14

Monitoring Erosion Using Microtopographic Features

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ABSTRACT

Experience has shown that rain erosion-induced microtopographic features can be grouped into seven types: original or resistant clods, eroding clods, flow paths, prerills, rills, depressions and possibly basal cover. The features represent the erosion that has occurred during a period previous to observation. Features are recorded per 25 cm on lines of 12.5 m along the contour. An indicator of erosion intensity can be derived from the erosion feature distribution. The indicator is calculated as the percentage of eroded clods plus two times the percentage prerill and rill area. It shows significant to highly significant correlation with measured soil loss. This opens up the possibility of evaluating cropping systems and conservation practices for their protective effect against erosion. The erosion intensity can be compared for sites that represent the situation with and without conservation practices. The method can be used to monitor the development of erosion during a rain shower, a rainy season, or a series of years by recording the presence of the features at time intervals. Case studies in Colombia, Nepal, Tanzania and Thailand demonstrate the use of the microtopographic features for monitoring erosion intensity.

MICROTOPOGRAPHIC FEATURES AND SOIL EROSION

Rainfall erosion leaves behind microtopographic features on the soil surface. The possibly bewildering variation in soil surface microrelief is often called "random roughness". However, careful study of the erosion-induced microrelief has led us to distinguish seven features of microtopography (Table 1). A detailed description can be found in Bergsma (2001). The distribution of these features changes as the erosion proceeds, and it can be monitored. The aim of the monitoring is not to estimate soil loss, but to register the erosion intensity under different cultivation systems in locally representative conditions.

The method, which has so far been applied in Thailand, Nepal, Colombia, Tanzania and the Netherlands for various cultivation systems, uses the accumulated effect of the rain erosion in an erosive period previous to observation as it is expressed in the microtopographic erosion features (Bergsma, 1992, 2001; Bergsma and Farshad, 2003).

Recording the different types of features allows the determination of an indicator, hereafter referred to as *erosion intensity indicator*. The method can be used equally well for fields of annual or perennial crops, forests, plantations and grassland.

Using the indicator of erosion intensity, different types of land use can be judged in a comparative way. In other words, the erosion hazard of cultivation systems can be compared. Thus, the recording of microtopographic features can give immediate information on the relative resistance to erosion of areas within a soil and water conservation (SWC) project, for instance those with different practices on otherwise comparable sites. Perhaps of greater practical importance for the evaluation of SWC projects is recording the features on comparable sites

Table 1 Microtopographic features used to describe the soil surface (abbreviations in parentheses are used in the following tables and figures).

Microtopographic feature	*Brief description*
Original or resistant clods (res)	Resistant forms and those created by recent tillage
Eroded clods or surfaces (ero)	Forms rounded by splash and disintegration
Flow paths or surfaces (flo)	Flat areas of shallow unconcentrated flow, often with braiding pattern of lag sediment
Prerills (pre)	Shallow channels of concentrated flow, up to 3-5 cm deep
Rills (ril)	Micro-channels deeper than prerills and up to 20 cm deep
Depressions (dep)	Small low areas, enclosed by clods
Vegetative matter (veg)	Basal cover of plants and litter

outside the project area, as this will give information about the difference between the situation with and without conservation.

RELATED STUDIES ON SOIL MICROTOPOGRAPHY AND EROSION

Several erosion studies have paid attention to soil microrelief and some researchers recognized components of the microrelief.

Merritt (1984) identified four stages of micro-rill development:

1. sheet flow
2. flow line development
3. micro-rills
4. micro-rills with headcuts

There appears to be some correlation of the stages of micro-rill development of Merritt with the microtopographic features used in the method presented here. Stages 1 and 2 of Merritt, the sheet flow and the flow line development, could correspond with the *flow areas* of the present method; stage 3 could correspond with the development of *prerills*. The headcuts of stage 4 may begin as cross-scarps in the bed of prerills, which then take part in the development of rills.

