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Soil loss by rainwash: a case study from Rwanda

by

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with 13 figures

Zusammenfassung. Es besteht eine gewisse Kontroverse über die Bedeutung des Erosionsproblems in Rwanda. Unsere Daten, die über eine Zeit von 10 Jahren am Rwaza-Hügel (Runyinya-Butare) gesammelt wurden, unterstützen die Ansicht, daß die Erosion durch Abspülung sehr aktiv ist. Insbesondere kultivierte Parzellen erfahren einen sehr bedeutsamen Bodenverlust, der hier auf ungefähr 120 Tonne/ha/Jahr bei einem konvexen Hangelement von 11° bis 22° geschätzt wird. Die Messungen an Erosionspflöcken und Daten von Auffangwannnen zeigen:
- eine enge Beziehung zwischen Bodenverlust und Landnutzung;
- eine saisonale Änderung der Bodenverlustraten;
- eine Beziehung zwischen dem räumlichen Erosionsmuster und der Hangform;
- eine zyklische Variation von Kolluvien und Abtragung in hangabwärtiger Richtung;
- ein proportional weniger bedeutender Abspülungseffekt bei größeren Niederschlägen;
- die Bedeutung des Niederschlagregimes in Hinsicht auf die Abspülung.

Summary. A certain controversy exists about the seriousness of the erosion problem in Rwanda. Our data, collected over a period of 10 years at Rwaza hill (Runyinya-Butare) support the opinion that erosion by rainwash is very active. Especially cultivated fields undergo very considerable soil loss, estimated here at about 120 tons/ha/year on a convex slope element of 11° to 22°. Erosion pin measurements and data from collector trenches show:
- a close relationship between soil use and soil loss;
- a seasonal variation in soil loss rates;
- a relationship between spatial erosion pattern and slope configuration;
- a cyclic variation of colluviation and erosion in downslope direction;
- a proportionally less important rainwash erosion effect for bigger rains;
- the significance of the pluvial regime in terms of rainwash erosion.

Résumé. Une controverse existe quant à la gravité de l'érosion au Rwanda. Nos. données, collectées durant 10 années sur la colline de Rwaza (Runyinya-Butare) confirment l'opinion que l'érosion par ruissellement est très importante. Ce sont surtout les champs cultivés qui subissent une perte en terre considérable, estimée ici à environ 120 tonnes/ha/an. Il s'agit d'un élément de pente convexe dont l'inclinaison va de 11° à 22°.

Des mesures sur des pieux d'érosion et dans des fossés collecteurs montrent:
- un rapport étroit entre l'usage du sol et les pertes en terre;
- une variation saisonnière de la vitesse des pertes;
- un rapport entre la distribution spatiale de l'érosion et la configuration de la pente;
- une alternance cyclique de l'intensité de l'érosion du haut vers le bas de la pente;
- un effet érosif proportionnellement moins important lors des grandes pluies;
- le rôle du régime pluvial en ce qui concerne l'érosion par ruissellement.

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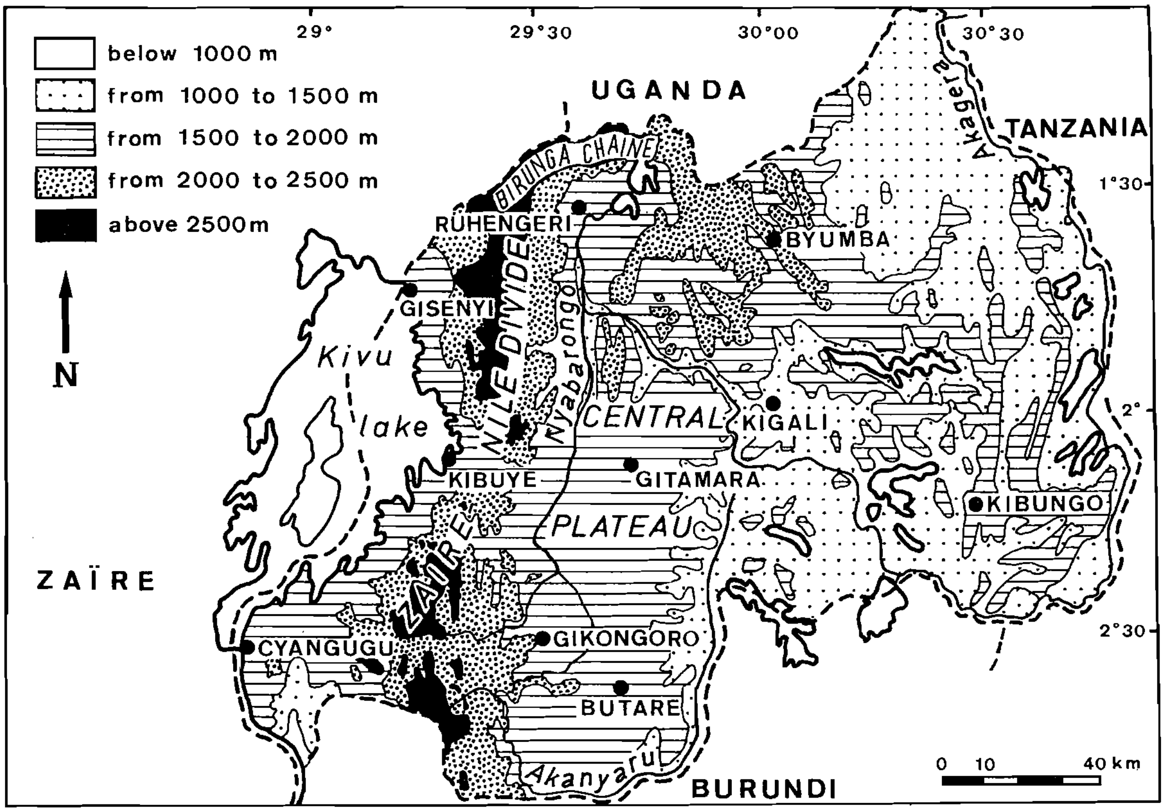

Fig. 1. Topographical map of Rwanda.

1 *Introduction*

Rwanda is a hilly country, situated in Central Africa at the estern border of Lake Kivu at a latitude of 2° South. Its altitude varies between 1,000 m and more than 2,500 m (fig. 1). The substrate is mainly composed out of quartzitic and phyllitic precambrian rocks, overlain by different types of ferrallitic soils. Annual precipitation increases from about 800 mm in the East to over 2,000 m min the West. The economy of the country relies greatly on the self sufficiency in food production by agricultural activities. The demographic explosion, with an annual increase of the population by over 3% has forced people to reclame the whole territory, including hill sides often steeper than 25°.

Many researchers in Rwanda are convinced that rainwash reduces the extension of the humic top soil at an alarming rate. This horizon constitutes the only fertile element of the sometimes deeply weathered kaolinic soils. So, rainwash might partly explain the actually observed decline in productivity. It is true that at the end of the big rainy season, lasting from January to June, rills, gullies and hydraulic steps can be seen on many places. But quantitative data on soil loss by wash are very scarce and not always in agreement. This study deals with quantitative soil loss data from Rwaza hill in Southern Rwanda. They were collected between 1977 and 1988. They reveal a number of correlations with precipitation characteristics and soil use.

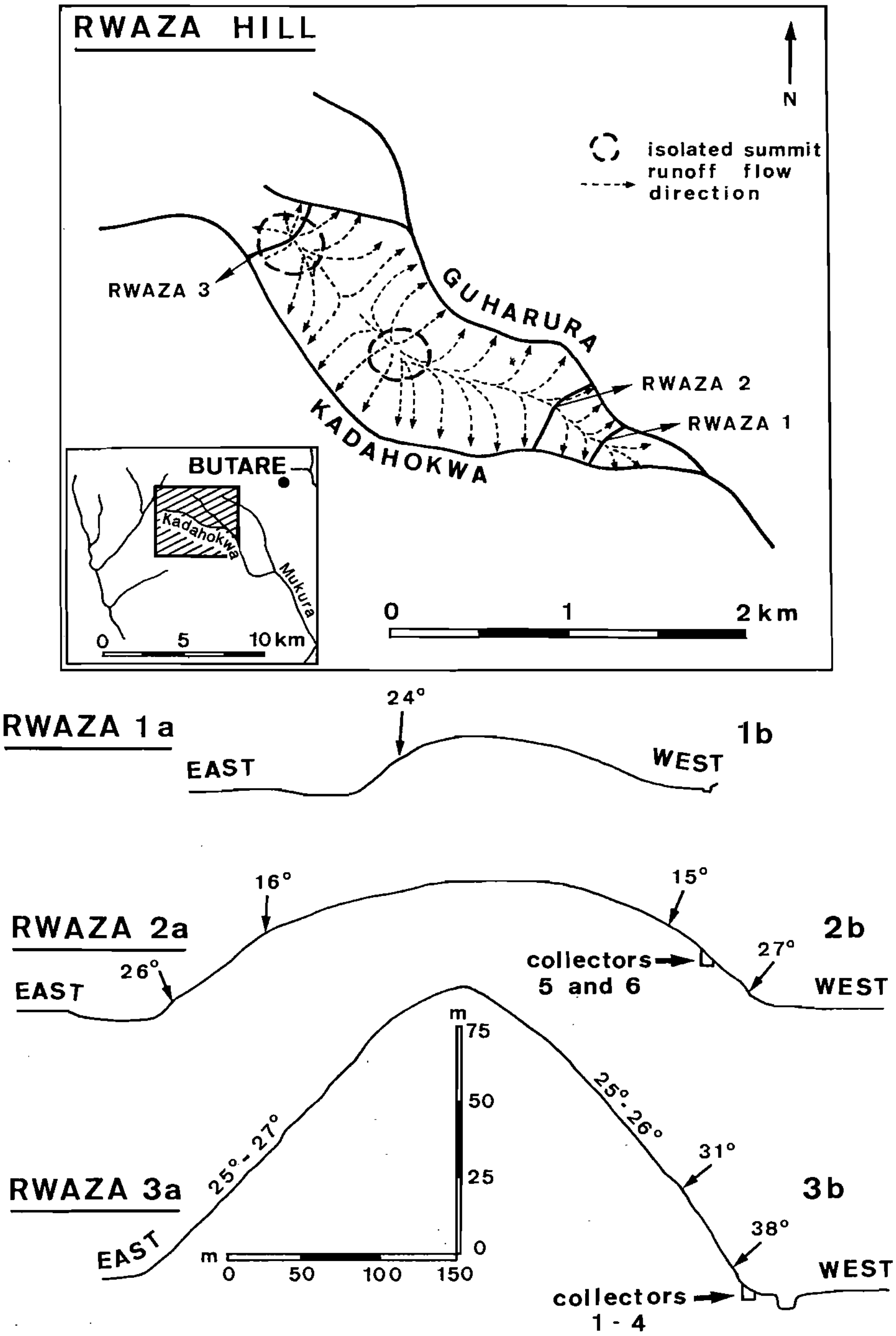

Fig. 2. Localisation of Rwaza hill and the three cross-sections RWAZA 1, 2 and 3.

