on these plots and the unit *P* factors were used, and on the other the *P* values for contouring were used. Table 3 presents the results of each of these runs for all of the plots and for a data set containing only the contoured plots. In both cases, assuming the *P* factor to be unity slightly increased the model efficiency (0.02 and 0.04, respectfully). When contouring *P* factors were used, the USLE tended to underestimate erosion; however, *P* factors of one caused it to overestimate erosion. Since much of the data did not contain detailed information on the type of contour or the ridge height used, many of the plots that were described as being contoured may not have represented true contouring but were instead just planted on the contour. Therefore, it is difficult to draw any conclusions from this test except for the fact that information such as the contour ridge height should be included in the process of selecting contour *P* values.

Table 3. Effect of Universal Soil Loss Equation (USLE) support practice (*P*) factors on predicted soil loss.

	All plots†		Contoured plots‡	
Parameter	$P \leq 1$	$P = 1$	$P < 1$	$P = 1$
	kg m^{-2}			
USLE-predicted soil loss	3.22	3.64	2.84	4.22
Avg. error	−0.28	0.13	−0.25	1.12
Avg. magnitude error	2.13	2.24	2.08	2.42
Model efficiency	0.58	0.60	0.66	0.70

† 1638 observations, average measured soil loss = 3.51 kg m^{-2}.
‡ 499 observations, average measured soil loss = 3.02 kg m^{-2}.

Table 4. Summary statistics for Universal Soil Loss Equation predictions from data gathered before and after 1960.

Parameter	Pre-1960†	Post-1960‡
	kg m^{-2}	
Avg. measured soil loss	3.67	2.80
Avg. error	−0.54 ± 4.67	0.82 ± 3.37
Avg. magnitude of error	2.25	1.62
Regression statistics		
Slope	0.50	1.16
Intercept	1.28	1.70
Correlation coefficient	0.59	0.81
Model efficiency	0.57	0.65

† n = 1325 observations.
‡ n = 313 observations.

In order to investigate the effects of using older data, which would have lower crop yields, less intense tillage practices, and different methods of data collection, the data set was split into pre- and post-1960 groups and the same tests were performed on each set. Table 4 presents these results. The overall model efficiency was about 0.08 better and the average magnitude of error was 0.63 kg m^{-2} less for the post-1960 data set. The USLE tended to underpredict erosion (avg. error of −0.54 kg m^{-2}) on the pre-1960 data, while it tended to overpredict (avg. error of 0.82 kg m^{-2}) on the post-1960 data. Since the post-1960 data set was much smaller, it is difficult to draw conclusions; however, there appears to be a trend of decreasing soil loss while USLE predictions remain constant. This decrease in soil loss can be attributed to the increased crop yields, differences in tillage, and better management practices, which may not be represented in the USLE factor values used in this study.

A difference between this study and Wischmeier (1972) is the fact that this study used calculated EI values from measured precipitation instead of the *R* values from isoerodent maps. In order to examine these effects, *R* values were determined and an additional set of predictions were made. These results are shown in Table 5. The use

Table 5. Comparison of statistics using rainfall and runoff factor (*R*) values and erosion index by (EI) values.

Parameter	Average EI†	*R* value†
	kg m^{-2}	
Average value	178 (57–372)‡	184 (70–340)
Ratio *R*/EI	1.08 (0.65–1.48)	
Avg. error	−0.34	−0.13
Avg. magnitude error	1.36	1.37
Avg. magnitude error Plots <8-yr record	1.63	1.66
Avg. magnitude error Plots ≥8-yr record	1.36	1.35
Model efficiency	0.75	0.73

† n = 208 observations, average measured soil loss = 3.47 kg m^{-2}, and average record length = 8.10 ± 3.71 yr.
‡ Range.

Table 6. Relative importance of Universal Soil Loss Equation parameters based on analysis of model efficiencies.

Parameter removed	Avg. value	Efficiency with avg. value	Lost efficiency†
		%	%
Erosion Index (EI) or rainfall and runoff factor (*R*)	178	0.59	0.15
Topographic factor (*LS*)	1.15	−0.01	0.75
Soil erodibility factor (*K*)	0.30	0.59	0.16
Cropping and management factor (*C*)	0.34	0.02	0.72
Support practice factor (*P*)	0.85	0.80	−0.05

† Loss in efficiency calculated by subtracting the model efficiency using the average value for the parameter from the maximum model efficiency for the data set of 74.5%.

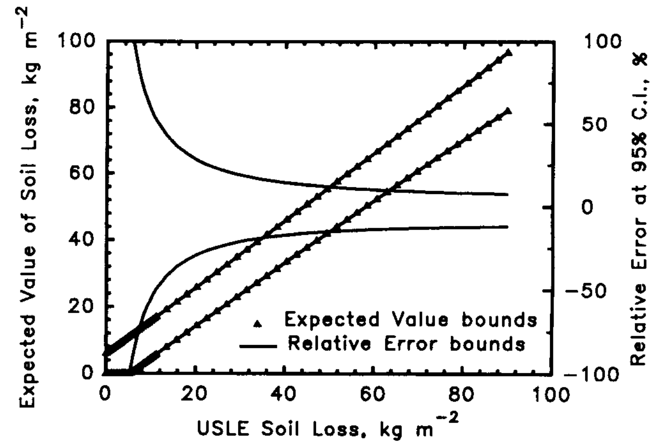

Fig. 4. Expected 95% confidence intervals and error percentage for Universal Soil Loss Equation predictions based on regression analysis of average annual data using calculated Erosion Index values for natural runoff-style plots.

of *R* values dropped the overall Nash–Sutcliffe model efficiency by only 0.02. The ratio *R*/EI = 1.08 indicates that, on the average, the *R* values were slightly higher than measured EI values. This resulted in a slightly lower average soil loss error; however, there was not a significant difference in the magnitude of error. This indicates that the use of *R* values is appropriate for using the USLE to estimate erosion for the locations used in this study.