Auzet (2001) discusses parameters for erosion prediction that can be derived from soil surface characteristics: vegetation cover, stone cover, crust development and surface roughness. They were insufficient to describe the influence of soil surface structure and microrelief on total erosion. A conclusion is that lack of knowledge of erosion processes and their interactions could be partly compensated for by describing in a simple way the soil surface characteristics that relate to types of processes.

Comparing the soil surface characteristics of Auzet with the microtopographic features (Table 1), the *vegetative cover* could be partly similar to *basal cover*. *Stone cover* would be classified as *resistant clods*. *Crusts* would most often be *flow surfaces*. *Surface roughness* would not be random, but has proved to be composed of seven distinguishable components.

Unexpected results may be found by using the present method of microtopographic features. Mainam (1991) showed that contour bunds of medium height have more erosion than bunds of low height in an area in northern Thailand. The higher the bunds, the more erosion occurs by overflowing in the heavy rains. Van Dijk (2001) suggests there is a large influence of oriented roughness that results from tillage. Overland flow may be more frequent in cases where up-and–down-slope tillage has been practised, but it is more diffuse and less erosive than the concentrated flow resulting from the tillage that diverts flow sideways.

Poesen (1988) gave an overview of the mechanisms of incipient rilling and gullying in the Belgian loess region. It gave attention to the development of surface (and subsurface) erosion features, whereby one feature is often a stage in the development of another.

Stages of change of the soil surface structure as caused by rain have been observed by Valentin (1985). The area of observation was in Niger near Agadez, at the southern fringe of the Sahara. Three soils were involved in his study: a pebble-covered desert pavement, a sandy soil, and a clayey alluvial soil. Stages that were observed in the development of the soil surface topography are the following:

1. *Before the rain:* the clods have sharp edges.
2. *During the rain that is absorbed by the soil:* the shapes of the clods are cratered, grains are washed free, swelling takes place, and small particles are moved downwards.
3. *At the beginning of the overland flow:* clods have become smooth. When the soil becomes saturated some deposition at the foot of clods takes place, there is exposure of resistant parts; some flow paths develop.
4. *When there is overland flow:* the surface of the clods consists of micro-aggregates, slaked material, and crusts. Surface flow erodes the clods sideways, and remnants of crusts occur in deposits.

In the observations made by Valentin (1985) the clods with a sharp-edged shape observed before the rain are similar to *original or resistant clods* of the present method (Table 1). After the rain starts, initially clods with cratered shape occur, and at the beginning of overland flow clods have become smooth and resistant parts are exposed. These forms will correlate with *eroding clods* and some remaining *resistant clods*. In the presence of overland flow, lateral erosion of the clods occurs; this correlates with the formation of *flow paths*.

Imeson and Kwaad (1990) found periods to be distinguished in the evolution of the structural elements starting from freshly tilled topsoil:

1. A short period with freshly tilled soil.
2. A period in which rainfall-induced processes lead to stepwise degradation of soil structure and a stepwise decline of various soil physical processes.
3. A period in which a continuous crust is present at the soil surface and in which no further change in soil physical properties takes place, except by biological activity.

In a study by Andrieux et al. (2001) soil surface features were described by criteria that can be observed at the field scale. Relating the surface criteria of Andrieux et al. with the microtopographic features in the method presented here (Table 1), the *surface seal* would probably be a *flow surface*. *Roughness* does not correspond with any feature, because roughness is described by its component features in the present method. *Grass cover* and *crop residue* would be similar to *basal cover* in the present method. *Stones* would be classified as *resistant material*. *Topsoil structure* is not considered as such.

In other research on the influence of soil surface on erosion, the microrelief height distribution receives attention. It plays a role in studies of storage capacity and overland flow generation. In several cases, stereoscopic methods have been used (Borselli et al., 2001; Ciarletti et al., 2001; Farres and Merel, 2001; Farres and Poesen, 2001).

On a very detailed scale, surface relief has been recorded by laser scanning of soil surface profiles. Areas of a few square metres could thus be modelled very accurately in three dimensions (Huang et al., 1988). Applications were the determination of surface storage capacity and the connectivity of overland flow paths (Abedini et al., 1997). Improvements on the laser device completed in 2001 allow measurement of 0.5 x 4 m area in about 7.5 minutes with 0.5 mm accuracy (Darboux and Huang, 2003).

