PLOTS FOR EVALUATING THE CATCHMENT CHARACTERISTICS AFFECTING SOIL LOSS

2 — Review of Plot Studies

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ABSTRACT

This review is based on 102 papers dealing with soil-loss plot studies. The reasons for having plots as the unit of experimentation are briefly discussed, and the use of plot studies to evaluate the factors affecting erosion are described. It was found that there was no standard design of plot equipment, and experimental design was usually inadequate for statistical examination of results. Consequently the results themselves are often unconvincing. The problems of extending data beyond the plots are discussed and the use of soil-loss equations described.

BACKGROUND

Fractional-acre plots have been used to study soil and water losses for fifty years. Since the first plots were established in the United States in 1917 (Mutchler, 1963), they have been widely used in erosion and run-off studies.

Lowdermilk (1931) searched the European literature from the 1950s for studies which attempted to evaluate the factors influencing soil loss and run-off. He found that where studies attempted to explain one catchment characteristic in terms of stream flow (itself the resultant of many factors) the results were invariably confused. "To avoid the perpetration of this type of confusion, experimentation was begun to isolate various factors at work, to measure their influences separately, and later to synthesize and trace the influences of these factors into larger . . . watersheds . . . The run-off plot was adopted in place of the watershed as a unit of experimentation. . . . " Since the 1930s the use of plot studies in hydrological research has been supported by a number of authors.

A basic premise of plot studies has been that, by locating plots in a similar environment, all variables can be controlled except the one to be studied (Van Doren and Bartelli, 1956). That is, if all

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factors except (say) vegetation are comparable, then the differences in soil loss and run-off can be attributed to the differences in vegetation. The validity of this and other assumptions, and the credence which can be placed in some of the results, have been discussed by the author in another paper (Hayward, 1967).

DESIGN OF SOIL-LOSS PLOTS

Of the papers covered in this review there were three-quarters as many plot designs as there were plot studies. Mutchler (1963) noted that the differences in design were due to the different requirements of each study and a lack of communication between workers.

Plot sizes ranged from an eight-square-foot laboratory plot (Duley, 1939), to slightly over a quarter of an acre (Van Doren, Stauffer and Kidder, 1950). The most common size was 1/40 to 1/50 acre. Plot lengths varied from six feet (Duley, 1939) to 272 ft (Wiltshire, 1947). Although his was not strictly a plot study, Meck (1949) used irrigation furrows on slopes of up to 900 ft in length.

Laboratory studies such as that of Duley (1939) and Zingg (1940), and lysimeter studies such as that of Lowdermilk and Sundling (1950) used plot areas ranging from 1/2,000 to 1/5,000 acre.

Studies which investigated soil loss from cropping systems used plots with areas of 1/20 to 1/80 acre. In general these plots were six, 10 or 12 ft wide and 35, 70 or 72.6 ft long. Width was often determined by drill size and tractor use within the plot. Length appears to have been determined by the recommended terrace interval for the district, or the available length of uniform slope.

Studies which investigated the influence of the vegetation factors on soil loss show a similar variety of design. Marston (1952) used four 1/40-acre plots and four 1/10-acre plots, while Dunford (1954) used 1/100-acre plots (6 ft 6 in.$\times$69 ft). Costin, Wimbush and Kerr (1960) used 1/750-acre plots (6 ft$\times$10 ft) and Soons (1967) used 1/1,000-acre plots (4 ft $7\frac{1}{2}$ in.$\times$9 ft). The New Zealand Forest Service plots in the Craigieburn Forest Park (Canterbury) are 4.84 ft$\times$10 ft (C. L. O'Loughlin, pers. comm.).

Details of plot design and construction have been given by Costin *et al.* (1960), Wiltshire (1947), Garcia, Hickey and Dortignac (1963), and Mutchler (1963). It appears that each author believed that his design was satisfactory for his purpose.

DESIGN OF EXPERIMENTS

Brandt (1941) discussed the design of plot experiments for measuring soil and water losses. He noted that "In addition to measuring the difference between two or more treatments . . . the experiment must furnish a criterion by which the degree of confidence that can be placed in the result may be judged. . . . For all designs, there are two requisites — replication and randomization. There are two purposes in replication, increasing precision and providing an estimate of error. There are other ways of increasing precision, . . . but no other way of providing an estimate of error. The sole purpose of randomization is to ensure that the estimate of error be valid."