2 *The study area and measurement techniques used*

Rwaza hill lies at about 3 km to the north-west of Butare (fig. 2). It is an elongated outlier of a main massif, separating Mwogo from Akanyaru head-waters. The substrate is composed out of phyllitic rocks, becoming more quartzitic to the North.

The soils on Rwaza Hill generally show a 0–50 cm thick humic A-1 horizon, overlying a red-brown subsoil, 1 to 3 meters thick. A stone-line separates the latter from the underlying weathered phyllites. As a general rule the clay content (kaolinite) increases from 12–19% in the humic horizon to 23–33% in the red-brown subsoil. In the center of cross-section RWAZA 1, this soil profile is covered by a colluvial mantle, 50 cm thick. On the East side of RWAZA 1, on the East and West side of RWAZA 2 and on the small summit of RWAZA 3, the soil is partly or completely truncated.

Two techniques have been used to measure soil loss by rainwash.

2.1 *Nails, used as erosion pins*

In 1977, more than 2,000 nails with a length of 15 cm have been inserted into the soil. Their head accurately level to the soil surface. They were placed in a network of square meters, occupying a 3 to 5 m wide zone, following three cross sections over Rwaza hill (fig. 2). A first inspection in 1978 revelaed that a number of nails were covered by sediment. But some nails were protruding several centimeters above the surface, and also a number of them were missing. In order to avoid this problem and to establish data over a more representative period of several years, missing nails have been replaced and all have been inserted deeper into the soil by means of a graduated peg, their head being relocated at exactly 5 cm below the soil surface. After four years, a number of nails have been dug out, the distance between soil surface and nail head being accurately redefined. In this way local raising or lowering of the surface was determined at every length interval of 1 m along the three cross-profiles and in a zone 3 to 5 m wide.

The erosion pin method has some disadvantages. First of all, the method cannot be used in cultivated fields. Hoeing not only implies a risk of perturbance of the pins, but also leads to a temporal raising of the general field topography, followed by a gradual lowering due to the subsequent collapse of soil aggregates and the compaction of the soil surface by sealing and microcrusting. Therefore, the location of the three cross-profiles was chosen in order to pass only through fallow and grass land and *Eucalyptus* sp. plantations.

Furthermore, once raising or lowering of the soil surface is established, the method does not provide any information about the responsable process. So it could be observed on cross-profiles RWAZA 1 and 2 that fine aggregates, brought to the surface by ants, can locally build up a fine layer of several millimeters thick within only a few weeks. These aggregates are easily evacuated by runoff whereas the hard soil surface remains practically unaffected. The erosion pin method fails to account for this type of export of soil material.

Other errors might be due to vertical movements of the nails relative to the soil. This can happen in the case of important ant activity: the in situ soil resettles as a result of the collapse of a dense network of small faunal galleries and cavities. Figure

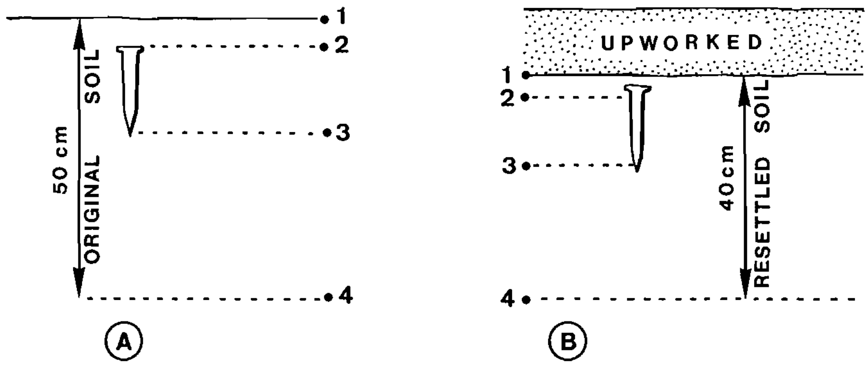

Fig. 3. The resettlement of soil after biogenic upworking of fines. A, original soil levels 1, 2, 3 and 4; B, the same soil levels after faunal upworking of fines and resettlement of the soil: the rigid nail cannot follow the resettlement movement and moves in respect to the soil levels 1, 2, 3 and 4, which approach each other.

3 illustrates how a rigide erosion pin necessarily undergoes displacements relative to the in thickness schrinking soil, when the soil around it resettles. As the activity of ants could be observed on certain parts of Rwaza hill to a depth of 50 cm and more, the use of 15 cm short erosion pins may introduce not identified errors. It should also be born in mind that the method only provides data on points and one can only hope that these data are representative for the evolution of the general surface. Finally, the method, as applied here, does not allow repetitive measurements in order to evaluate seasonal dynamics: as the nail heads are inserted to 5 cm below the surface, only one measurement is possible, at the moment of excavation of the tracers.

2.2 *Collector trenches*

Soil loss by rainwash has also been measured in collector trenches, 50 cm deep and wide. Four trenches, totalizing a length of 110 m are located on a contour line at the base of cross-profile RWAZA 3B (fig. 2). They drain a hillside of 15.390 m^2, sloping to the south-west with an average inclination of about 25°. It comprises pasture grounds interrupted by a few Eucalyptus sp. plantations.

Two other trenches (5 and 6) are located below a complex of houses and cultived fields (fig. 2). They lie at both sides of cross-profile RWAZA 2B and at about 120 m from the flat summit of the hill. Both trenches drain in first instance the fields below which they are installed, but they collect also some runoff coming from the houses higher on the slope. Observations during rain allowed to evaluate the surfaces draining to trenches 5 and 6 as respectively of ± 800 m^2 and ± 2,000 m^2. The slope above the trenches is slightly convex in form with a slope gradient between 11° and 22°.

Two types of measurements have been executed. First of all the trenches have been emptied at regular times. The volume of collected earth has been estimated by passing it through buckets of 10 liters. In order to obtain correct emptyings, the level of the trench bottoms was indicated by the presence of a plastic sheet. In November 1984, bricks have been inserted into the trenches, the upper side of every brick being level with the bottom surface. When the bricks and the plastic sheet became gradually covered, the thickness of the sediment layer was measured by inserting a bycicle spoke into the soil till it reached the hard brick surface. Every trench contained one brick every 2 m. In this way a volumetric estimation of the increase of sediment in the trenches was made after every rainy day, and the contribution of a number of single wash events to total erosion could be assessed.

All the data, obtained, have been linked with precipitation records, provided by simple pluviometers in the close vicinity of the trenches and a pluviograph with a daily rotation, installed in the valley of the Guharura river (fig. 2).

The use of collector trenches shows a number of shortcomings. First of all, not all material, coming from the hill side is permanently stored in the trenches. Underestimation of erosion can follow from:

- overflow of the trenches by runoff. This happened six times in the period from 1978 to 1984 in trenches 1 to 4. Trenches 5 and 6 overflowed eight times from 1979 to 1984;
- leaching: fine soil particles can eventually disappear with water infiltrating in the trench walls.

On the other hand, erosion can be overestimated by disintegration of the trench walls. In 1986, eight and seven years after the installation of respectively trenches 1 to 4 and trenches 5 and 6, the disintegration of the worsest section has been evaluated to about 20 litres per current meter of trench. This volume, however, constitutes less than 1% of the total volume of earth recovered from the trenches during that period. This slight overestimation might partially compensate for the underestimations, mentioned above.

The use of collector trenches has some advantages over the erosion pin method as applied here: seasonal differences in soil loss rates can be established and collectors can be used to estimate soil loss in a cultivated area. But on the other hand, the erosion pin method can give more information concerning the partial area contribution to soil loss.

3 *Soil losses estimated from the measurements on the nails*

Figure 4 graphically shows the vertical changes of the soil surface in relation to the nailheads, as recorded after four years (1978–1982). Every vertical line represents one measurement. The point to point variability has been smoothened out by replacing the vertical change on every point by the mean vertical change over five consecutive points: the point in question and the two points in up- and downslope direction. The resulting erosion-sedimentation line, although still heavily undulating, gives a more comprehensive image of the local dynamics of lowering or raising of the surface in relation to the buried tracers.

