The effect of rainfall factors and antecedent soil moisture on soil loss on a low-angled slope in a semi-arid climate

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Abstract

The influence of rainfall factors and antecedent soil moisture on soil loss on untilled pasture was investigated for a period of 4 years. This study seems to indicate that the EI_{30} variable of the universal soil-loss equation, as well as the Hudson index ($KE > 25$), are not appropriate measures for predicting soil loss from natural pasture in a semi-arid climate. Antecedent soil moisture, apparently, has litte or no relationship to soil loss under these conditions. Rainfall amount and the calculated variable of rainfall x rainfall intensity, seem to be better estimators of soil loss. This study also emphasised the importance of the plant canopy cover (or lack of it) on the rate of soil loss.

Introduction

Wischmeier (1959) found a high correlation between soil loss and the product of rainfall energy and the maximum 30 min rainfall intensity (EI_{30}) on fallow and row-cropped plots. This study was undertaken to investigate whether the same or some other relationship is applicable to natural grazing in a semi-arid climate. The possible importance of antecedent soil moisture on surface-wash erosion was another important consideration for initiating this study.

The area studied is near Bloemfontein in the Orange Free State (Fig. 1). Bedrock of this slope is mostly shale and siltstone of the Beaufort Group (Triassic) with some dolerite (Jurassic) at the top of the hillock (Fig. 2). The slope is covered by a sandy topsoil (Le Roux and Roos, 1983). For a semi-arid climate, the slope is well covered by vegetation, the ground cover being 27 per cent (Le Roux and Roos, 1982). The paddock enclosing the slope is well managed and no signs of accelerated erosion were detected. The profile of the slope and the position of the wash-traps are shown in Fig. 2. The average slope for the 10 wash-traps is 2,6 degrees, or 4,5 percentage grade.

The rainfall characteristics for the nearest station (Reddersburg) are shown in Fig. 3. The actual rainfall figures for the 4 years of this study are shown in Table 1.

Previous research

Only some of the more important studies relevant to the present research will be referred to. The development of soil-loss equations (for use on tilled soil), and employment of rainfall erosivity parameters date from the early forties. The first equation including a rainfall factor was the Musgrave equation of 1946 (Wischmeier and Smith, 1978). During the following years the universal soil-loss equation (USLE) was developed by scientists at the Runoff and Soil Loss Data Laboratory at Lafayette, Indiana (Smith and Wischmeier, 1962).

Wischmeier *et al.* (1958) developed a new rainfall parameter (EI_{30}) as a factor of erosivity for predicting soil loss. In this parameter the E value is calculated for all rainfall events of half an inch (12,5 mm) or more:

$$KE = 916 + 331 \log_{10} I$$

where I represents the intensity of a storm, expressed in inches per hour. Morgan (1986) changed this to (SI units):

$$KE = 11{,}87 + 8{,}73 \log_{10} I$$

where:
I is measured in $mm.h^{-1}$ and
kinetic energy is expressed in $J.m^{-2}\ mm^{-1}$.