From the literature available to the author it would appear that only four of 69 studies were designed along the lines suggested by Brandt. Meyer and Mannering (1961) investigated the effect of corn-stalk trash on soil and water losses. Each of the six treatments had two replicates, and the experiment was laid out on a randomized block design. Dunford (1954) investigated the influence of grazing intensity on soil and water losses and used two replicates of each treatment. Treatments were randomized within each block. A further 19 studies were replicated or partially replicated in their treatments, but apparently were not randomized.

Wischmeier, Smith and Uhland (1958) discussed the problem of bias likely to be associated with using data over short time periods. "[Bias] is usually minimized in good statistical designs by randomization, but in soil- and water-loss studies effective randomization over some of the extraneous variables may not be possible because of physical and economic limitations. For example, for soil-factor evaluation it would be difficult to find a range of major soil types within an area compact enough to have identical rainfall."

Because of the design of the experiments, there are a number of assumptions common to all studies. Firstly, it has been assumed that by siting plots on similar soils, slopes and aspects, the effect of all variables except the one studied will be insignificant. Differences in results can therefore be attributed to the differences in treatments. Similarly, it has been assumed that the data obtained from plot studies were unbiased, or that bias was negligible. The randomization of treatments in four studies removed some of the possible bias, but none of the studies reviewed considered the possibility of bias due to the presence of the plot. Finally, all studies assumed that plot results were applicable — to a greater or lesser degree — beyond the limits of the plot.

STATISTICAL ANALYSES

A distinction is made here between the "muddy boots" approach to soil-loss experiments and the analysis/synthesis approach. A "muddy boots" study is one in which the author obtains data from his own plots. Analysis/synthesis studies are those in which the author assembles and processes data from several studies. Of the "muddy boots" studies, 46 did not replicate or randomize treatments. Most authors, however, gave quantitative results or an assessment of the relative effectiveness of the treatments. The lack of proper design in these studies may mean that the results are either obscure or misleading (Brandt, 1941).

Not all the authors who replicated treatments statistically analysed the results. Many noted wide variation between replicates and meaned or totalled their treatment data. Garde and Van Doren (1949) found large variations between replicates and presented averaged data. Beale, Nutt and Peel (1955), Jones (1961), Logan (1960) and Cameron (1952) likewise presented meaned data.

Other authors, however, produced statistically significant results. Dunford (1954) was able to evaluate the effects of three simulated grazing intensities on soil and water losses. Precipitation and soil and water losses were measured from six plots before applying the three treatments (two replicates). Erosion losses from grassland ranged from 111 lb. to 163 lb. per acre. These differences were statistically insignificant. After treatment, soil losses per acre were 134 lb., 145 lb. and 316 lb. from no grazing, moderate grazing and heavy grazing respectively. Dunford found that significant increases in soil loss were obtained only from heavy grazing. He therefore concluded that moderate grazing was permissible on relatively gentle slopes.

Duley and Ackerman's 1934 study is worth noting because it was the first and still remains one of the few to analyse its results statistically. The authors investigated run-off and erosion from plots of different lengths, and found that run-off from short plots exceeded that from long plots on 96 occasions out of 114, but that there was greater erosion from long plots than from short plots on 61 occasions out of 114. The authors used Salmond's D/E ratio* and found values which indicated that the run-off results were not due to chance. It was therefore safe to conclude that short slopes would yield a larger percentage of run-off than long ones. However the erosion losses were less consistent, and the results did not appear to be statistically significant.

Meyer and Mannering (1961) reported results from their investigations into minimum tillage. They gave the significance of their results at one and five per cent levels. Similarly in their 1963 study the significance of treatment differences was reported at one and five per cent levels.

Throughout the United States data from many soil loss experiments have been accumulated at the Agricultural Research Service's Run-off and Soil Loss Data Centre at Purdue University. Up to

* Where D=standard deviation, and E=probable error.

10,000 plot-years of data have been assembled and analysed for the variables which are primarily responsible for the differences in soil loss and run-off from crop land. The data have also been tested for the mathematical relationships between these variables and surface run-off and soil loss (Wischmeier, 1966; Wischmeier, Smith and Uhland, 1958).