3.1 *The data from the three cross-profiles (fig. 4)*

Profile RWAZA 1 is characterized by massif accumulation, except on the steepest part of RWAZA 1A, where the slope attains 24°. Two reasons explain the high

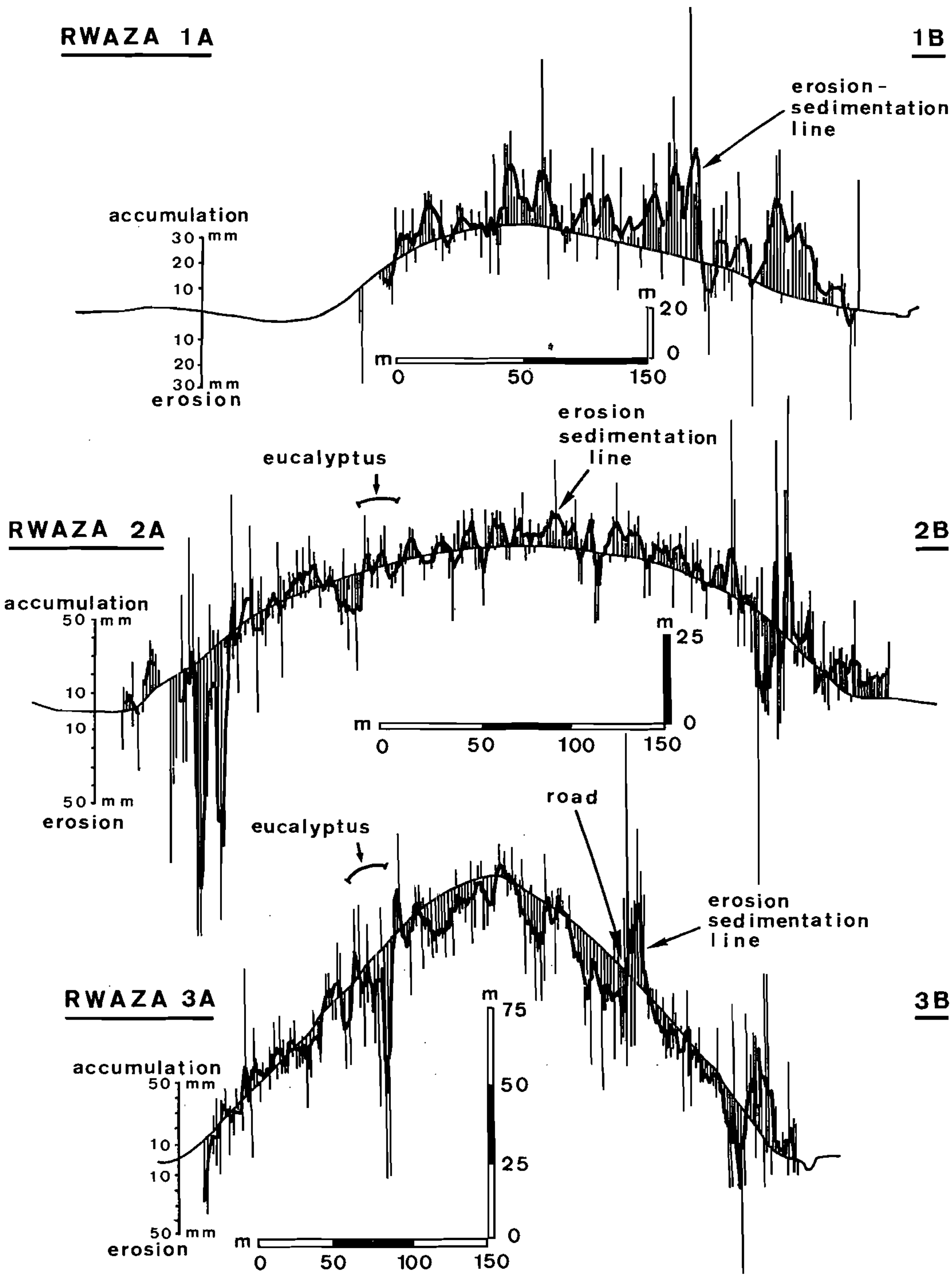

Fig. 4. Erosion pin measurements on Rwaza hill, 1978–1982. The erosion-sedimentation line (see text) is indicated.

accumulation rate. First of all, faunal activity, especially by ants, accounts for accumulation at the surface of fine particles extracted from deeper soil horizons. A second partial explanation is given by the form of the hill. The south-eastern part of Rwaza hill, where profiles RWAZA 1 and 2 are located, has a rather flat and wide summital crest dipping to the south-east. As shown in fig. 2, runoff partly follows this crestline and spreads to the nose and to both sides of the hill. This divagating runoff pattern probably accounts partially for the observed diffuse accumulation.

Important accumulation on the slightly convex hill summit is also present on profile RWAZA 2. The reasons are probably the same as in the case of RWAZA 1. But the situation is more complex on both steep hill sides. As soon as the slope locally exceeds ± 16°, accumulation is replaced by diffuse erosion. Those belts of higher erosion are marked on both sides of the hill by a concave slope section, visible quite well on cross-profile RWAZA 2A, but also present on RWAZA 2B. These concave sections interrupt the general convex form of the hill and the truncated soil profile indicates that the actual erosion here is not a temporary phenomenon but a trend since long time. But the most surprising phenomenon is observed somewhat downslope, just above the short concavity giving way to the flat valley floors. The steepest slope sections of the entire cross-profile occur here with inclinations of respectively 26° and 27° at the East and the West side of the hill. It is amazing to observe here accumulation, which seems even more important than the accumulation in the flat valley!

Contrary to the former cases, the straight and steep (25°–26°) slopes of cross-profile RWAZA 3 are mainly characterized by erosion. A marked parallellism with RWAZA 2 exist at the lower part of RWAZA 3B where a local increase of the slope to 31° is marked by an erosion peak. But lower on the slope accumulation starts where the local inclination reaches 38°!

3.2 *General comments on the data from the three cross-profiles*

3.2.1 *The point to point variability of the data and their representativity*

Fig. 4 shows that zones with prevailing accumulation most times also undergo local erosion and vice versa. Therefore the representativity of the erosion pin method depends on the density of the observation points. On Rwaza hill, the measured dynamics of the topographical surface agree well with stratigraphical and pedological observations: prevailing erosion is often observed on places where the soil is truncated, while zones of important accumulation are underlain by a soil, either buried below a colluvial mantle or thicker than elsewhere. It seems therefore that the general tendency, observed during four years, corresponds to a longer existing trend.

3.2.2 *Slope configuration and local slope inclination*

The erosion pin measurements point to the complex nature of erosional and depositional processes in rill and interrill flow, especially where it comes to individualize the role of local slope inclination. Recent studies reveal, indeed, that the latter shows a variable relationship with rill erosion (e.g. GOVERS 1987) as well as with interrill erosion (e.g. BRYAN 1979).

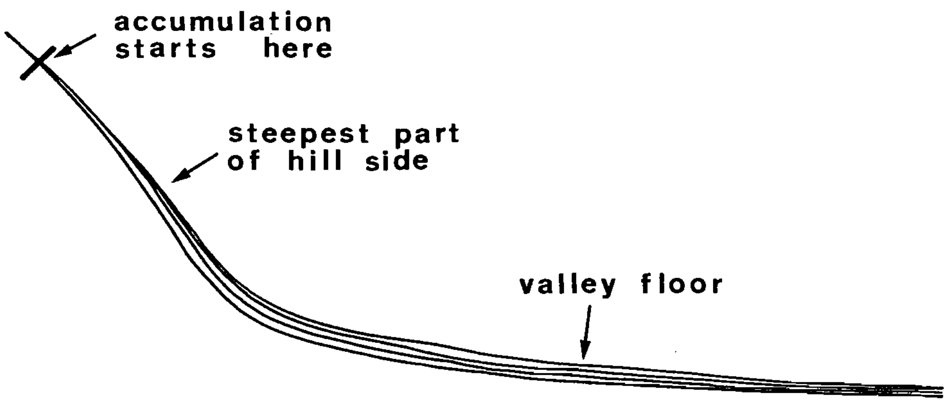

Fig. 5. Accumulation, correllative to erosion higher on the hill, is not restricted to the flat valley floor but takes also place on the lower, often the steepest, part of the hill side.

On Rwaza Hill erosion by overland flow generally increases with increasing slope inclination. But there exists a sudden change towards massive colluviation above a certain slope angle. At RWAZA 2 this change occurs when the slope exceeds 26°–27°, at RWAZA 3B when the slope becomes steeper than 36°. In both cases colluviation occurs on the steepest part of the slope profile. It is thought that this phenomenon should be explained in the context of slope configuration. In the cases considered here, the steepest slope sections are situated low on the hill side, just above the flat bottomed valley. Colluviation seems to extend from the valley to the hill side as shown on figure 5.

3.2.3 *The undulating form of the erosion-sedimentation line*

The erosion-sedimentation line is not flat as might be expected: it shows an undulating pattern with a remarkably constant wave-length (fig. 6). Some of the minima on this line are situated in areas of accumulation and thus indicate points of minimal deposition. Other minima occur in erosion belts and indicate local erosion maxima.