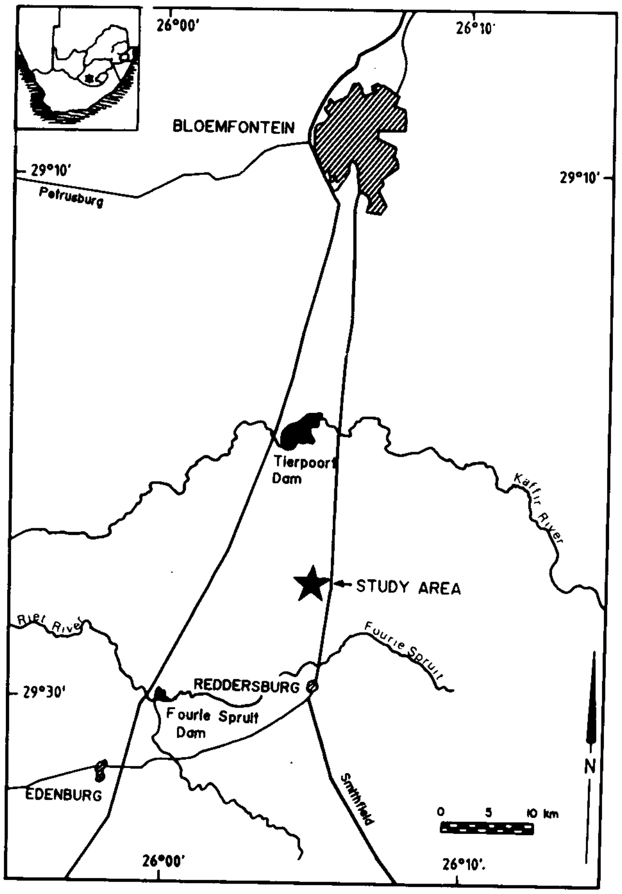

Figure 1
The location of the study area

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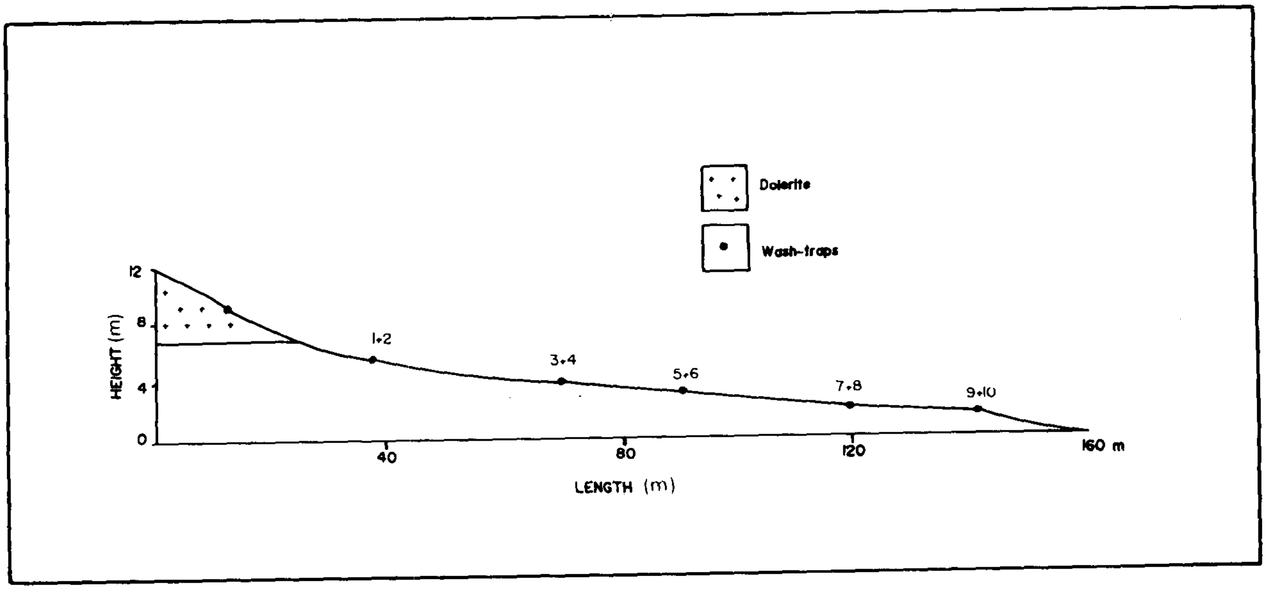