Regression analyses have been extensively used and several variables have been shown to have a close relation to soil and water loss; nevertheless such a relation does not imply a causal dependence of one factor on the other (Finney, 1965) and no statistical procedure can uncover the underlying laws governing run-off and soil loss until the basic physical relationships are better understood (Mustonen, 1967).

Some results from these studies will be mentioned later with respect to the universal soil-loss equation and the factors which influence soil loss. The principal authors in this field are W. H. Wischmeier and D. D. Smith.

FACTORS INFLUENCING SOIL LOSS

Influence of Plant Cover

Many authors have used plots to compare erosion and surface run-off losses under grass swards and other cultivated crops. For example Duley and Miller (quoted by Duley, 1952) used 1/80-acre plots to measure the effects of different crops and tillage practices on run-off and erosion. They estimated that it would take 3,550 years to erode the top seven inches of grass sward, but only 25–30 years to erode the top seven inches of bare or ploughed land.

Uhland (1935) noted that although the percentage of precipitation lost as run-off may be quite high under a grass sward, the amount of soil loss was usually low. J. R. Carreker in a submission to the Committee on Agricultural Hydrology (1948) supported this view when he stated that, while ground cover was important in reducing the amount of run-off, it was even more important in reducing the amount of soil loss. Many authors have emphasised this aspect of ground cover, among them Dickson (1929), Horner, McCall and Bell (1944), Marston (1952), Kittredge (1954), Costin, Wimbush and Kerr (1960), and Gilmore (1965).

Boost and Woodburn (1942) showed that where the surface soil was exposed to raindrop splash, soil particles became detached and were removed in run-off. However, where the soil was protected by a mulch suspended just above the surface the raindrop energy was dissipated before it struck the ground, and although there was little difference in run-off, there was a marked reduction in soil loss. From this the authors concluded that raindrop splash, not run-off, was responsible for soil loss.

Veihmeyer (1951) reported that when plant cover was destroyed by fire, maximum soil losses from the burned plots were 21 times those from unburned plots. However, he also noted that this difference represented only 0.0004 in. per plot. Lowdermilk (1930, 1931) reported that the destruction of forest litter increased soil losses from 50 to 6,000 times. He described cultivation without adequate precautions as "suicidal agriculture".

Influence of Cropping and Cultivation

Lowdermilk's concern for adequate precautions with cultivation has been shared by many authors who have investigated soil and water losses associated with cropping and cultivation. Moldenhauer and Wischmeier (1960) showed that contour cultivation, as opposed to up and down slope cultivation, reduced soil and water losses. Young, Mutchler and Wischmeier (1964) found that, regardless of slope, soil loss from all plots farmed across slope was 27% of the total for all plots farmed up and down slope. Even on a two per cent slope, Van Doren and Bartelli (1956) found that contour farming reduced soil loss to 0.52 of that from up and down slope cultivation.

A minimum number of tillage operations has also been shown to reduce soil loss (Meyer and Mannering, 1961), and if such operations left part of the crop residue on the surface of the soil, losses were substantially reduced (Neil, 1939; Beale *et al.*, 1955).

All authors who investigated soil losses from cropping systems reported benefits from longer rotations, regardless of soil type or slope. For instance, Whitaker, Jamison and Thornton (1961) found that soil loss from corn grown in rotation was only 60% of that from continuous corn. In Australia, Lamy (1949), Cameron (1952), Logan (1960) and Jones (1961) reported increased soil losses with shorter rotations. North American workers have found similar results, and Carreker (1946) noted that the influence of the rotation became greater as slope increased.

Several authors reported that cereals should be grown in rotation with a legume and/or grass (Carreker, 1946; Horner, 1960; Adams, Henderson and Smith, 1959) as these acted as a cover crop and protected the soil during the winter. It was also found that, even after the cover crops had been ploughed in, they continued to be beneficial (Woodburn, 1945; Neal, 1939; Duley, 1939; Brill and Neal, 1950; Beale *et al.*, 1955).