On equally detailed scale, digital photogrammetry has been used to study sediment transport (Stojic et al., 1998) or to construct an elevation model of the soil surface; a model of 8 sq m area can be made in 10 minutes (Wegmann et al., 2001).

Studies of the change in the soil surface microrelief during erosion conducted for instance by Jester et al. (2001) and Torri et al. (2001) show that the decay of surface relief that occurs in defined conditions of rainfall and soil wetness is associated with a tendency of roughness increase when channel flow occurs. Like Andrieux et al. (2001), these authors do not work with components of the roughness.

To be able to realistically conclude about flow depth and (micro)channel occurrence, one has to look at what really happens in the field (Jetten, 2001). The method presented here uses direct field observation of the three-dimensional components of the microtopography and field stereophotos for reporting purposes.

Assessment of current erosion damage (Herweg, 1996) describes eroded parts of fields with their land use and management, seen in the local erosion toposequence. Five general microrelief classes are used, going from fresh clods to a smooth surface.

The *Handbook for Field Assessment of Land Degradation* (Stocking and Murnaghan, 2001) uses field indicators of erosion to derive an estimate of soil loss. Three indicators are related to the general surface microtopography of fields: pedestals, armour layer, and rock exposure. *The Handbook* stresses the viewpoint of the land user and the socio-economic-political conditions in which the land user has to work.

Table 2 shows a brief comparison of these two methods and the method using soil surface topography.

METHOD OF RECORDING FEATURES

In a field to be studied, the general eroded part indicates the place of highest erosion hazard. There, a measuring tape (of, for instance, 2.5 m length) is stretched along the contour, so that the features made by flow are met across the tape during recording. The tape has alternate coloured intervals of 25 cm. For each interval the dominant microtopographic feature type is recorded. The recording uses 50 intervals, following a contour line. Each tape interval represents 2% of the area and the percentage distribution of the seven features is determined. The procedure is repeated twice along parallel lines, situated at one or two metres above or below the first observation line.

The procedure is not difficult to learn and does not take much time to apply. A short video shows the recognition of the features under natural rainfall (Bergsma, 2003). In a case of erosion plots bordering each other, up to 24 records have been made in one day. It is more efficient and

Table 2 Characteristics of three methods of monitoring land degradation.

Assessment of current erosion damage	*Microtopographic erosion features*	*Field assessment of land degradation*
The method estimates soil loss from recent storms by rill volumes, as a part of the site description. It is not a means of predicting soil loss. Site description is repeated at intervals of one or more years to monitor erosion damage.	Microtopographic erosion features are recorded along the contour. An indicator of erosion intensity is derived, which correlates with measured soil loss. A comparison of erosion intensity can be made for sites of different land use or conservation practices.	It aims to identify underlying causes and effect of conservation and rehabilitation on land of individual users. The degree of erosion is derived from various estimators of soil loss and expressed in t/ha.
It is not a method for assessing the general status of land degradation	It is not a method for assessing the general status of land degradation or soil loss in t/ha.	*The Handbook* gives guidelines to assess land degradation, its causes and fitting remedies.

Fig. 1 Measuring tape with coloured intervals of 25 cm, stretched along the contour for recording microtopographic erosion features; the site is a maize stubble field on loess, in Zuid Limburg, the Netherlands.

stimulating to have a team of two persons in the field. The feature recording can be done on any type of land use, be it annual or perennial crops, grassland, forest, orchard or plantation. The method was used in several doctoral studies (Turkelboom, 1999: 87-90; de Bie, 2000: 143-164).

INDEX OF EROSION INTENSITY DERIVED FROM THE MICROTOPOGRAPHIC FEATURES

A record of the different types of microtopographic erosion features allows the determination of an indicator of erosion intensity. Using this indicator, the intensity of erosion of different types of land use and cultivation systems can be compared. The indicator of the erosion intensity is derived from the most serious erosion features, which are rills, prerills and flow paths. The indicator is calculated as the percentage flow area plus two times the percentage prerill and rill area. The unequal weight allotted to features tries to represent the relative importance of the features in the erosion process that causes soil loss.