It was first thought that the undulating pattern resulted from a regular spatial distribution of ant nests, but observations in the field were not convincing. Moreover it can be observed how the distances between minima become irregular on places where the normal runoff pattern is interrupted by artificial obstacles as roads and trenches. A nice exemple is visible on cross-profile RWAZA 3B (fig. 6), where the erosion-sedimentation line shows no minima over a distance of about 30 m below a road. This road concentrates runoff into a gutter from where it spreads out again, causing considerable deposition just along the section of the cross-profile considered. This case suggests that maxima in the erosion-sedimentation line correspond to places where runoff spreads out. Minima should correspond to local concentration of runoff water. The undulating aspect of the erosion-sedimentation line suggests therefore that natural runoff concentrates and spreads out at regular distances. This spatial organisation can be compared with the rillpattern, observed in a number of cultivated fields (fig. 6), where the distance between rill "nodes" is of the

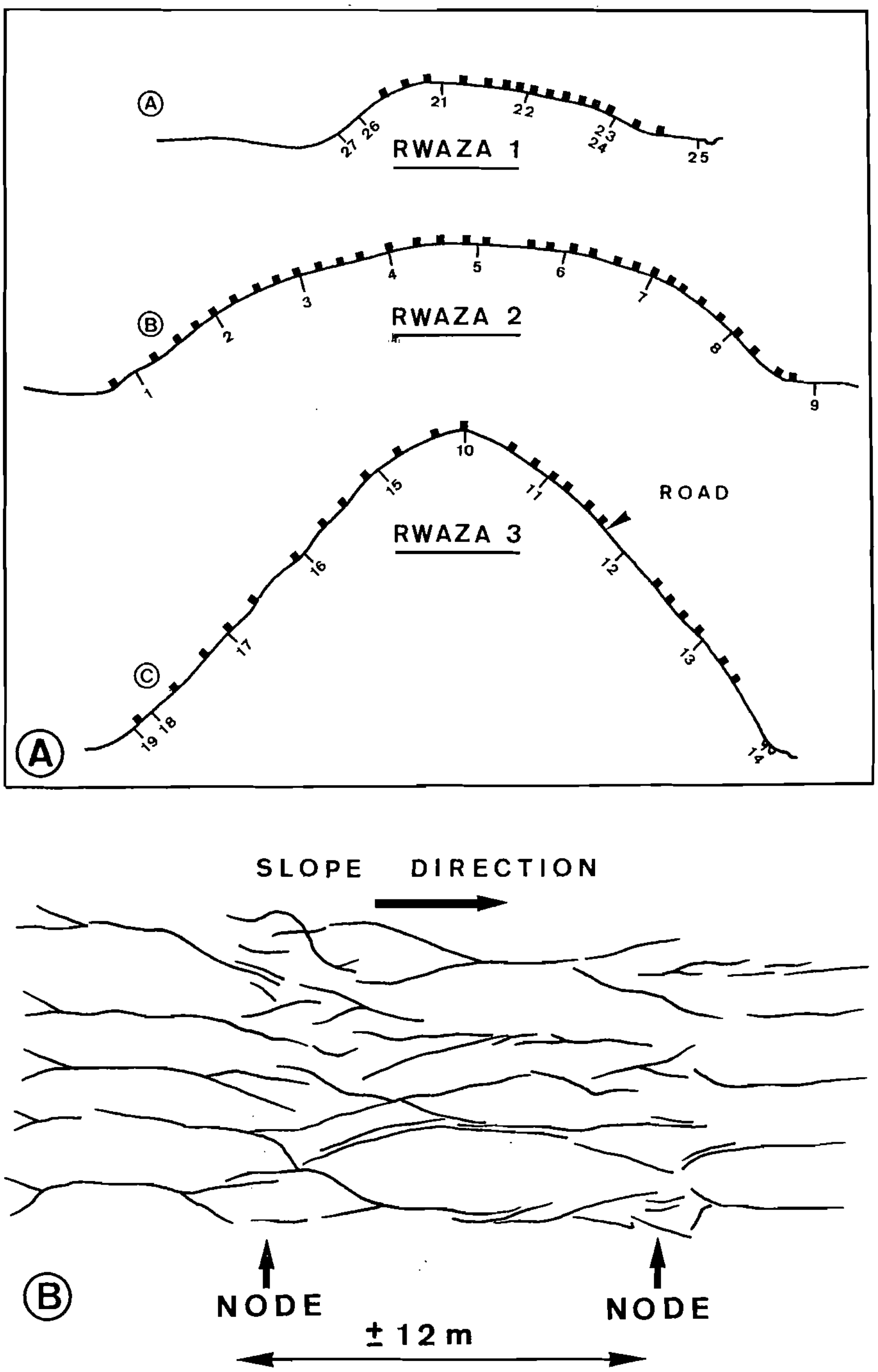

Fig. 6. A, localisation of minima in the erosion-sedimentation line of fig. 4; B, rill network as observed in a field in western Rwanda on a 39° slope!

same order of magnitude as the distance between the minima in the erosion-sedimentation line, recorded at Rwaza.

The cyclic alternation of colluvial belts of divagating runoff with belts where runoff (re)concentrates and incises has recently also been observed in experimental setups by BRYAN & POESEN (1989). Although an explanation of the phenomenon has not been forwarded yet, the authors think that discharge may control the distance between the nodes. Our field information, dating from 1982, does not add new elements to this discussion, but proofs the phenomenon to exist.

3.2.4 *Discussion on the soil protective role of Eucalyptus sp. plantations*

The three erosion pin trajectories pass through two small plantations of *Eucalyptus* sp. trees. The absence of a grassy under-growth here might be due either to the high water extraction from the superficial soil by the radial root system, or to the liberation of terpenes, intoxicating the grasses (MUNYARUGERERO 1978). The bare soil, often observed below the trees, remains unprotected and is often subjected to accelerated wash.

The measurements on the nails (fig. 4) show that erosion under the *Eucalyptus* trees is higher than on grassy land. This is visible on profile Rwaza 3A, where erosion is very pronounced, not only in the small forest, but also downslope, where the first minimum in the erosion-sedimentation line is still more pronounced than the minima lower down the hill. Another case is situated on cross-profile Rwaza 2A (fig. 4). The small *Eucalyptus* plantation is situated where the erosion-sedimentation line shows a maximum, which, however, is less pronounced than the maxima more upslope. The first minimum below the plantation is more marked than the other minima further downslope. This indicates that small *Eucalyptus* forests are important runoff generators, whose erosional effect extends farther downslope than the plot limit.

3.2.5 *Absolute erosion data*

The measurements on the nails allow to calculate the main erosion or accumulation for the six hill sides. The four year period, considered here, shows a net accumulation of 1,5 mm on Rwaza 1A, 12,8 mm on Rwaza 1B and 6,8 mm on Rwaza 2B. Net erosion is observed on the other cross-profiles: 4,6 mm on Rwaza 2A, 7,2 mm on Rwaza 3A and 5,0 mm on Rwaza 3B (from the top of the slope to the contour line of trenches 1 to 4).

These data will be compared with the data from the collector trenches and with the existing data from elsewhere in the country.

4 *Soil losses measured in the collector trenches 1 to 4*

4.1 *Erosion rate on hill side RWAZA 3B from 1980 to 1982*

The measurements in trenches 1 to 4 are only reliable since the start of the small rain season in 1980, but they are still continuing today. This gives the opportunity to compare erosion on Rwaza 3B as measured by the nail technique from 1978 to 1982

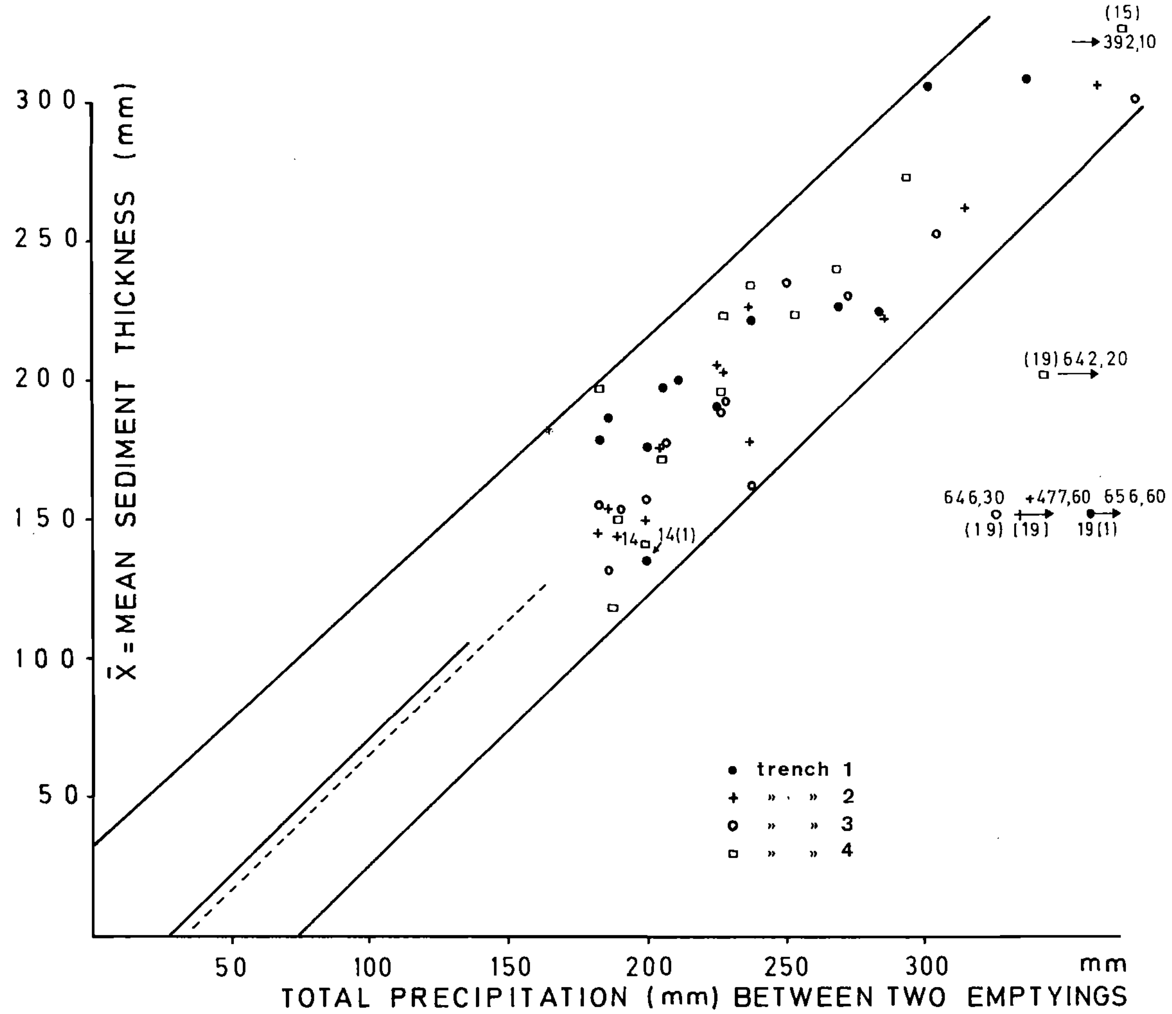

Fig. 7. Trenches 1 to 4, emptyings 6 to 19. Thickness of sediment (mm) in the trenches and coresponding precipitation totals (mm).