Jones (1961), and many other authors, reported that soil loss and run-off varied widely from year to year, and that this variation was often as great as, or greater than, the variation between treatments. However, seasonal losses within a year tended to follow a more regular pattern (Brill and Neal, 1950). Many authors could therefore identify the period of greatest hazard. Thus Brill and Neal (1950) found that in New Jersey, the greatest losses were likely to occur in the summer and early autumn. Horner, McCall and Bell (1944) found that in Washington, winter was the critical period. Lamy (1949) found that in New South Wales (Australia) the greatest losses occurred in the period from January to June, which was also the time when wheat fields were fallow and in a finely cultivated state prior to sowing. Consequently he advocated either a shorter fallow, or contour, and stubble-mulch farming.

Influence of Slope Steepness and Length

Gard and Van Doren (1949) reported that, while cropping was without doubt an important factor in soil loss, there were some situations in which slope factors dominated the erosion process.

The first studies on the effect of slope are attributed to F. O. Bartelli in 1927 (Duley and Ackerman, 1934), and these were followed by laboratory and field experiments by Duley and Hays in 1932. Neal (1937) used a constant-length laboratory plot which could be adjusted for degree of slope. By applying simulated rainfall to a "fallowed" surface, he found that soil losses varied as the 0.7 power of the degree of slope.

In 1940, Zingg analysed plot data for the influence of slope on soil loss. As the plots had not always been designed for slope studies, some adjustments to the data were necessary to enable comparisons to be made. The average of the adjusted data showed that doubling the degree of slope increased soil loss 2.8 times, and doubling the horizontal length of slope increased yield 3.03 times. Zingg then applied simulated rainfall to various degrees and lengths of slope. The averaged results showed that doubling the degree of slope increased soil loss 2.61 times, and doubling the horizontal length of slope increased loss by 3.03 times. From this he suggested that the influence of the slope factors could be expressed in the forms:

$$X = CS^m L^n$$

and

$$A = CS^m L^{n-1},$$

where X = total soil loss from land slope of unit width,
L = horizontal length of land slope,
S = degree of land slope,
C = constant of variation,
A = average soil loss per unit area from a land slope of unit width,
m = the exponent for degree of land slope,
n = the exponent for horizontal length of land slope.

For field conditions the relation of slope length and degree to soil loss could be expressed in the rational equation:

$$X = CS^{1.4} L^{1.6}.$$

Borst and Woodburn (1940), using artificial rainfall on fallow plots, reported a similar exponent for degree of slope of 1.3. Musgrave (1947) found exponents of 1.35 for degree of slope and 0.37 for length of slopes. Similar exponents were noted by Browning, Parish and Glass (1947). Van Doren and Bartelli (1956) found exponents of 1.45 and 1.53 for five and nine per cent slopes respectively, with an average of 1.5. Using plot lengths of 36, 70, 140 and 210 feet the same authors found that the exponent of horizontal slope length varied from 0.4211 on five per cent slopes, to 0.3499 on nine per cent slopes. The average was 0.38.

Smith and Wischmeier (quoted by Wischmeier, Smith and Uhland, 1958) analysed data from plots on slopes between three per cent and 22 per cent. They suggested that the data were more accurately fitted by a parabolic curve than by the exponential type. They presented the equation:

$$A = 0.43 + 0.30S + 0.04S^2,$$

where A = soil loss in tons per acre,
S = per cent slope.

Wischmeier, Smith and Uhland (1958) noted that "evaluation of the effect of per cent slope on soil loss was complicated by three major weaknesses in data: (a) the data are too limited, (b) the slope effect is frequently completely confounded with the effectiveness of contouring, which is itself believed to be a function of slope, and (c) with few exceptions the range of slopes included in an experiment was too small to give a good indication of the type of curve that would best describe the relationship". They also noted that the relation of slope factors to soil loss often varied more from year to year on the same plot than it varied between plots. In severe storms general trends were sometimes reversed. From an analysis of 15 sets of data from north-central, and north-eastern states the authors noted a "rather wide" variation in the slope-length exponents. However, these differences were not significant at the 10 per cent level and their weighted arithmetic mean was 0.46. They noted that a group meeting at Purdue in 1956 recommended a slope-length exponent of 0.5 ± 0.1, and this value of 0.46 was within these limits.

Barnett and Rogers (1966) carried out a simulated rainfall study, and tested 34 independent variables for their influence on soil loss. "The best predictive factor for soil loss per EI* was $(\text{slope})^{1.7}$, which explained 75 per cent of the variation per EI." (In this, as in all studies, slope was measured as a percentage.)