The indicator values appeared to correlate with measured soil loss in previous research cases (Table 3 and Bergsma, 2001).

Table 3 Measured soil loss and erosion intensity derived from microtopographic features.

Location and date	*Number of erosion plots, as treatments × replications*	*Spearman rank correlation coefficient*		
		All individual plots	*Number of plots excluded †*	*Plots grouped per treatment*
Chiang Dao, Thailand, August 1994	5 × 4 and 2 × 1	0.39	3: 0.76*** 4: 0.79***	0.69 † 1 treatment: 0.85*
Doi Tung, Thailand, July 1997	5 × 4 and 3 × 1 of which 8 plots studied	0.59	1: 0.84*	0.90** † 1 treatment: 0.94**

*** = significance level of 0.001
** = significance level of 0.01
* = significance level of 0.05

† = excluded for reasons of faulty plot management, deposition within plot, and one derived but unlikely extreme erosion intensity in 1997

The comparison of the measured soil loss and the indicator of erosion intensity has led at times to recognition of faulty soil loss measurements as well as faulty feature observations.

The feature method is not meant to detect erosion-governing factors with the aim that a (better) prediction of soil loss may be attempted. The feature method aims at a comparison of the actually observed erosion intensities that are characteristic of local land use types. It provides a comparison about the relative resistance to erosion of these land use types. This in turn will support the evaluation of SWC projects. Rural extension workers and land use planning officers can benefit from these elementary data for their recommendation of certain cultivation practices.

EXAMPLE OF MONITORING EROSION TO EVALUATE THE EFFECT OF CULTIVATION PRACTICES

In an area of about 30 km^2 near the village of Lom Kao, north of the city of Phetchabun, Thailand, the erosion development in five major land use types was monitored using microtopographic features over a period of two months, starting roughly at the beginning of the rainy season. The sites were comparable in rainfall erosivity, general topography and soil (Table 4; basic data from Woldu, 1998).

The microtopographic erosion features were recorded with repetitions situated in the upper, middle and lower part of the field. Records of features were made after each rain in June and July, and once in August. The last record had only two repetitions, both made in the middle part of the field with one metre between the lines. These records of feature distribution are shown in Fig. 2. This pattern of change in

Table 4 Characteristics of five fields near Lom Kao, Thailand.

Field code	*Location*	*Parent material, soil, position, steepness*	*Cultivation system (the critical factor for erosion intensity is in italics)*
1A	Hill-land, 2 km E of Lom Kao.	Parent material: Shale. Soil: fine silty over skeletal Typic Paleustults and Typic Haplustults (association), moderately deep to deep, well drained, Ap coarse strong subangular blocky, pH 4, CL over B-horizon, pH 3.5, C. Position: straight mid-slope. Steepness: 28%.	Four years fallow after forest, now one-year-old mixed orchard with tamarind, spacing 6 m × 6 m (some 8 m × 8 m), tillage once by tractor, up and down slope, weeding by tractor *only around trees, elsewhere weeds and rough soil surface*.
1B		Parent material: Shale. Soil: Lithic Ustorthents, Ap and part of B lost by erosion, topsoil gravelly silty clay, bedrock here at 20 cm, at 50-60 cm elsewhere. Position: straight mid-slope. Steepness: 26%.	20 years maize cultivation, then five years fallow, now ploughed for tamarind planting, up and down the slope; there is high soil animal activity and *weed growth*.
2	Hill in Piedmont, 12 km N of Lom Kao, 1 km NW of Ban Kok Kathon.	Parent material: Andesite. Soil: Pachic Haplustolls, moderately deep to deep, moderately well drained, Ap Silty clay, 0-2% gravel, weak fine to medium subangular blocky, pH 7.5. Position: straight mid-slope. Steepness: 28%.	Maize, tillage once by tractor, up and down slope, plants in rows along contour till 20° off, spacing 40-50 cm between plants, 50-80 cm between rows, 5-9 plants per m^2, *some empty spaces*, germination uneven because of lack of moisture and poor seed, weeding once when plants are at knee height, 150 kg NPK applied half at planting and half after weeding.