with collector trench data from 1980 to 1982. During the latter 2 years, the volume of sediment collected is the equivalent of a layer of 4,3 to 5,1 mm thick, equally redistributed over the drained area of 15,390 m^2. This is about twice the erosion recorded by the nails (5 mm in 4 years). This difference can be partly due to the fact that the erosion pin method fails to monitor the export of soil worked up by the soil fauna. It must also be mentioned that the trenches 1 to 4 are situated aside of the nail profile line and that the area, draining to the trenches, includes a small Eucalyptus plantation and a belt of incipient gullying downslope. This probably sufficiently explains the difference between erosion data recorded by the two methods. However, the measurements in the collectors are probably more representative than the erosion pin data: the first comprise the total loss over an area of 15,390 m^2, the latter result from observations on 200 points dispersed over a surface of only 750 m^2.

4.2 *Some general remarks about the evolution of the erosion on Rwaza 3B*

Figure 7 shows the correlation between the mean thickness of sediment in the trenches and the total precipitation involved, at the different times the trenchess were emptied. the period, considered here, extends from September 1980 till May 1985 and includes emptyings 6 to 19.

4.2.1 *Erosion as a function of total rainfall*

First of all the data cloud falls within a rectilinear belt, indicating a direct proportionality between total rainfall and erosion in a time lag of the order of several weeks or

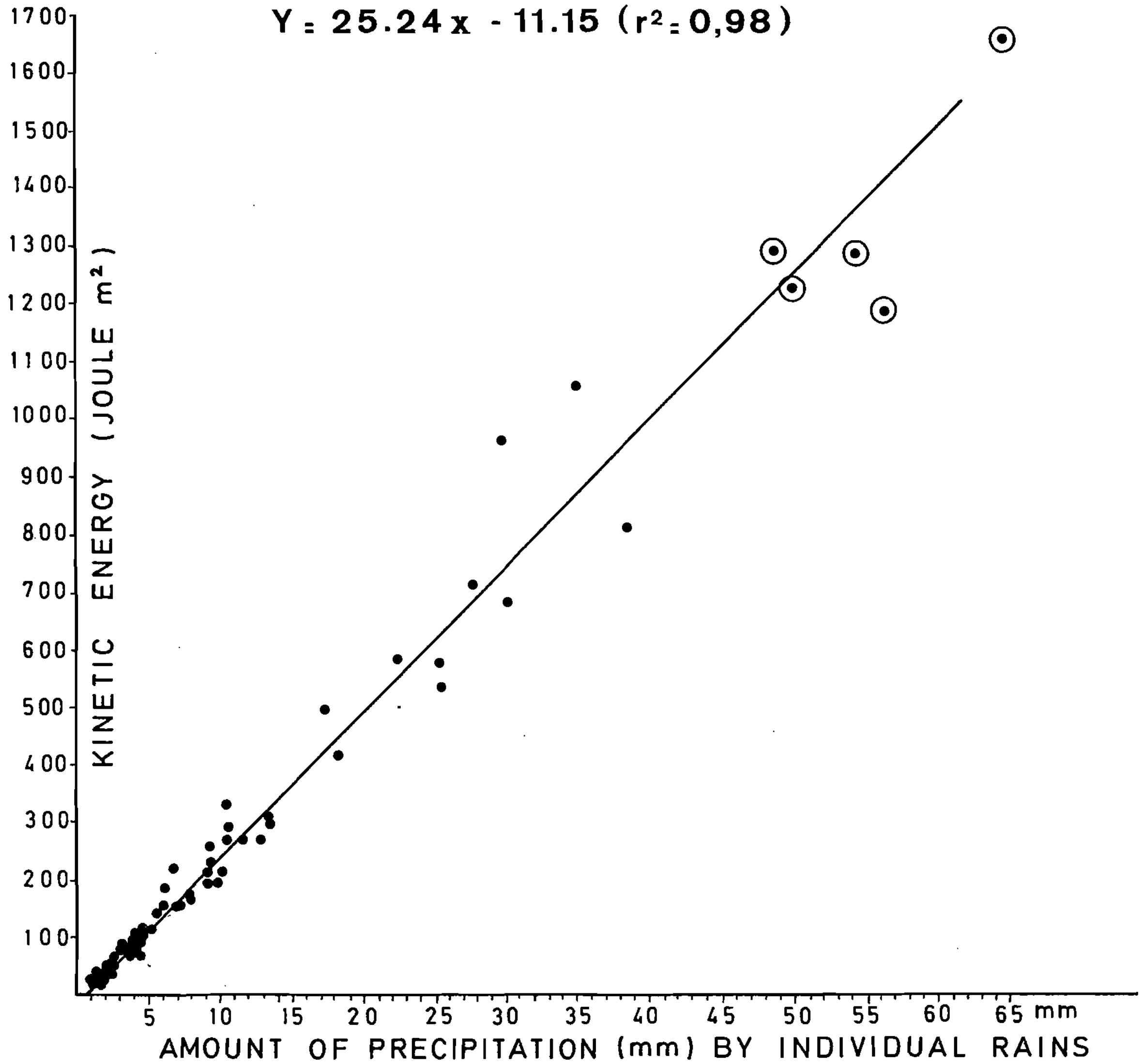

Fig. 8. Kinetic energy produced by individual rains of different magnitude. The five biggest rains recorded are separately indicated.

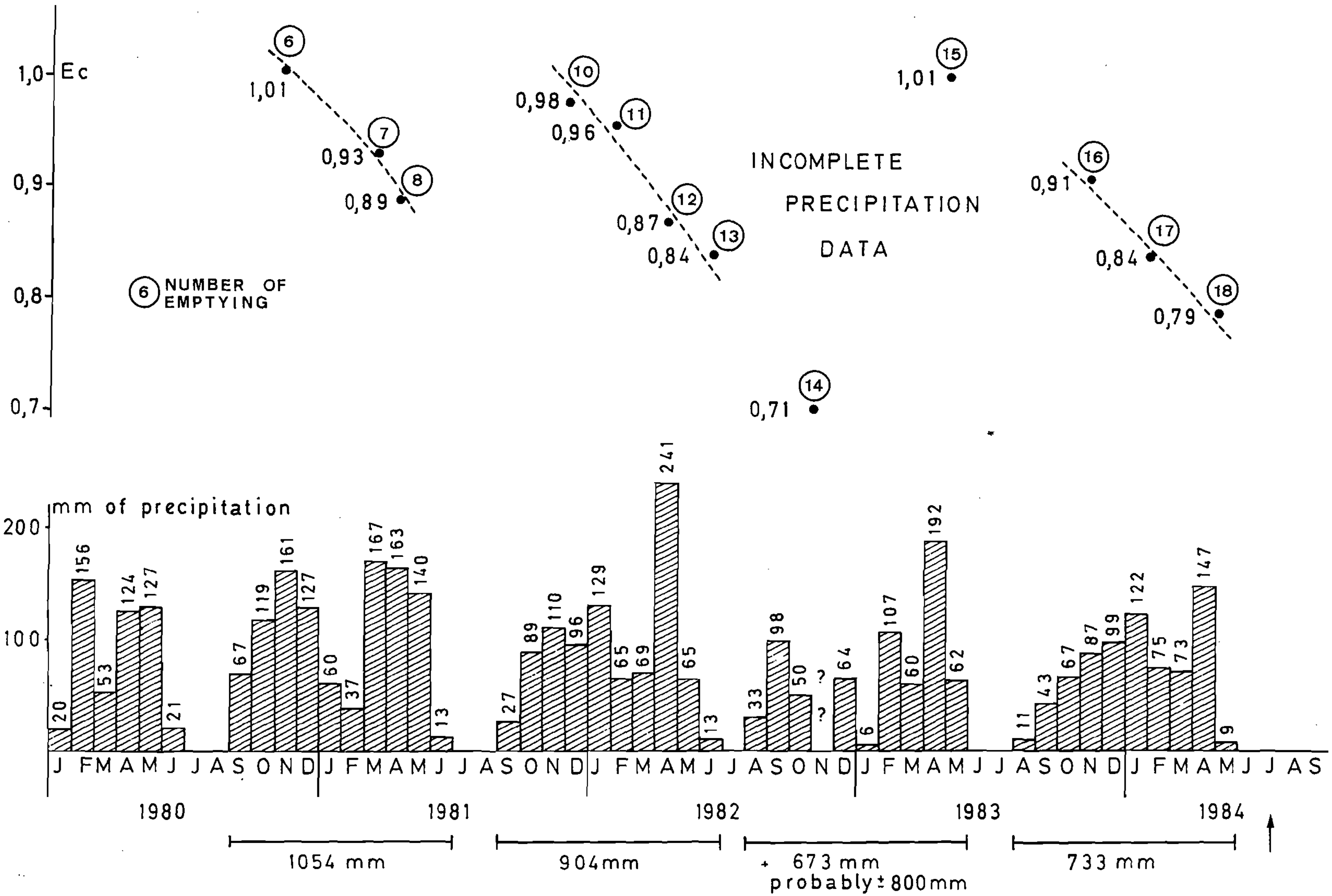

Fig. 9. Evolution of the Ec-coefficient (see text) in trench 4 during four consecutive hydrological years.

months. This result is amazing as it can be supposed that erosion rate is governed by a large number of variables: soil water content, different rainfall characteristics, as intensity, duration and obliqueness, and vegetation cover. Therefore, this linear relation must represent a main situation of all this temporal variables.