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* EI is the product of a rainstorm's total kinetic energy and its maximum 30-minute intensity.

A study by Meck (1949) is, however, at variance with the generally accepted findings. He investigated soil loss from row crops under irrigation, his plots being irrigation furrows rather than conventional run-off plots. From these he measured soil loss from lengths up to 900 ft. He found active erosion at the top end of the field, but no soil or water losses at the bottom. From this he concluded that — in this case at least — the conventional measure of soil loss in tons per acre from the bottom of the plot was of no value in determining erosion losses or soil movement on the field. Gard and Van Doren (1949) considered that the shape of the slope may be of greater importance than its length.

Influence of Rainfall Factors

Baver (1937) recognized intensity and amount as two of the important rainfall variables which affected soil loss, but the results from plot studies analysed for these two characteristics were very variable.

It has been established that high intensity storms tend to mask cultivation treatments (Moldenhauer and Wischmeier 1960) and that a few such storms cause a high proportion of the total soil loss (Brill and Neal, 1950). Lamb, Free and Wilson (1944) reported that over a $7\frac{2}{3}$-year study 13 per cent of the total number of rains which produced run-off caused 57 per cent of the total soil loss. Carreker (1954) found that soil loss between seasons varied from five to 51 tons per acre, and that this was caused by the number of erosive storms*, rather than the total volume of run-off. These storms accounted for 75 to 90 per cent of the total soil loss.

In an attempt to determine rainstorm characteristics which influenced soil loss, Wischmeier (1959) analysed 8,000 plot-years of data from 37 widely-scattered projects. From multiple regression analyses the variable EI was found to be the characteristic which gave the best indication of a storm's ability to erode soil. When EI values for storms greater than 0.5 in. were summed for each year, they explained 72–85 per cent of the yearly variation in soil losses for widely-separated localities.

Rogers, Barnett and Cobb (1964) investigated the influence of simulated rainfall and slope length, and their interactions on soil loss. A regression of soil loss on the product of rainfall intensity and amount explained 81 per cent of the variation in soil loss. However, the product of rainfall intensity $\times$ rainfall amount $\times$ $(\text{slope})^{0.7}$ explained 92 per cent of the variation. None of the chemical or physical soil characteristics measured were effective in explaining variation in either soil loss or run-off.

* An erosive storm was defined as one which removed more than 1,000 lb of soil per acre from continuous cotton.

Influence of Soil-Conservation Practices

One of the early problems facing the soil-conservation movement in the United States was that of evaluating the effectiveness of the proposed remedial measures.

Smith (1941) estimated that terracing in association with contour farming reduced soil loss to three per cent of that from up and down hill operations. Carreker (1946) reported that soil loss from plots on a seven per cent slope was in the order of 28 to 82 tons per acre per year. However, on an 11 per cent slope of half the length losses amounted to only 25 tons per acre per year. Consequently, the author recommended terrace intervals of 70 feet on a seven per cent slope, and 35 feet on an 11 per cent slope.

Soil ripping, which also breaks surface length and interrupts overland flow, has been shown to be effective in some situations. Dortignac and Hickey (1963) found that ripping reduced soil losses by up to 85 per cent and water losses by up to 96 per cent.

Strip cropping has been shown to reduce soil losses substantially. Losses from plots which were strip cropped were shown to be about half those from contoured plots (Van Doren and Bartelli 1956 — quoting work of Borst *et al.*, 1945; Smith *et al.*, 1945; Hays *et al.*, 1949).

Mannering and Meyer (1961) investigated the management of crop residues as a conservation practice. They showed that shredding cornstalks in the autumn and leaving the residue on the surface reduced winter soil losses by 50 per cent. Both Duley (1939) and Horner *et al.* (1944) recommended that after harvesting, crop residues be left on the soil surface to reduce soil losses in the winter and early spring. Taylor, Hays, Bay and Dixon (1964) noted that continuous corn yielded three bushels per acre more than corn grown in a three-year rotation. To avoid the soil losses associated with continuous cropping, the authors investigated mulching techniques and found that a mulch of corn stover and barnyard manure gave excellent control of soil and water losses.