(Table 4 Contd.)

(Table 4 Contd.)

3 A	Hill in northern Piedmont, 14 km N of Lom Kao, 1.6 km N of Ban Kok Kathon.	Parent material: Andesite. Soil: Ustic Dystropepts (eroded), Ap 10-15 cm, pH 6.0, profile is moderately deep, well drained, topsoil clayloam, 'cloddy' strong medium subangular blocky over B, clay. Position: straight mid-slope. Steepness: 32%.	Maize, tillage by heavy tractor, one time, up and down slope, crop residue hinders ploughing and *is removed* beforehand, seedbed preparation and weeding by hoe, plants in rows roughly along the contour, rows spaced 70-85 cm, plants spaced 35-60 cm, on average 9 plants per m^2, germination uniform, stand denser than at Site 2, fertilizer applied at planting and when plants are at knee height.
3 B		Parent material: Sandstone. Soil: Kanhaplic Haplustults, Ap 15 cm, topsoil sandy clayloam, fine and loose topsoil structure, strong medium subangular blocky. Position: straight mid-slope. Steepness: 28%.	Sweet potato, tillage by heavy tractor along the contour, plants spaced 15-20 cm on convex ridges made by tractor, spaced 125 cm, 60 cm high, *running down the slope*, soil was pulverized by plowing and ridge making (over-worked), lowering the grade of soil structure.

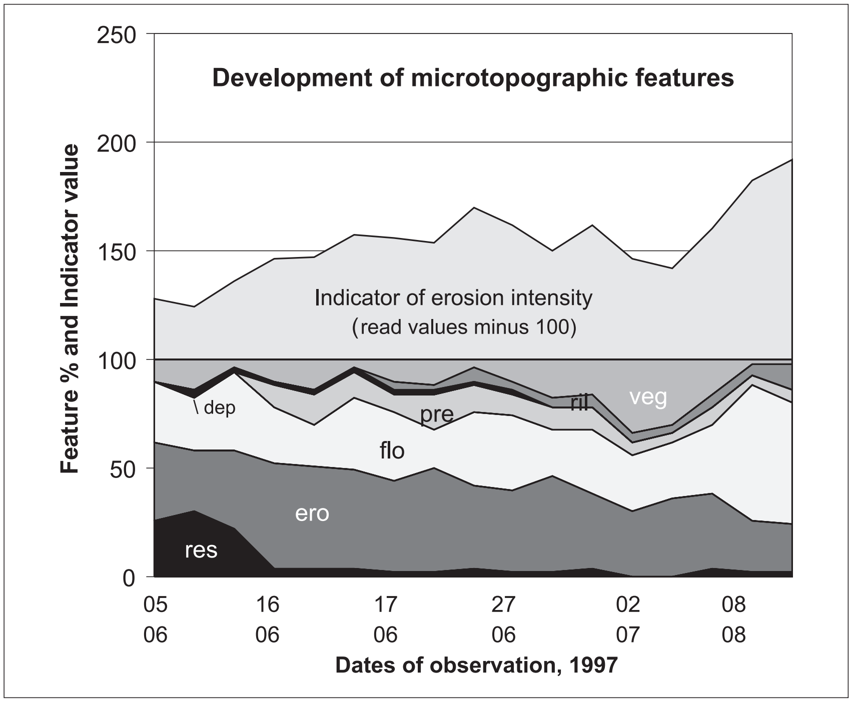

Fig. 2 Microtopographic features during a two-month period (Site 2, Woldu 1998). Recording is repeated two times in August and three times at other dates. See Table 1 for abbreviations.

microtopographic features under successive rains is often found in the development of erosion over time.

On Site 2, the *area of flow paths* remains rather constant during the first five rains but increases strongly in August after harvest and the removal of residue. *Prerills* start after the second rain, and their importance remains rather constant till July, when basal cover increases. *Rills* occur after the third rain. They continue to cover a small part of the area and increase in August after basal cover disappears. The *basal cover* provided by the crop and the weeds remains low and constant during four rains. It increases in July because of crop residue and weed growth. It disappears after burning in August.