The linear relationship between erosion and rainfall amount seems more logical from the energetic point of view. Indeed, as the micro-interfluves between rills occupy an important part of the total surface, erosion can largely depend on the kinetic energy of the raindrops which causes soil particle detachment. It appears now that the rainfall kinetic energy of an individual rainstorm at Rwaza is proportional to its total precipitation. This is illustrated on figure 8, where the kinetic energy (E_k) is calculated as the sum of energy produced by the different pluviophases of constant rainfall intensity (I), in which every storm can be subdivided. The formula

$$E_k = 210{,}3 + 89 \log_{10} I$$ (LAL 1977)

has been used here to calculate the kinetic energy produced by every single pluviophase. Thus total erosion is not only proportional to the amount of precipitation but also to the total kinetic energy produced. The linear relation between kinetic energy and rainfall amount as observed at Rwaza has also been found elsewhere (CHARREAU 1969).

4.2.2 *Erosion related to the pluvial regime*

There is, however, a complication. The regression line (fig. 7), indicating the relation between erosion and precipitation, does not pass through the origin of the x- and y-axes, but falls slightly below. The regression line for the trenches 1 to 4 can be written as:

$$X = 0{,}86P - 2{,}23$$

where X = the main thickness of sediment (in millimeters) in the trenches, the day of emptying.
P = total amount of precipitation (in millimeters) between the new and the former emptying.

It appears that zero erosion occurs at a total precipitation of 2,59 mm: Generally speaking, this means that every individual rain storm of less than 2,59 mm and also the first 2,59 mm of precipitation of bigger rains do not contribute directly to erosion. In this way an important part of the total precipitation remains not erosive. For the year 1981, 226 rain events have been recorded, but only 84 out of them produced more than 2,59 mm of precipitation. So only 583 mm of the 904 mm contributed directly to erosion, 35,5% of the total precipitation infiltrating directly into the soil before runoff starts. Therefore even slight changes in rainfall regime can strongly influence total erosion even if the total annual precipitation remains unchanged.

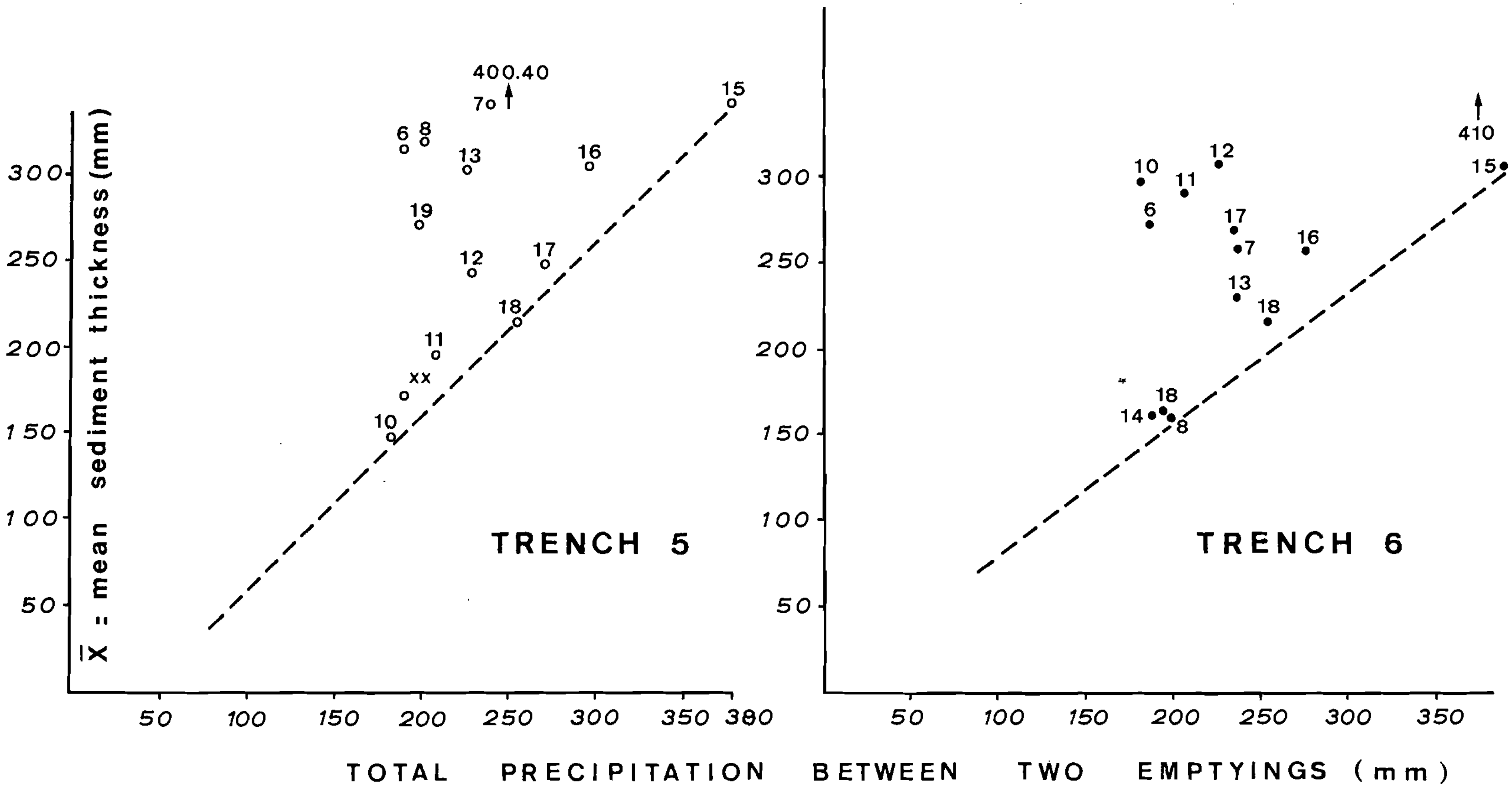

Fig. 10. Trenches 5 and 6, emptyings 6 to 19. Thickness of sediment (mm) in the trenches and corresponding precipitation totals (mm).

4.2.3 *Seasonal trends in erosion*

Although there is a pronounced linear relation between erosion and precipitation (fig. 7), the data points occupy a rather wide belt around the regression lines. This is at least partly due to seasonal variations in the erosional efficiency (Ec) of the rainfall, expressed by the proportion:

$$E_c = \frac{\text{thickness of sediment in trench (mm)}}{\text{total amount of precipitation (mm)}}$$

Figure 9 shows how during three out of four consecutive hydrological years, the Ec-value decreases during the rainy season. The precipitation data for 1982–1983 are incomplete, what explains the aberrant results for that period. More reasons might explain this seasonal decrease of Ec:

1. It is known that a higher soil water content at the start of the rain often affects the erodibility of fine soils in a negative way (BRYAN, GOVERS & POESEN 1989, LE BISSONNAIS, BRUAND & JAMAGNE 1989). One can expect a general increase of this antecedant soil moisture content during the course of the rainy season.

2. The grassy vegetation on RWAZA 3B strongly degenerates during the dry season in the summer. Overgrazing plays an important role. But during the rainy season there is a gradual restauration which implies an increasing soil protection.

4.2.4 *The effect of overgrazing*

Till now we have discussed erosion at RWAZA 3B from 1980 to April 1984, including emptying 18. The subsequent emptyings show a drastic reduction in erosion, visible from emptying 19 on (31th of May 1985, fig. 7). In 1989 the total erosion on this 25° slope was nearly zero, although much runoff water was occasionally collected in the trenches. The reason is obvious: the two owners of the slope decided in 1984 to reforest RWAZA 3B with *Eucalyptus* sp. trees, and the plots could not be used anymore as grazing ground. The result was a spectacular development of the grasses, becoming more than 50 cm high in some places.

5 *Collector trenches 5 and 6 below two cultural complexes*

5.1 *Absolute data of erosion in both cultivated complexes*

On the base of estimations of the volume of earth recovered from the trenches between 1980 and 1984, erosion here is very high: 15,970 litres and 39,820 litres of sediment were collected in trenches 5 and 6, draining a surface of respectively ± 800 m^2 and ± 2,000 m^2. This resulted in both cases in a general lowering of the surface by 20 mm! This is about 4 times as much as the general lowering of the surface of the overgrazed hillside Rwaza 3B during the same period.