A number of studies have accepted mulching as an effective technique but have been concerned with type and rates of mulch application. For example Swanson and Dedrick (1965) tested 19 mulch treatments for their ability to protect a soil surface against water erosion. They concluded that, on a pound for pound basis, prairie hay and wheat straw were comparable with and were more effective than woodchips. The most effective treatment was half a ton per acre of prairie hay anchored with one-sixteenth of a pint of asphalt emulsion per square yard. Similar studies have been reported by Swanson, Dedrick, Weakly and Haise (1965).

Influence of Soil Factors

Comparatively few plot studies have investigated the influence of soils, and soil factors, on erosion and run-off. Peel (1937) studied the physical characteristics of some soils, and concluded that their relative erodibility was indicated by such characteristics as percolation rate, suspension percentage, and dispersion ratio.

Van Doren and Bartelli (1956) deduced an erodibility rating for six Illinois soils. Their deduction involved adjusting soil-loss data from different studies for uniformity of slope length, cropping practice, rainfall intensity, and other factors. Similarly Barnett, Rogers, Holladay and Dooley (1965) found the relative erodibility of 13 soils in South Carolina and Georgia.

EROSION PROCESS

Lowdermilk and Sundling (1950) used lysimeters to study the formation and significance of an erosion pavement. They found that the erosion rate decreased throughout a simulated rainstorm as the finest particles were removed in surficial flow. Their removal led to the domination of the soil surface by larger particles, until ultimately an erosion pavement was formed. An analysis of the eroded material showed that it contained a greater proportion of fine material than did the original soil. Similar results were found by Swanson, Dedrick and Weakly (1965).

RELATED STUDIES

In addition to soil-loss and run-off studies, plots have been used in infiltration studies where the problems of experimental design and data analysis are similar.

Dortignac (1951) and Rowe (1940) noted that a reliable mean could be obtained from a minimum number of samples by sampling homogeneous infiltration/erosion strata. Within each stratum the random selection of plot sites gave a valid estimate of the experimental error. Dortignac (1951) considered the problem of bias from the Rocky Mountains infiltrometer and concluded that "variation due to vegetation and soil differences between any two adjacent infiltrometer positions can be expected to far exceed any errors due to the measuring apparatus."

EXTRAPOLATION BEYOND PLOT

Although most authors advised caution in extrapolating from plot results, they generally assumed that their data had an application beyond the plot — for instance most automatically converted soil loss per plot into soil loss per acre. While authors were usually cautious, a number had greater confidence in their results and suggested that they could be applied to greater or lesser amounts of the surrounding country.

Lamy (1949) quoted data from four storms on one 1/40-acre plot. He considered this data to be typical of all fallow plots in his study.

Date			*Points of Rain*	*lb. Soil/acre*	*% Run-off*
8.12.47	......	......	259	7,879	43
13.12.47	......	......	123	5,819	56
21.12.47	......	......	91	8,470	62

Cox (1950) quoted the same figures and noted that they " . . . were obtained as a result of research into run-off and soil loss at Wagga Soil Conservation Research Station, which is situated in the Riverena district of New South Wales (Australia). Results are therefore applicable to a large part of the southern wheat belt." Similarly Logan (1960) reported " . . . the results have been obtained from small plots, under specific land use treatments, and are on a single slope and soil type and consequently must be interpreted with these factors in mind. However, both the soils and slopes are typical of much of the Wellington district (New South Wales) and it is considered that the results are applicable over a fairly wide area."

Most North American workers on the other hand tend to support J. R. Carreker's submission to the Committee on Agricultural Hydrology (1948). In discussing a storm on 6 January 1946, he reported that the maximum rate of run-off from a 19.2-acre catchment was 2.3 inches per hour. Fractional-acre plots with similar slope cover and soil produced maximum run-off in excess of four inches per hour. Correker concluded " . . . we must admit there are a number of things we don't know concerning expansion of plot data on rainfall and run-off."

Many attempts have been made to relate plot data to field conditions through rational or empirical equations. Zingg (1940) analysed soil-loss data from several studies for the influence of degree and length of slope. As an expression of the effect of slope factors on soil loss he proposed the rational equation:

$$X = CS^{1.4}L^{1.6},$$

where X=total soil lost from a land slope of unit width,
S=degree of land slope,
L=horizontal length of land slope,
C=a constant of variation which combines the effect of weather, soil crops or rotation and treatment.

Zingg did not assume that the equation represented absolute values for any specific soil or condition. It was merely the average of the available data.