Table 5 shows percentage cover by features on two dates. On July 2 much basal vegetation exists on some of the five fields. A month later the fields have less basal cover, harvest has taken place, residues have been burned or have rotted, and land preparation by tillage has turned residues

Table 5 Relative erosion intensity on 2 July 1997 and 8 August 1997.

Field	*Features on 2 July 1997*							*Indicator of erosion intensity*	
	res	*ero*	*flo*	*pre*	*ril*	*dep*	*veg*	*Value*	*Rank*
1A	4	40	20	1	2	1	32	26	1
1B	0	39	21	4	0	1	35	29	1
2	3	38	28	10	5	1	15	58	3
3A	1	39	24	19	15	0	2	92	4
3B	3	69	2	7	18	0	1	52	2
Field	*Features on 8 August 1997*							*Indicator of erosion intensity*	
	res	*ero*	*flo*	*pre*	*ril*	*dep*	*veg*	*Rank*	*Order*
1A	3	24	31	18	-	-	22	67	1
1B	2	13	61	20	-	-	4	101	4
2	2	23	59	14	-	-	2	87	3
3A	5	18	49	25	3	-	-	105	4
3B	2	40	36	1	21	-	-	80	2

under. Field 1B has a relatively stronger increase in erosion intensity between the two dates. This reflects the different influence of the crop growth and the post-harvest situation.

Field 3A of maize is 4-6% steeper than other sites. At the later date a number of rills has changed into prerills under the influence of splash in the uncovered stage. The sweet potato field 3B has cultivation ridges and furrows that run down the slope but are not formed by erosion.

The data of all five fields studied by Woldu (1998) show a tendency of three stages in the development of erosion that has been found generally in our studies and that was also noticed by Valentin (1985) in the soil surface relief. There is a first stage of rapid change, a second stage of rather constant feature distribution, and a last stage of rapid change again.

In the case of Site 2 of Woldu, the transitions are around the dates of 16/6 and 2/7. The three phases can be seen in Figs. 2 and 3.

Development of Microtopographic Features and Final Erosion Intensity

Erosion intensity derived from microtopographic features was studied on 22 fields in the area of Kao Khor, Thailand (Mainam, 1991) for various site conditions and crop management practices. It was found that the development of microtopographic erosion features during the observation period has characteristics that allow prediction of the final

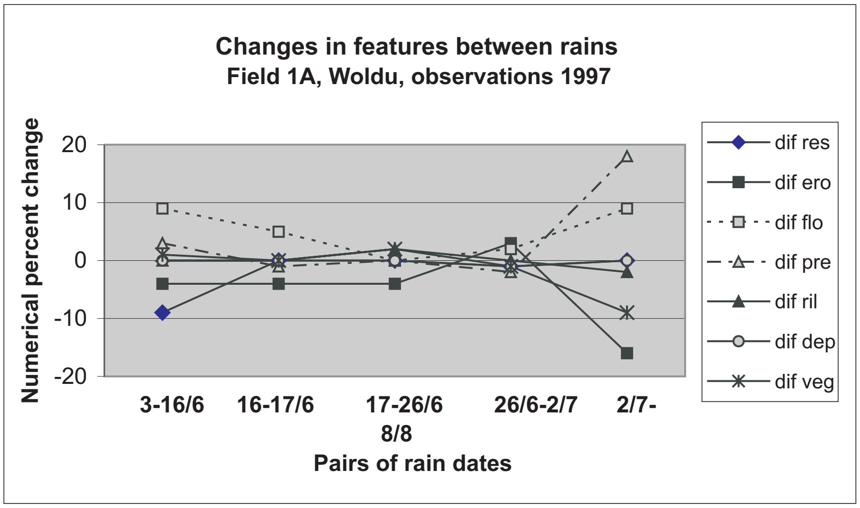

Fig. 3 Example of three phases in erosion feature development.

Table 6 Correlation between the development of certain microtopographic features and the erosion intensity at the end of the observation period, 29/4-24/5, 1990 (data of Mainam, 1991).