Figure 2
Profile of the slope and positions of the wash-traps

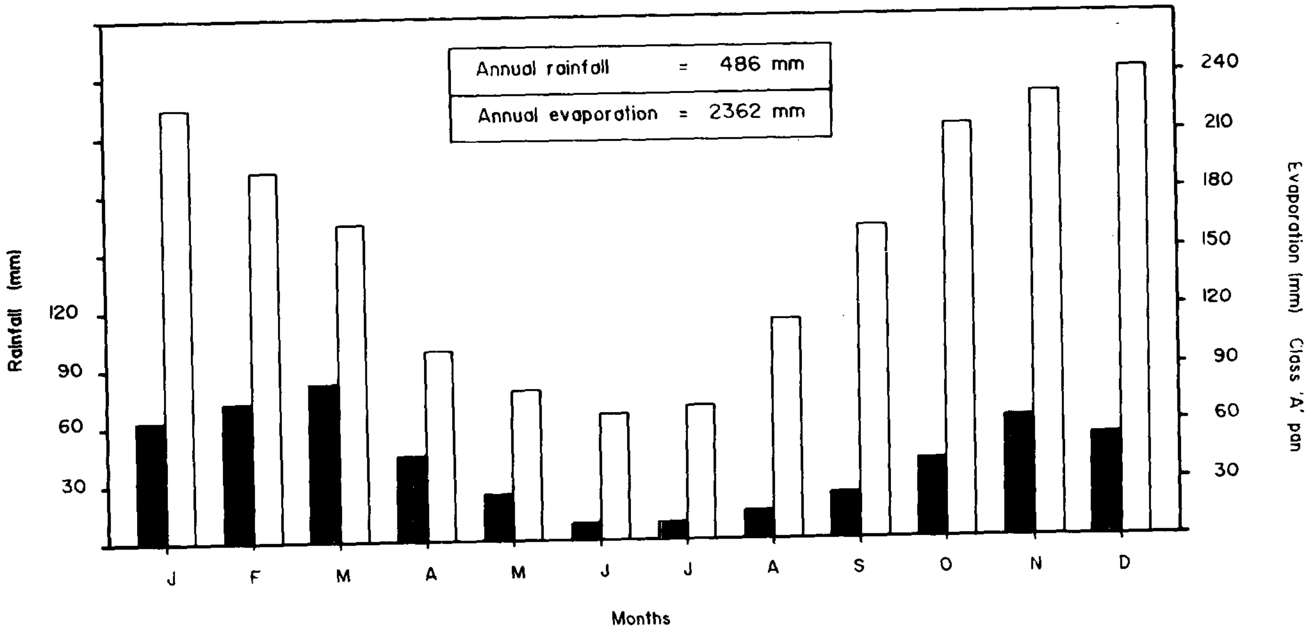

Figure 3
Rainfall characteristics of the area (Reddersburg)

Building on the exploratory work of 1958 (Wischmeier and Smith, 1958 and Wischmeier *et al.*, 1958), Wischmeier (1959) extended the data base to include 37 projects from 21 states in the USA. This work showed (for the USA) that rainfall amount is generally a poor predictor of soil loss and that the 30 min rainfall intensity (compared to the 5, 15 and 60 min intensities) correlated best with soil loss. The product term of storm energy multiplied by the 30 min maximum intensity (EI_{30}) proved to be the best indicator of soil loss from both tilled fallow and soil cultivated to grow crops of cotton, oats and maize. Correlations ranged from 0,84 to 0,98. This variable (EI_{30}) was subsequently employed as the R-factor in the USLE (Wischmeier, 1960).

Hudson (1971) found that his KE>25 variable, in which all storms of less than 25 $mm.h^{-1}$ are excluded, was a better predictor of soil loss than EI_{30} for tropical regions.

In a guide for conservation planning, Wischmeier and Smith (1978) pointed out that it is not possible to predict soil loss for specific storms due to the unpredictable fluctuations of secondary parameters.

The history of really getting to grips with rainfall erosion on a national scale in South Africa, is a short one. Smithen compiled an EI_{30}-map for South Africa in 1981 (McPhee and Smithen, 1984).