When comparing measured and predicted values, Wischmeier and Smith (1978) stated that care must be taken to ensure that the duration is sufficient to account for cyclical effects and random fluctuations in uncontrolled variables whose effects are averaged in the USLE factor values. To investigate the effect of duration of record, the plots were divided into two groups. One had plots with <8 yr of records and the other had records >8 yr. The plots with longer records had an average error of approximately 0.30 kg m^{-2} less than those with shorter records when using either calculated EI values or *R* values. Ideally, a study such as this would only contain plots with durations of 22 yr or more; however, there is very little long-term soil loss data available. This is one limitation of the USLE. When it is used to make estimates of soil loss, the user must expect significant annual variations from the predicted values of soil loss.

Model efficiencies were also used to assess the approximate contribution of each USLE parameter to the total error in the USLE. To do this, average values were calculated for each of the variables in the USLE. Each variable was then removed one at a time and replaced by its average value. Estimated soil loss and model efficiencies were then calculated using the average and the remaining four parameters. The resulting model efficiency then represented the efficiency of the USLE if the one parameter in question were not included. Table 6 presents the loss of model efficiency due to the use of the average value instead of individual parameters for each USLE variable. The topographic factor and the cover and management factor were determined to be the two most important variables using this method, as the model efficiency was reduced to only −0.01 and 0.02, respectively, when average values were used for these variables. This indicates that more effort should be placed on determining these parameters as they will have a greater effect on the estimated soil loss. These factors were followed in importance by the soil erodibility factor, the rainfall and runoff factor, and finally the support practice factor. The *P* factor was shown to have very little influence (a gain of 5% in efficiency); however, it is interesting to note that the model efficiency actually improved when an average value of 0.85 was used on all of the plots.

Assessing the accuracy of any model involves determining how much confidence can be placed in the estimates from the model. This was accomplished by using the measured values and regression analysis to determine the upper and lower 95% confidence interval for each prediction in our data set. These results are depicted in Fig. 4. While these confidence intervals will only be applicable to average annual estimates using measured EI values on natural runoff-type plots, several general trends can be observed that will probably be applicable to other conditions. First of all, the confidence intervals show the overprediction at lower erosion rates and underprediction at higher rates. For a prediction of 3.0 kg m^{-2}, the expected values of actual soil loss range from 0.0 to 8.65 kg m^{-2}, with an average expected value of 2.69 kg m^{-2}. At the higher soil loss rates, the predicted values are greater than the expected values. A prediction of 75 kg m^{-2} actually corresponds to an expected soil loss value of 78 kg m^{-2}. Another interesting facet of the confidence interval is that the absolute range between the upper and lower 95% confidence interval does not increase rapidly. At soil loss predictions of 5 kg m^{-2}, the confidence interval goes from 0 to ≈10.8 kg m^{-2}. At predictions of 50 and 90 kg m^{-2}, this range has increased to 13.4 and 17.2 kg m^{-2}, respectfully. In terms of percentage of expected soil loss, these ranges are actually decreasing (Fig. 4). The error percentage, calculated by subtracting the predicted value from the expected value and dividing by the expected value, actually decreases at increasing values of soil loss. For soil loss predictions <5 kg m^{-2}, the observed soil loss could range ±100%, while at predictions >50 kg m^{-2} it should be within ±15% of the predicted value. In other words, accuracy in terms of the difference between the measured and observed data, is better at the higher erosion rates. Information such as this could be extremely useful when using the USLE in water quality models or in the process of estimating total soil loss for budgets in a given watershed or state.

CONCLUSIONS

1. The USLE applied to 208 natural runoff plots with an average record of 7.9 yr plot^{-1} had an average magnitude of error of 1.36 kg m^{-2} and a Nash–Sutcliffe model efficiency of 0.75 in terms of average annual predictions. Prediction of the 1638 individual annual erosion values had an average magnitude of error of 2.13 kg m^{-2} and a model efficiency of 0.58.
2. In general, the USLE tended to overpredict soil loss on the plots with lower erosion rates and underpredict soil loss on the plots with higher erosion rates.
3. The use of R factors determined from isoerodent maps instead of calculated EI values from measured precipitation resulted in a drop in model efficiency of 0.02 for the locations used in this study.
4. The cover and management and topographic factors had the most significant effect on the overall model efficiency. This indicates that most of the research emphasis should continue to be placed on these parameters.
5. The accuracy of the USLE predictions in terms of the difference between measured and predicted values was shown to improve with increasing values of total soil loss.

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