Musgrave (1947) suggested that soil loss could be predicted from the equation:

$$E = IRS^{1.35}L^{0.35}P_{30}^{1.75},$$

where E=soil loss in acre-inches,
I=inherent erodibility of soil in inches,
R=a cover factor,
S=degree of slope (per cent),
L=length of slope in feet,
P_{30}=maximum 30-minute rainfall amount for a two-year frequency, in inches.

Smith (1941) suggested that plot data could be applied to field conditions if they were modified by Woodruff's rational equation:

$$A = CS^{7/5}L^{3/5}.$$

where A = average soil loss in tons per acre per year and C, S and L represent the characteristics defined by Smith and Zingg. As the values of A, S and L are known for a given plot over a given time period, the value of C may be determined. "If the plots are operated up and down hill and the equation is to be used in making field applications involving mechanical practices (such as contouring, terracing, and strip cropping), a factor must be introduced into the equation to provide for the effect of these practices. If the soil loss with a given practice is expressed as A_1 then $A_1 = AP$ . . . " (where P = the conservation practice). Therefore:

$$A = A_1/P = CS^{7/5}L^{7/3}.$$

If the values of C, S, A and P are known, then maximum slope length can be determined by solving:

$$L = (A_1/PC)^{5/3}5^{7/3}.$$

Using this equation Browning, Parish and Glass (1947) attempted to extend plot data to soils which had not been studied. By incorporating a number of estimates in the equation they predicted soil losses for several Iowa soils.

Smith and Whitt (1948) used the equation:

$$A = C . S . L . K . P,$$

where A = average annual soil loss in tons per acre per year.
C = average annual related soil loss from plots in tons per acre per year.

S, L, K, and P are multipliers to adjust the plot soil loss (C) for per cent slope (S), length of slope (L), soil group (K), and conservation practice (P), when their field values are different from their plot values. The authors noted that if the equation were used in another climatic district a rainfall factor would have to be included. Values were provided for each factor on a Shelby soil so that probable field losses could be calculated from plot-loss data. The authors also reported that the equation had been used to calculated erosion losses in northern Missouri from storms in May and June of 1947. Calculated losses from cultivated land averaged 28 tons per acre. The results of a field survey indicated losses of 30 tons per acre.

Van Doren and Bartelli (1956) reported that the use of their equation made it possible to estimate soil loss quickly and accurately for almost any possible combination of conditions. Each factor known to influence erosion was given an erosion influence value which could be used in the equation:

$$A = (T.S.L.P.K.I.E.R.M.),$$

where A=annual estimated soil loss in tons per acre per year.
T=tons per acre of measured soil loss from soil type (considered unity) of given slope with known conservation practices and cropping pattern,
S=steepness of slope.
L=length of slope,
P=practice effectiveness (appropriate factor expressing effectiveness of the particular supporting practice under consideration in solving for A above),
K=soil erodibility,
I=intensity and frequency of 30-minute rainfall.
E=previous erosion,
R=rotation effectiveness,
M=management.

In 1961 W. H. Wischmeier proposed the Universal soil-loss equation (Olsen and Wischmeier, 1963):

$$A = R.K.L.S.C.P,$$

where A=soil loss in tons per acre.
R=rainfall-erosion index,
K=soil-erodibility factor.
LS=length and per cent slope factors.
C=cropping/management factor,
P=factor for special conservation practices.

A and K have dimensions of tons per acre while all other factors are dimensionless.

The relation between, and the values of, the factors in this equation have been reported by Smith and Wischmeier (1957), Wischmeier, Smith and Uhland (1958), Wischmeier (1959, 1960, 1966), and Olson and Wischmeier (1963). The application of the prediction equation to field conditions has been described by Springer, Breinig and Springer (1963) for Tennessee, Thoreson and Maddy (1963) for Iowa, and Longley and Bondy (1963) for Kansas. These descriptions note that the equation has been adapted to a slide-rule form to enable rapid computation of soil loss in the field.

"It must be recognised that this method [of predicting soil loss] is empirical and as such it is subject to the limitations of empirical relationships. It is the best approach now available for . . . [selecting the best cropping system, conservation practice or estimation of soil loss]. With added research and use, its accuracy can be improved." (Smith and Wischmeier, 1957).

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