The erosion on the grassy section between the two cultural compexes could be estimated by the measurements on the nails. As stated above, cross-profile Rwaza 2B as a whole, saw between 1978 and 1982 a net accumulation of 6,8 mm. On the base of a few nail data from points protected against runoff from upslope, the biogenic upworking can be estimated at 10 mm for that period. So, it can roughly be estimated that real soil loss in the grassy area between the two cultural complexes amounts to

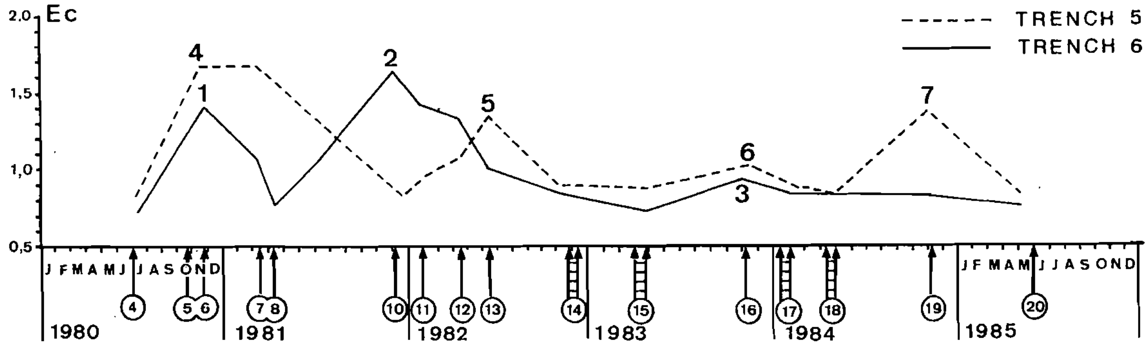

Fig. 11. The seasonal evolution of the Ec-coefficient in the cultivated fields above trenches 5 and 6. The maxima correspond to the following cultural activities: 1, hoeing and planting banana trees; 2, hoeing; 3 and 6, harvesting sweet patatoes; 4, hoeing and planting of harricots; 5, planting sweet potatoes and cassawa; 7, harvesting cassawa.

about 3 mm in 4 years. Erosion in the cultivated complexes can be evaluated as more than 6 times higher than on the grassy stretch with the same slope configuration.

5.2 *Variations in erosion intensity following the agricultural calendar*

Erosion on the cultivated plots is not nicely related to total rainfall as in the case of the overgrazed slope RWAZA 3B (fig. 10). The Ec-coefficient shows important fluctuations in function of agricultural activities (fig. 11): every labour such as hoeing, weeding and harvesting, implying the loosening of part of the topsoil is followed by an increase of Ec. This can be explained by the fact that a loose and artificially aggregated topsoil will be very prone to wash, generated on upslope sections with lower infiltration capacity (Moeyersons 1989). In this respect, the absolute erosional impact of the agricultural activities depends largely of the meteorological conditions, before crops or grassy vegetation can start to play soil protective role.

6 *Some remarks about the contribution of individual rains to total erosion*

Although erosional data from different parts in the world accumulate at an increasing rate (Saunders & Young 1983), it still remains a matter of discussion (Ohmohri & Hirano 1988, Wollman & Miller 1960) whether erosion by big rains with a low recurrency is proportionally higher, lower or equal to erosion caused by the ordinary, nearly daily rains. It appears that quantitative data, relevant to this discussion and relative to diffuse or slightly concentrated rainwash, in fact, do not exist.

6.1 *The distribution of total rainfall over individual rainstorms*

During the period October 1978 – June 1986, 687 rains of less than 1 mm of precipitation, and 203 rains between 1 and 2 mm have been recorded (fig. 12). The number of rains decreases with increasing precipitation class. During this eight year period we registrated 53 rainstorms of more than 20 mm. 16 rainstorms of more than 30 mm, 6 rainstorms of more than 40 mm and 3 of more than 50 mm. Rainstorms of more than 40 mm occur somewhat less than once a year, and produce about 5% of the total precipitation (fig. 12).

6.2 *The erosional effect of individual wash events in the 1984–1985 season*

After each rain, the increase in thickness of the sediment layer in the trenches has been compared with the corresponding amount of rainfall (fig. 13). During the period considered, the grassy vegetation above trenches 1 and 2 was developing, grazing being prohibited by the owners. The situation was different above trenches 5 and 6. The period, taken into consideration, starts here at the end of the erosional peak shortly after manioc harvesting and extends over a fallow period during which grasses gradually cover the parcel. However, the protective role of the grasses was

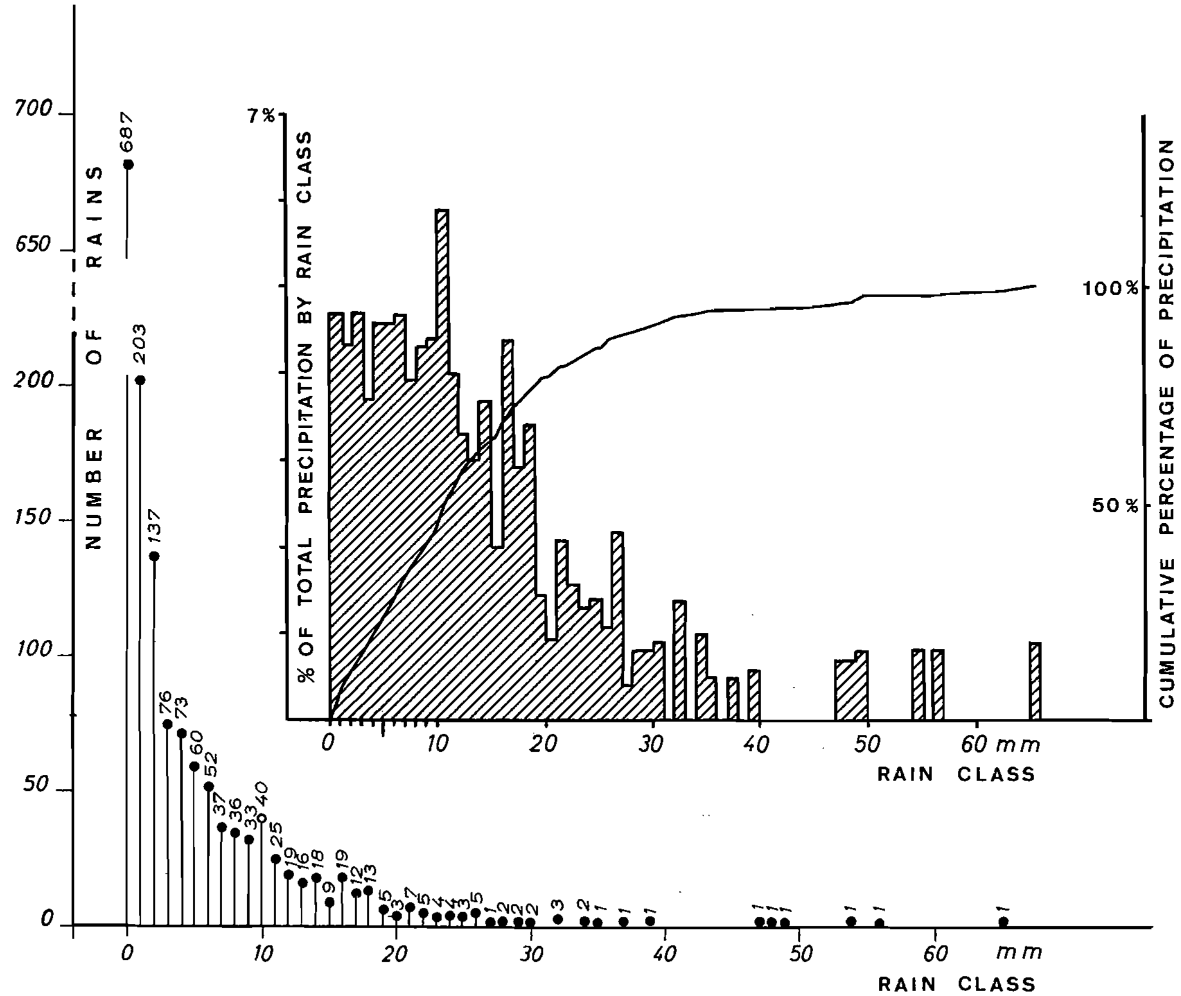

Fig. 12. Number of rains by rainclass and absolute and cumulative percentage of total precipitation by rain class, for the period 1978–1986. Individual rains are classified, on the base of their total precipitation, in classes: 0–< 1 mm, 1–< 2 mm, 2–< 3 mm etc.

partly restricted by goats, sheeps, pics and chickens, scratching around. The tendency illustrated in the four cases, is quite the same. Two points have to be stressed:

1. manually traced regression lines show that rains of less than about 2 mm provoke no erosion. This confirms what has been mentioned above;

2. for rains of more than about 2 mm, erosion increases with the magnitude of the rain. However, the "regression line" is not rectilinear but flattens with increasing precipitation. So it appears that e. g. a storm of 30 mm produces only about twice the erosion provoked by a rain of 10 mm.

While the first point can be explained by complete water infiltration at the start of the rains, the tendency described under point 2 is much more difficult to understand. It probably points to a decrease of the Ec-value during the course of a single rain. This might be explained as follows:

1. between two rains, the number of free lying soil particles, easily transported during the first part of the next wash event, increases by faunal upworking of fines and cracking of bigger aggregates by insolation;

2. during a rain, the protective role of some grasses increases (e. g. *Cynodon dactylon* sp. erected when dry, will fall down when wetted);

3. at the start of a rain, the runoff film is less developed in extension and thickness so that splash detachment is more important than later on.

Arguments 1 and 3 have also been forwarded by COLLINET (1987) in Western Africa. Although the explanation for the existing tendency in figure 13 might be subject to speculation, the tendency itself is an important phenomenon. It indicates that rainstorms of 40 or even 50 mm, although giving the highest absolute erosion rates, should not be considered as triggers of extreme diffuse rainwash erosion. However, other erosional processes, such as rotational and planar sliding, debris flows and mud streams may occur. Therefore, big rains of 40 mm and more should be considered as very important in respect to total soil loss.