TABLE 1
TOTAL ANNUAL RAINFALL AND THE RATE OF SOIL LOSS FOR THE PERIOD OF THIS INVESTIGATION

	Year	Rainfall (mm)	Runoff events (Number)	Soil loss $t.ha^{-1}\ yr^{1}$
Year preceding	1981	549	-	-
Period of investi-gation	1982	609	15	0,26
	1983	323	8	0,10
	1984	359	9	0,15
	1985	574	10	0,41
	Average	466*	11	0,23

*Long-term average is 486 mm

TABLE 2
CORRELATIONS OF SOIL LOSS (y) WITH RAINFALL AMOUNT (P), EI_{30}, KE>25, ANTECEDENT SOIL MOISTURE (ASM), RAINFALL INTENSITY (I_{30}) AND A PRODUCT FACTOR OF P AND I_{30} ($P\ I_{30}$)

	P	EI_{30}	KE>25	ASM	I_{30}	PI_{30}
y	0,71	0,32	0,16	0,28	0,59	0,87
p*	0,00	0,02	0,16	0,04	0,00	0,00

*p = probability

Smithen and Schulze (1982) suggested that SI units be used for the EI_{30} variable and that the absolute values be multiplied by 10^{-3}. From this an iso-erodent map was compiled. They included all rainfall events exceeding 12,5 mm of rain, but only those less than 12,5 mm if 6,3 mm or more is recorded in 15 min. For the introduction of the USLE in South Africa (Crosby *et al.,* 1983) the EI_{30} variable was accepted as the predictor for rainfall erosion.

In all the articles quoted above, rainfall data were employed to predict soil losses from tilled soil. In a study of sediment losses from drainage basins in the USA, Langbein and Schumm (1958) found that erosion losses reached a maximum at a rainfall of 10 to 14 inches (254 to 356 mm) per annum. The decrease in sediment yield below 254 mm and above 356 mm was attributed to low runoff in the former and the increased vegetative cover in the latter case.

Research methods

Five pairs of wash-traps (300 mm wide) and somewhat modified from the instrument described by Gerlach (1967), were installed on the slope (Fig. 4). Rain wash and sediment were collected in 25 ℓ cans, and the volume of water and mass of dry sediment were determined in the laboratory on a weekly basis. A registering and check gauge were installed on the terrain. From the graphs on the recording gauge rainfall amounts and intensities were obtained. The former was checked against a non-registering gauge on the terrain. Intensities were calculated from the inclined traces of the curves on the recording charts.

Soil loss, the dependent variable, could be ascertained unambiguously for most rainfall events (87%) since more than one runoff producing storm per week was recorded only for five cases. In these cases total soil loss, total rainfall and the average maximum intensities (30 min) for the week were used.

Soil moisture was calculated from three samples of soil cores (r = 38 mm, l = 150 mm) taken weekly from regularly spaced sites on the slope. These were weighed and oven dried, and the loss of moisture was determined in the usual way. From these a graph of soil moisture against time was drawn. Moisture loss occurred at a decreasing rate over time and showed a typically reversed J-shaped curve i.e. asymptotic to the x-axis. Since the soil porosity was known (32,5%) the curves were adjusted according to the amounts of rain falling between runoff events and the empirically determined rate of moisture loss. The estimated percentage (mass) of soil moisture before each rainfall event was read off from the graph. Only one storm of less than 10 mm (7 mm) produced runoff and the soil moisture content varied between 1% (dry) and 26% (saturated).

The EI_{30} and KE>25 index of Hudson (1971) was calculated from the same energy values (see Morgan, 1986, p. 47), but intensities of less than 25 $mm.h^{-1}$ were excluded in the case of the Hudson index. Simple correlation and regression analyses of soil loss as dependent variable against various independants were then conducted.

Results

Table 2 gives the correlations of soil loss with certain rainfall variables and antecedent soil moisture. These correlations are based on 39 runoff events for the 4 years of this study. Three events (of the 42) were eliminated from this study because of the unavailability of rainfall intensity values due to a faulty recording rain gauge. Table 1 lists the rate of soil loss per year for the period of this investigation.