	Duration of fall in res	*Amount of fall in ero*	*Duration of rise of ril*	*Period up to rill formation*	*Period up to pre/rill formation*
Rs	0.76	0.71	0.82	0.86	0.91
t value	5.2	4.5	6.3	7.7	9.8
Sign. level	0.0005	0.0005	0.0005	0.0005	0.0005

Duration and Period are expressed in number of rains
Rs = Spearman rank correlation coefficient
t-value = Student's *t*
Sign. level = Statistical significance level
res = resistant/ original clods pre = prerills
ero = eroding clods and surfaces ril = rills

erosion intensity. Table 6 shows correlations between the Erosion Intensity Indicator on the final date of observation and the development of certain microtopographic features up to that date. Such a correlation holds for the period of crop influence. In the post-harvest stage, other large changes in erosion features may occur, such as are shown by field 1B (Table 5).

The length of period up to rill development. This characteristic of erosion development has the great advantage that it is rather simple to use as an indicator in the field. The start of rill formation is easier to observe than the continuation of an increase in rill area. Correlation with the final erosion intensity was high.

Period up to pre/rill formation. The period up to prerill and rill formation shows a stronger correlation with the final erosion intensity than rill formation alone. It is, however, less easy to apply and carries greater risk of subjective judgement. The period, as always measured by the number of rainstorms, ends when prerills start to form, or when there is a rise in prerill formation that is distinct from a previous constant level. Rills usually form later than the prerills.

The use of a single microtopographic feature will be practical in some cases, but the erosion intensity index gives a more comprehensive measure of erosion resulting from a previous period.

ACCURACY OF MEASURED SOIL LOSS AND PRECISION OF THE INDICATOR OF EROSION INTENSITY

At some erosion stations, the eroded bedload is kept in the collector furrow while the suspended load overflows a barrier and is allowed to pass. Bedload is measured on a hand-held balance that has for instance a 9 kg maximum load. A correction is made for the moisture content. This method is judged to be more accurate than sampling from a barrel that has received the sediment, because after stirring the water and sediment, the sand-size particles will settle too quickly to be represented well in a sample taken from the barrel. Zöbisch et al. (1996) stress the influence of the sampling procedure on the accuracy of soil loss data using barrels. In an experiment with five operators who sampled the same eroded volume, only three results agreed with each other within acceptable limits.

In the recommended procedure, there are three replications, made on lines one or two metres apart. A difference between the three feature records is caused by the natural variation of erosion in the field and an amount of error in the recording. To obtain an estimate of the error in the recording of the features, 10 repetitions of 50 feature readings were made on the same observation line of 12.5 m. The site was an arable field with maize stubble (autumn, 1998), in a loess region in Zuid Limburg, the Netherlands. It was concluded that recording the erosion-induced microtopographic features needs prior practice to rehearse the application of the details of their classification criteria. And from the data of the experiment a maximum observation error of 5 was found in the value of the erosion intensity indicator, average of three repetitions.

CONCLUSIONS

The following conclusions can be drawn from the present study:

- Erosion-induced microtopographic features show the accumulated effect of erosion over a period since the previous management of the entire soil surface. An erosion intensity indicator can be derived from the recorded features. In this way the erosion intensity on various sites can be compared. The comparison can be made for a certain moment or through monitoring the erosion development by repeated observations.
- In conservation planning, the use of the erosion intensity indicator is a rapid and simple way to compare the effect of land use systems. Their comparative erosion hazard can thus be judged. In a SWC project, partial areas may be compared as in a lay-out of alternative practices. The effect of a project as a whole may be judged from recording the features on comparable sites outside the project area as this will give information about the difference between the with-project and without-project situations.
- For practical purposes, the expected relative erosion intensity under land use types is indicated by the delay in rill development from the start of a rainy season or seeding time. The delay is expressed in the number of showers.
- In trying to characterize the expected erosion of an arable land use system by the development of microtopographic features, it is important to be aware of three stages in the development of the features, namely large changes in the microtopography after land preparation, minor changes during crop maturing, and large changes after harvest.

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