7 *Comparison with other soil loss data from Rwanda*

Erosion has always been considered as a serious problem in Rwanda (HARROY 1944). However the available data do not always support this point of view. Low erosion values were measured by WASSMER (1981) on cultivated plots on a 30° slope at Gisovu. LEWIS (1988), using a high number of Gerlach throughs, recorded also low soil loss values. The national mean in his study was evaluated at 0,4–7,4 tons/ha/year, with a seasonal maximum on a cocoyam field near Gikongoro of 17 tonnes/ha/half a year. Much higher values were obtained by VAN LONKHUYZEN & VAN ROOKHUIJZEN (1977). They measured soil losses between 5,5 and 7 tons/ha within two rains on a 15° slope. Very high data were also obtained by BEYERS & NYAMULINDA (1988) from erosion plots at Nyarutovu, where annual soil loss below different cultures and for several agrocultural methods varied between 42,3 and 336,7 tons/ha/year!

Our data support the last two mentioned studies, and confirm a very active transport intensity of sediment by wash. But soil use plays an important role. This is illustrated by the data from trenches 1 to 4 below the grassy slope RWAZA 3B. Here, the erosion rate of about 30 tons/ha/year, showed a spectacular decrease as soon as the slope was closed for cattle. On the plots above trenches 5 and 6, soil loss

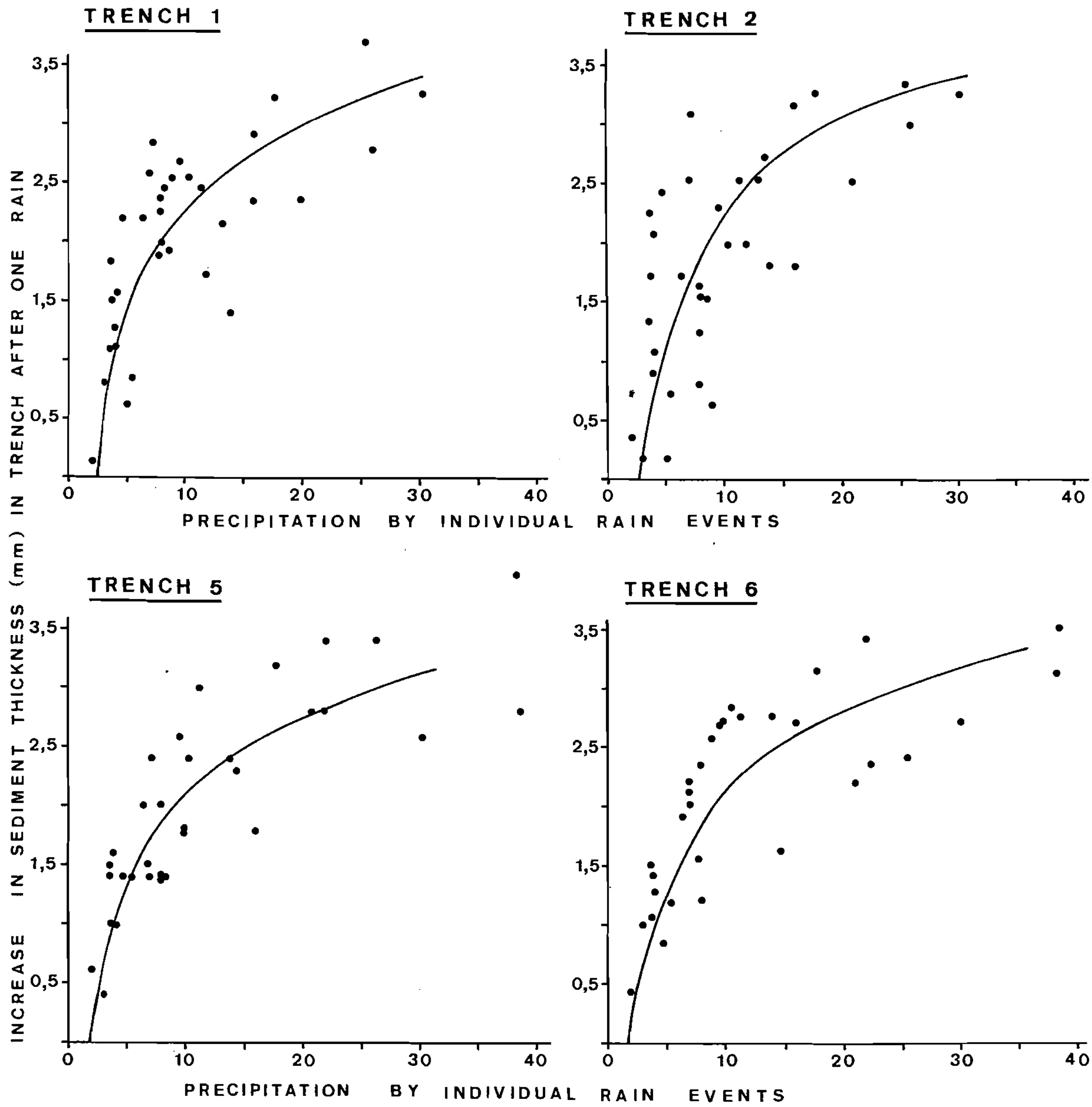

Fig. 13. The Ec-coefficient for rains of different magnitude during the period from 30–11–'84 to 31–5–'85, for trenches 1, 2, 5 and 6.

is of the order of 120 tons/ha/year. This is very much as the measuring period comprises periods of cultivation when erosion was very active, and periods of fallow, during which erosion is much lower.

Some researchers were puzzled why LEWIS (1988) obtained such low values on slopes where erosion always is considered as very important. Part of the anwer lies in the measuring technique, i. e. the use of Gerlach throughs. Attempts have been made by BEYERS & NYAMULINDA (1988) to calibrate the used type device in their experimental plots. The provisional results show that:

1. the contributing source area is extremely difficult to estimate with any confidence;

2. the traps used are too small to reallisticaly reflect soil loss totals in the given environmental context.

8 *Conclusions*

8.1 *External factors governing rainwash erosion*

The cultural landscape in its actual state constitutes the scenary for massive diffuse or slightly concentrated denudation, partly counterbalanced by important correlative deposition elsewhere. The locuses of denudation and accumulation are determined by different factors.

8.1.1 *Slope configuration*

Foot slopes ranging from 26° to 38° are often characterised by massive colluviation while other slopes, higher on the hill, but less steep, undergo erosion. This phenomenon is difficult to explain if it is taken out of the context of slope configuration. It seems indeed normal that material eroded from the hill side is partly redeposited in the flat bottomed valley. But it can be observed that the colluvial wedge extends to beyond the short basal concavity between hill and valley, occupying also the lower and steepest part of the hill side. This image is confirmed by stratigraphical observations on other hills around Butare. It has indeed been observed that dark colored horizons, present in the colluvial deposits in the valley, extend from the centre of the flat valley to far on the hill side, where they are sometimes interpreted as buried soils. The geomorphological position of this dark horizons can only be explained by past periods of colluviation, simultaneously going on on the lower half of the steep hillslopes and in the flat bottomed valleys. This observation, together with the erosion pin measurements, shows a non classical slope evolution model which needs more investigation in the future.

8.1.2 *Soil use*

Soil use has an important impact on erosion. On the 25° slope of RWAZA 3B, erosion is still insignificant since the time the grassy vegetation could freely develop. Before that period, the same slope, overgrazed, loosed annually about 30 tons/hectare. On RWAZA 3B and 2A, soil loss was still higher in the small *Eucalyptus* plantations where no grass cover could develop. The highest erosion rates have been measured in the cultivated complexes above trenches 5 and 6 where soil loss amounted to 120 tons/ha/year.

8.1.3 *Artificial obstacles to runoff*

Especially roads and the trenches bordering them, thoroughly disturb the evacuation of water and sediment. A road climbing obliquely a hill or following a contour line often concentrates considerable amounts of runoff from higher on the slope. In a few points this water will pass over or, when a culvert is present, below the road to continue its way downslope. When the water released from here divagates again, an artificial alluvial cone develops even on very steep slopes. This is e. g. the case on RWAZA 3B. In other instances the waterflow remains concentrated and important ravines may develop within a few years (MOEYERSONS 1989).

8.2 *Hydraulic behaviour of overland flow*

The measurements at Rwaza revealed that zones of accelerated colluviation alternate with belts of pronounced erosion in downslope direction. The field observations suggest that colluviation or reduced erosion occurs on places where overland flow is divagating to diffuse runoff (nodes) and erosion or reduced colluviation where more individualised rills incise. The distance between nodes of divagating flow is of the order of 10 meters. This phenomenon might have to do with the hydraulics in thin water films. The regular pattern can be interrupted by artificial obstacles.

8.3 *The relative importance of small and big rains*

Finally the relative importance of big and small rainfall events in terms of soil loss could be assessed. In general, more than 2 or 2,5 mm of precipitation are needed to generate runoff. This means that in the actual pluvial regime about 35% of the total precipitation is harmless as it infiltrates directly into the soil. For rains of more than 2 or 2,5 mm, erosion by rainwash increases with precipitation amount. This increase is nevertheless not proportional to the increase of precipitation: a rain of 30 mm gives only two times as much rainwash erosion as a rain of 10 mm. Extrapolation allows to estimate the rainwash effect of a storm of 50 mm or more, which occurred only 3 times in eight years, to about 2,5 times of this of a rain of 10 mm. However, such big rains seem often to trigger other erosional processes, related to different types of mass movements. In this respect big rains can be considered as locally very dangerous.

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