Discussion

Runoff producing amounts of rainfall correlated quite well with and "explained" (r^2x100) about 50% of the variance in soil loss. The EI_{30} variable, however, "explained" an unexpectedly low 10% of soil loss. This is attributed to two main factors. Firstly, rainfall is inversely correlated with rainfall intensity (Le Roux and Roos, 1986a). This is important since kinetic energy (E) in the EI_{30} factor is obtained indirectly, as previously indicated, from rainfall intensities. The second factor is that most of the rainfall energy is dissipated on the plant canopy and therefore of much less importance than surface flow.

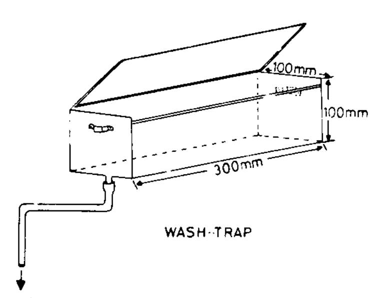

Figure 4
The wash-trap used in this study

The KE > 25 index is of no value as a predictor of soil loss in this region ($r^2 = 0,03$). The main reason for this is the 25 mm.h^{-1} cut-off point for rainfall intensity. Only 20% of the 39 rainfall events producing runoff occurred at intensities required by the Hudson index. The small number of events (9) also explains the high value of 0,16 for p(Table 2). Antecedent soil moisture correlates poorly (0,28) with soil loss. This is probably to be expected in a semi-arid climate where rainfall events are infrequent and rain usually falls on dry soil.

Rainfall intensity (maximum 30 min intensity, I_{30}) proved to be a better predictor of soil loss than expected in the light of the good ground cover. It is therefore not surprising that the product term of precipitation and intensity "explains" 76% of the soil loss. In the first instance this high correlation can be attributed to the fact that with higher rainfall more runoff is available to remove the usually dry, loose soil. With increasing intensity of rainfall, splash erosion is increased, and a further contributing factor may be the turbulence induced in the moving film of surface flow by falling rain drops.

Table 1 seems to indicate that soil loss and total annual rainfall did not correlate well. This aspect was discussed previously (Le Roux and Roos, 1986b) where it was pointed out that soil loss depended, to a certain extent, on the rainfall of the previous year. If the previous year received above average precipitation, soil loss diminished; the reversed being true following a dry year. This study began in 1982 after a year of above average rainfall (549 mm in 1981). Although 1982 had an exceptionally high rainfall (609 mm), soil loss did not increase as much as that shown in 1985, which had less rainfall but followed after two dry years. The 1985 year actually produced 60% more runoff sediment than the 1982 year which had a higher rainfall. More or less the same affect is apparently produced by different grazing practices. Du Plessis and Mostert (1965) found that for two similar runoff plots, under the same climatic and soil conditions as for the present study, but with moderate and heavy grazing (for 16 and 17 years respectively) the soil loss was 0,25 and 0,49 t.ha^{-1}yr^{-1}. On an ungrazed plot the soil loss diminished to 0,15 t.ha^{-1}yr^{-1}. These figures probably indicate the importance of plant canopy cover on the mechanics of soil erosion since the basal cover usually remains very much the same. In a rainfall simulation study on natural field conditions of varying canopy and basal cover Snyman and Van Rensburg (1987) found a dramatic increase with diminishing percentage of ground cover. Unfortunately the basal and canopy cover effects could not be distinguished since both varied sympathetically.

Conclusions

This investigation seems to indicate that the rainfall factor developed for the USLE and KE > 25 index are poor predictors of soil loss on well-managed natural grazing terrain in a semi-arid climate. Antecedent soil moisture is of little use as a variable to account for soil loss in this area. Runoff producing rainfall amounts and intensities correlate well with soil loss - the product term of these being a very good predictor.

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